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Analyzing Traceability Models in E-Commerce Logistics: A Multi-Channel Approach

Fan Jiang[1], Shaoqing Tian[1*], Siniša Sremac[2], Eldina Huskanović[3]

[1] School of Agriculture and Rural Affairs, Hainan University, 570228 Haikou, China
[2] Faculty of Technical Sciences, University of Novi Sad, 21102 Novi Sad, Serbia
[3] Faculty of Transport and Traffic Engineering, University of East Sarajevo, 74000 Doboj, Bosnia and Herzegovina

[*] Correspondence: Shaoqing Tian (tiansqing@hainanu.edu.cn)

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Abstract: This investigation explores the dynamics of logistics information traceability within the realm of e-commerce, emphasizing the simultaneous existence of diverse sales channels in the digital landscape. It adopts Stackelberg game theory to dissect multi-channel pricing strategies, underscoring the significance of consumer preferences pertaining to logistics information traceability and pricing structures. The study meticulously constructs a supply chain framework, predominantly supplier-driven, integrating both platform-based retail and direct sales channels. This framework serves as the basis for examining fluctuations in retail pricing and the aggregate profit margins under varying decision-making scenarios. It is revealed that platforms operating independently and opting for third-party logistics services for information traceability tend to achieve elevated traceability levels. In contrast, direct sales models managed by suppliers and utilizing e-commerce platform logistics services are associated with enhanced traceability. These insights contribute to a nuanced understanding of the strategic choices in e-commerce logistics, especially in the context of information traceability. This study's findings have broad implications for designing efficient logistics systems in the e-commerce sector, catering to the evolving demands of the digital economy.

Keywords: Logistics information traceability; E-commerce platforms; Supply chain; Stackelberg game theory

1 Introduction

With the evolving consumer preferences, a marked expansion in the e-commerce market is being witnessed, growing rapidly at an unprecedented rate [1]. As delineated in the "2023 Global Payments Report" by FIS's Worldpay, the global e-commerce market is demonstrating substantial resilience and vitality, with forecasts suggesting an escalation in global e-commerce transactions from approximately 6 trillion USD in 2022 to a staggering 8.5 trillion USD by 2026. Within this burgeoning landscape, the Chinese e-commerce market is anticipated to maintain a robust compound annual growth rate of 9% through to 2026.

Historically, e-commerce platforms predominantly functioned as resellers, marketing products procured from upstream suppliers, exemplified by Amazon's resale of music on iTunes. In this model, it was characteristic of e-commerce platforms to hold ownership of the products [2]. Nonetheless, a paradigm shift has been observed in the e-commerce domain, with major retail entities like Amazon and Walmart transitioning towards an agency sales model, as seen in Amazon Marketplace and iBook Store. In this evolving model, e-commerce platforms, serving as agents, empower suppliers to exert control over retail pricing and facilitate direct sales to consumers, in exchange for a service fee remitted to the platform [3]. This shift towards agency sales, propelled by enhanced pricing transparency, has piqued the interest of numerous e-commerce platforms, a notable example being the Chinese smartphone manufacturer Xiaomi's product sales through JD.com. Despite the growing traction of the agency sales model, certain sectors continue to adhere to traditional resale approaches [4]. The "2022 Amazon Small Business Empowerment Report" highlights that over 60% of the platform's sales originate from third-party sellers, primarily composed of small and medium-sized enterprises.

In recent years, the selection of sales models by e-commerce platforms has emerged as a prominent topic [4], accompanied by several challenges. The market, characterized by intense competition, is plagued by the prevalence of counterfeit and substandard goods, leading to frequent prohibitions on the sale of such items [5]. Notably, in the Asian market, counterfeit pharmaceuticals constitute up to 60% of the total market, and the luxury fashion industry is similarly afflicted by this issue [6]. Addressing this challenge effectively remains a complex dilemma for businesses. On one side, it is imperative for suppliers to consistently enhance the quality of their products, as continuous improvements in quality are known to positively impact their reputation [7]. On the other side, e-commerce platforms capitalize on their strengths by employing data-driven marketing strategies, demographic analysis, and targeted advertising, thus offering a comprehensive suite of data marketing services to stimulate demand [8].

Additionally, counterfeit products are recognized as causing significant harm to both brand integrity and consumer interests [9], thereby tarnishing the reputation of the entire consumer market and impeding sustainable market development [10]. In response, there has been a rise in the adoption of blockchain-based logistics traceability systems [11]. These systems, leveraging the unique attributes of blockchain's distributed ledger technology in conjunction with technologies like the Internet of Things [12], facilitate extensive product traceability. This comprehensive traceability encompasses recording details of product origin, raw material sourcing, production processes, logistics information, and anti-counterfeiting certification, culminating in a one-code-per-item system. Moreover, anti-counterfeit code chains serve a crucial role in monitoring and identifying the unauthorized circulation and usage of anti-counterfeit codes, thereby aligning with consumers' practical requirements for product traceability. This enhancement in traceability not only fortifies brand trust but also elevates brand image, safeguarding the interests of both enterprises and consumers [13].

The "2020 Blockchain Traceability Service Innovation and Application Report" demonstrated that the implementation of blockchain-based anti-counterfeit traceability services by brands led to a significant increase in sales. Specifically, sales of nutrition and health products and infant formula milk powder surged by 29.4% and 10.0%, respectively, with other product categories also experiencing growth in sales. Therefore, logistics information traceability services have been acknowledged as a pivotal factor in driving consumer demand and bolstering brand reputation. To assure product quality and enhance user experience, some platforms have been integrating their blockchain technologies to develop proprietary "blockchain" systems, while others have been collaborating with third-party blockchain anti-counterfeit traceability platforms to offer consumers reliable anti-counterfeit traceability services [14].

The recognition of distinct service models, namely in-house and outsourced, each possessing unique advantages and disadvantages, is widely accepted in the realm of business operations. These models exhibit variability in service efficiency and cost, thereby influencing their impact on both corporations and consumers in diverse ways. It has been observed through studies that e-commerce platforms adopt varied sales models contingent on the differing efficiency and costs of services [4]. Consequently, this variation has manifested in the emergence of four distinct scenarios in the practice of logistics information traceability:

•Logistics information traceability services are provided by third-party institutions and operated by e-commerce platforms themselves.

•Logistics information traceability services are both provided and operated by e-commerce platforms.

•Logistics information traceability services are provided by third-party institutions and operated directly by suppliers.

•Logistics information traceability services are both provided and operated directly by suppliers.

This situational diversity gives rise to the central question of this study: What are the differences in logistics information traceability models based on the operational contexts of e-commerce platforms? Employing game theory methodologies, this research undertakes a comparative analysis of the operational characteristics inherent to different logistics information traceability models, focusing on their respective impacts on members of the supply chain within the scope of e-commerce platforms. Furthermore, the study delves into the decision-making factors influencing the selection of logistics information traceability models by e-commerce platforms.

2 Literature Review

The rapid development of the Internet has given birth to e-commerce, among which e-commerce platforms have become a popular business operation model. In this context, scholars have explored pricing issues and service operation strategies for e-commerce platforms. Based on the ownership of products, existing scholars classify them into three types: i) resale model, ii) platform model, and iii) hybrid model. The resale model refers to the e-commerce platform purchasing products from suppliers and reselling them to buyers in order to obtain profits. This is the self operated model of e-commerce platforms [15], such as retailers 7-11, Eastbay, Lowe's, and Zap POS. The platform model refers to suppliers paying commissions to the platform and then selling products directly to buyers. This is the supplier direct sales model [16], such as Alibaba, eBay, and the boutique outlets and Simon Shopping Center under Simon Real Estate Group. Mixed mode refers to the coexistence of resale mode and platform mode, where the platform can choose to act as a market and sell products directly to buyers for suppliers. Or act as a reseller to purchase products from suppliers and sell them to buyers. For example: JD.com, Tmall. Regarding the above three models, Dumrongsiri's research [17] found that Under the conditions of a balanced sharing market, the existence of dual channels plays an important role in balancing the marginal cost difference between the two channels. Hagiu's research [18] shows that the choice of platform and resale models depends on who has the best marketing information related to each specific product. Shi et al. [16] believes that the relationship between resale channels and market channels is substitutable. Li et al. [19] used panel vector autoregressive analysis to empirically point out that although mixed models are an inevitable trend that helps alleviate the burden of product expansion on resale, resale may also face sales erosion caused by supplier direct sales models. On top of typical sales models, Tian and Jiang [15]studies the impact of shared markets based on the C2C platform on distribution channels. In the operation of leasing service platforms, Choi et al. [20] analyzed the product information disclosure Nash game between two product leasing alternative leasing service platforms. The study showed that there is a critical threshold for information sensitive consumers, which helps each platform decide whether to disclose product information. Wang et al. [21] considered the decision-making and coordination problem of e-commerce supply chain based on manufacturer fairness, studied the optimal decisions in three scenarios, and pointed out that although e-commerce platforms are the dominant players, due to their unique operating methods, they obtain lower profits than manufacturers. Yang et al. [22] analyzed the Stackelberg game between manufacturers and electronic retailers, and explored the selection strategy and information sharing strategy of e-commerce sales models in a dual channel supply chain. Zhang et al. [23] discussed the optimal operational strategy of the platform supply chain in the presence of a secondary market. With the rise of big data and live streaming, Bai et al. [24] analyzed the strategic evolution paths of e-commerce enterprises, consumers, and governments in the context of big data killing based on evolutionary games. Lee and Lee [25] pointed out that there are differences in the correlation between the initial perceived overall product value, the degree of confirmation of reading reviews, and the final purchase intention among different tone of consumer online review reading.

Blockchain technology, characterized by its distributed storage and immutable nature, has been instrumental in addressing information asymmetry in traditional supply chains. Schmidt and Wagner [26] has shown that the integration of blockchain can mitigate the effects of uncertainty in supply chains, leading to reduced transaction costs. Furthermore, Hastig and Sodhi [27] have indicated that blockchain technology significantly enhances coordination within the supply chain and bolsters the integrity of data. Research by Dong et al. [28] has identified blockchain's capability to accurately locate product faults, thereby improving the efficiency of reverse logistics information traceability and enhancing overall supply chain responsiveness. Empirical research conducted by Ying et al. [29] has revealed that logistics information traceability, facilitated by blockchain, not only provides essential information impacting consumer purchasing decisions but also acts as a dependable indicator of product quality. This, in turn, bolsters consumer confidence. Similarly, Rueda et al. [30] have observed that food businesses can leverage traceability systems to underscore the trustworthiness of their products. Yeh et al. [31] have discovered that blockchain-enabled logistics information traceability services play a pivotal role in aiding consumer decision-making, particularly in the context of purchasing agricultural products. Using a Logit regression model, Harish et al. [32] have demonstrated that blockchain technology in logistics information traceability significantly elevates consumer repurchase intentions. Biswas et al. [33], in their research, suggest that consumer price sensitivity and a heightened focus on quality are key determinants in the adoption of blockchain technology. In terms of the impact on supply chain members, Wu and Yu [34] have delved into the application of smart contracts in blockchain within the automotive supply chain, examining blockchain's suitability in the domain of supply chain information sharing. Zhang et al. [35] focusing on manufacturers, retailers, and two third-party logistics companies, have analyzed optimal business strategies in the context of pre- and post-blockchain adoption. In scenarios where consumer sensitivity to product authenticity is high, Liang et al. [36] have found that the adoption of blockchain logistics information traceability technology results in higher wholesale, direct-to-consumer, and retail prices compared to scenarios lacking blockchain technology.

There are two modes involved in the construction of blockchain traceability platforms: self built or third-party built. On similar logistics platform construction issues, Liu and Liu [37] summarized the current development status of self built logistics and analyzed the impact of self built platforms on product prices, sales volume, prices, and sales differences from the perspective of consumers. Lou et al. [38] compares the effectiveness of two logistics services (retailers providing logistics services themselves or outsourcing them to third-party logistics service providers). The results indicate that although it reduces the double marginalization effect, providing logistics services to retailers is not always the best choice. Liu et al. [39] takes a supply chain consisting of two competing manufacturing enterprises and a retail platform as the research object, and makes decisions on two logistics construction models (independent investment by manufacturing enterprises or joint construction between manufacturing enterprises and retail platforms). Qin et al. [40] constructed a supply chain consisting of an e-commerce platform and sellers, where the platform chooses whether to share logistics service systems with sellers, and sellers choose whether to outsource logistics services to third-party platforms. They found that with the improvement of logistics service level and market potential, platforms and sellers cooperate as a balanced model. Niu et al. [41] constructed an analytical game model to examine whether e-commerce platform B, which does not have logistics advantages, cooperates with competitor

A, which has logistics advantages. They found that when the product competition intensity is in a moderate range, B benefits from cooperating with A. Previous research has mainly focused on the selection of logistics service strategies, and some scholars have also conducted research in other fields. Du et al. [42] studied the optimal selection strategy for online to offline (O2O) meal delivery models by businesses and found that when the advertising effect generated by self delivery is significant and consumers receive less revenue from third-party platform promotion, businesses should choose self built platforms and self-produced models. Zhang et al. [43] established a model consisting of manufacturers and third-party sharing platforms, indicating that in cases where consumer inconvenience costs are relatively low but marginal costs are high, manufacturers will establish their own sharing platforms, while in cases where consumer inconvenience costs are relatively high but marginal costs are relatively low, manufacturers will cooperate with third-party sharing platforms.

3 Logistics Information Traceability Models

3.1 Model Description

In the context of blockchain technology's capabilities for anti-counterfeit and logistics information traceability (encompassing the recording of product information from raw materials to sales), the prioritization of determining the traceability level T is paramount.

Reflecting on Sinkovics et al. [44] research, it is found that the costs associated with logistics input and infrastructure investment exhibit a quadratic relationship. Consequently, the cost of offering logistics information traceability services is denoted by cT^2, where c represents the cost factor of the service; a higher c implies a more elevated traceability level and concurrently increased operational costs. In scenarios where e-commerce platforms provide traceability services, a service fee f per unit cost is levied on suppliers. Conversely, suppliers operating on e-commerce platforms are obliged to pay a commission fee at a rate of e.

This paper centers on a supply chain comprising brand suppliers (such as Lenovo, Huawei, etc.), an extensive e-commerce platform (e.g., Tmall International, JD.com), and a wide consumer base. Within this supply chain, the upstream entities are product suppliers, while the downstream encompasses e-commerce platforms (e.g., JD.com, Tmall, Amazon, etc.).

Two primary logistics information traceability models emerge in this setting: platform logistics information traceability, and third-party logistics information traceability; coupled with two operational sales models of platform operation and supplier operation. Consequently, this results in four distinct supply scenarios within the e-commerce market.

3.1.1 The third party-platform (*TP*) model

The *TP* model exemplifies the combination of third-party logistics information traceability with e-commerce platform operation. Suppliers initiate this model by engaging third-party logistics information traceability service providers with a traceability level of T^{TP}, followed by the production and wholesale of products to the e-commerce platform at a price W^{TP}. Ultimately, the e-commerce platform retails these products to consumers at a price P^{TP} (Figure 1).

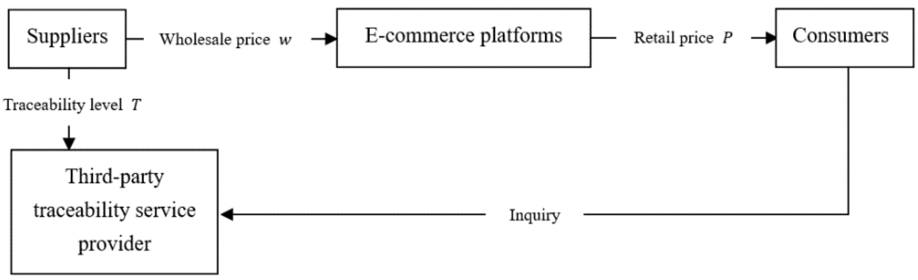

Figure 1. *TP* model flowchart

3.1.2 Platform-platform (*PP*) model

In this model, e-commerce platform logistics information traceability is combined with e-commerce platform operation. It is imperative for the e-commerce platform to first establish a traceability level of T^{PP}. Subsequently, suppliers engage in wholesaling to the e-commerce platform at the determined wholesale price W^{PP}. The final phase involves the e-commerce platform retailing the products to consumers at the retail price P^{PP}. This model is graphically represented in Figure 2.

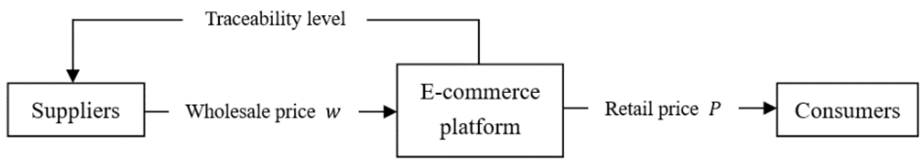

Figure 2. *PP* model flowchart

3.1.3 Third party-supplier (*TS*) model

This model integrates third-party logistics information traceability with supplier operation. Initially, the supplier identifies a third-party logistics information traceability service provider at a traceability level of T^{TS}. Following this, a commission at a rate of e is paid to the platform, leading to direct sales to consumers at the retail price P^{TS}. The flow of this model is depicted in Figure 3.

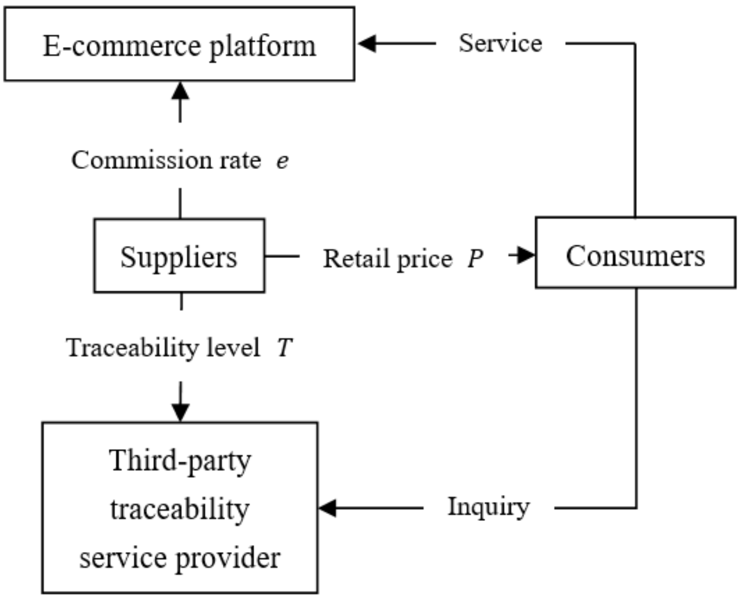

Figure 3. *TS* model flowchart

3.1.4 Platform-supplier (*PS*) model

This model represents platform logistics information traceability combined with supplier operation. The e-commerce platform commences by defining a blockchain logistics information traceability platform level of T^{PS}. Following this, a decision is made regarding the unit service fee *e* for traceability services. After the supplier fulfills the payment of service and commission fees to the platform, sales are made directly to consumers at the retail price P^{PS}. The schematic of this model is illustrated in Figure 4.

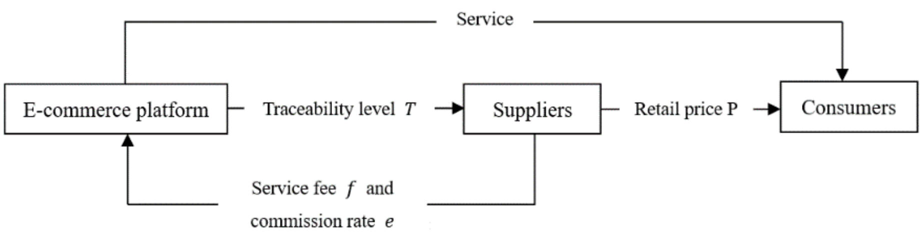

Figure 4. *PS* model flowchart

3.2 Model Construction and Solution

In the realm of consumer preferences, variability is observed concerning the level of logistics information traceability and pricing. Based on existing research, it is acknowledged that market demand is influenced by both the traceability level and the retail price of a product. It is identified that a lower retail price or a higher logistics information traceability level correlates with an increase in demand. Consequently, this paper adopts a linear demand function to represent market demand, effectively encapsulating these dynamics.

$$D_i = \delta - P_i + \mu T_i \tag{1}$$

where, i signifies one of the four supply models under consideration: ***TP***, ***PP***, ***TS***, or ***PS***. δ denotes the latent market demand for the product, while μ reflects consumer preference (or sensitivity) toward the traceability level, illustrating the degree to which changes in traceability affect market demand. The variables D_i, P_i and T_i correspond to the market demand, retail price, and logistics information traceability level, respectively, for each supply model i. Table 1 outlines the variables used in the model.

Table 1. Variables used in the model

Variables	Descriptions
$i \in \{TP, PP, TS, PS\}$	Supply models
D_i	Market demand under supply model i
W_i	Wholesale price of the product under supply model i
P_i	Retail price of the product under supply model i
T_i	Logistics information traceability level under supply model i
e	Commission charged by the e-commerce platform, with $0 < e < 1$
δ	Potential demand for the product, with $\delta > 0$
μ	Consumer preference (sensitivity coefficient) towards logistics information traceability service, with $0 < \mu < 1$
c	Cost factor for logistics information traceability service, with $c > 0$
π_p^i	Profit of the e-commerce platform under supply model i
π_s^i	Profit of the supplier under supply model i

3.2.1 *TP* model

In the *TP* model, it is initially established that suppliers incur an operational fee $c\left(T^{TP}\right)^2$ payable to the third-party logistics information traceability service provider. Subsequently, products are wholesaled to the e-commerce platform at W^{TP}, culminating in the platform retailing these products to consumers at P^{TP}. The profit function for the supplier, therefore, is determined as follows:

$$\pi_s^{TP}\left(W^{TP}, T^{TP}\right) = W^{TP} D^{TP} - c\left(T^{TP}\right)^2 \tag{2}$$

The e-commerce platform's profit function is derived similarly:

$$\pi_p^{TP}\left(P^{TP}\right) = \left(P^{TP} - W^{TP}\right) D^{TP} \tag{3}$$

where, $D^{TP} = \delta - P^{TP} + \mu T^{TP}$.

Employing a backward induction approach, the solution involves computing the partial derivative of the platform's profit function π_p^{TP} with respect to P^{TP} and setting it to zero. This process facilitates the determination of:

$$P_1^{TP} = \frac{\delta + \mu T^{TP} + W^{TP}}{2} \tag{4}$$

The substitution of P_1^{TP} into π_s^{TP} is followed by the calculation of the partial derivative of π_s^{TP} with respect to W^{TP}. This derivative is then set to zero, facilitating the derivation of:

$$W_1^{TP} = \frac{\delta + \mu T^{TP}}{2} \tag{5}$$

Subsequently, upon substituting P_1^{TP} and W_1^{TP} into π_p^{TP} and calculating the partial derivative of π_p^{TP} with respect to T^{TP} and setting to zero, the equilibrium level of logistics information traceability is ascertained:

$$T^{TP} = \frac{\delta\mu}{8c - \mu^2} \tag{6}$$

Finally, by incorporating T^{TP} into W_1^{TP}, the equilibrium wholesale price is obtained:

$$W^{TP} = \frac{4\delta c}{8c - \mu^2} \tag{7}$$

Similarly, the equilibrium retail price is determined by substituting T^{TP} and W^{TP} into P_1^{TP} :

$$P^{TP} = \frac{6\delta c}{8c - \mu^2} \tag{8}$$

Furthermore, substituting T^{TP}, W^{TP} and P^{TP} into the demand function D^{TP}, as well as the supplier's and platform's profit functions π_s^{TP} and π_p^{TP} for the *TP* model, yields:

$$D^{TP} = \frac{2\delta c}{8c - \mu^2} \tag{9}$$

$$\pi_s^{TP} = \frac{c\delta^2}{8c - \mu^2} \tag{10}$$

$$\pi_p^{TP} = \frac{4\delta^2 c^2}{\left(8c - \mu^2\right)^2} \tag{11}$$

The analysis reveals that the first-order partial derivatives of $T^{TP}, W^{TP}, P^{TP}, D^{TP}, \pi_s^{TP}$ and π_p^{TP}, when taken with respect to the operational cost factor c for logistics information traceability services, are found to be negative, namely, $\frac{dT^{TP}}{dc} = \frac{-8\delta\mu}{(8c-\mu^2)^2} < 0$, $\frac{dW^{TP}}{dc} = \frac{-4\delta\mu^2}{(8c-\mu^2)^2} < 0$, $\frac{dp^{TP}}{dc} = \frac{-6\delta\mu^2}{(8c-\mu^2)^2} < 0$, $\frac{dD^{TP}}{dc} = \frac{-2\delta\mu^2}{(8c-\mu^2)^2} < 0$, $\frac{d\pi_s^{TP}}{dc} = \frac{-\delta^2\mu^2}{(8c-\mu^2)^2} < 0$, and $\frac{d\pi_p^{TP}}{dc} = \frac{-8c\delta^2\mu^2}{(8c-\mu^2)^3} < 0$. This indicates a monotonically decreasing relationship. Consequently, it is observed that as the operational cost factor c increases, there is a corresponding decline in several critical parameters, namely the level of logistics information traceability T^{TP}, the wholesale price W^{TP}, the retail price P^{TP}, consumer demand D^{TP}, supplier profit π_s^{TP}, and platform profit π_p^{TP}. This discovery is pivotal for understanding the economic dynamics of logistics information traceability within e-commerce systems.

In a similar vein, the first-order partial derivatives of $T^{TP}, W^{TP}, P^{TP}, D^{TP}, \pi_s^{TP}$ and π_p^{TP} with respect to consumer preference μ for logistics information traceability services demonstrate positive values, namely, $\frac{dT^{TP}}{d\mu} = \frac{\delta\left(8c+\mu^2\right)}{(8c-\mu^2)^2} > 0$, $\frac{dW^{TP}}{d\mu} = \frac{8\delta c\mu}{(8c-\mu^2)^2} > 0$, $\frac{dP^{TP}}{d\mu} = \frac{12\delta c\mu}{(8c-\mu^2)^2} > 0$, $\frac{dD^{TP}}{d\mu} = \frac{4\delta c\mu}{(8c-\mu^2)^2} > 0$, $\frac{d\pi_S^{TP}}{d\mu} = \frac{2\delta c\delta^2}{(8c-\mu^2)^2} > 0$, and $\frac{d\pi_p^{TP}}{d\mu} = \frac{16\mu\delta^2 c^2}{(8c-\mu^2)^3} > 0$. This implies a monotonically increasing relationship. Therefore, as consumer preference μ for logistics information traceability services escalates, it concurrently leads to an increase in the level of logistics information traceability T^{TP}, wholesale prices W^{TP}, retail prices P^{TP}, consumer demand D^{TP}, supplier profit π_s^{TP}, and platform profit π_p^{TP}. This finding is crucial for e-commerce platforms in strategizing their logistics traceability services, aligning them with consumer preferences to enhance overall profitability and market performance.

3.2.2 *PP* model

In the *PP* model, it is initially established that the platform constructs and operates a logistics information traceability platform at a certain traceability level T^{PP}, incurring a cost denoted by $c\left(T^{PP}\right)^2$. The subsequent phase involves the supplier wholesaling products to the e-commerce platform at W^{PP}, which then retails these products to consumers at P^{PP}. The profit function for the supplier is thus formulated based on these operational dynamics.

$$\pi_s^{PP}\left(W^{PP}, T^{PP}\right) = W^{PP} D^{PP} \tag{12}$$

For the e-commerce platform, the profit function is similarly derived:

$$\pi_p^{PP}\left(P^{PP}, T^{PP}\right) = \left(P^{PP} - W^{PP}\right) D^{PP} - c\left(T^{PP}\right)^2 \tag{13}$$

where, $D^{PP} = \delta - P^{PP} + \mu T^{PP}$.

Employing the backward induction method for solution derivation, the partial derivative of π_p^{PP} with respect to P^{PP} is computed and set to zero. This computation facilitates the determination of:

$$P_1^{PP} = \frac{\delta + \mu T^{PP} + w^{PP}}{2} \tag{14}$$

The substitution of P_1^{PP} into π_s^{PP} is followed by the calculation of the partial derivative of π_s^{PP} with respect to W^{PP}. This derivative is then set to zero, facilitating the derivation of:

$$W_1^{PP} = \frac{\delta + \mu T^{PP}}{2} \tag{15}$$

Subsequently, upon substituting P_1^{PP} and W_1^{PP} into π_s^{PP} and calculating the partial derivative of π_s^{PP} with respect to T^{PP} and setting to zero, the equilibrium level of logistics information traceability is ascertained:

$$T^{PP} = \frac{\delta\mu}{16c - \mu^2} \tag{16}$$

Finally, the equilibrium wholesale prices are obtained by incorporating T^{PP} into W_1^{PP} :

$$W^{PP} = \frac{8\delta c}{16c - \mu^2} \tag{17}$$

The equilibrium retail prices are obtained by incorporating T^{PP} and W^{PP} into P_1^{PP} :

$$P^{PP} = \frac{12\delta c}{16c - \mu^2} \tag{18}$$

Additionally, by substituting T^{PP}, W^{PP} and P^{PP} into the demand function D^{PP}, as well as the supplier's and platform's profit functions π_s^{PP} and π_p^{PP} for the *PP* model, the following outcomes are derived.

$$D^{PP} = \frac{4\delta c}{16c - \mu^2} \tag{19}$$

$$\pi_s^{PP} = \frac{32\delta^2 c^2}{\left(16c - \mu^2\right)^2} \tag{20}$$

$$\pi_{\mathrm{p}}^{\mathrm{PP}} = \frac{\mathrm{c}\delta^2}{16\mathrm{c} - \mu^2} \tag{21}$$

It is observed that the first derivatives of $T^{PP}, W^{PP}, P^{PP}, D^{PP}, \pi_s^{PP}$ and π_p^{PP} with respect to the operational cost factor c for logistics information traceability services are negative, namely, $\frac{dT^{PP}}{dc} = \frac{-16\delta c}{(16c-\mu^2)^2} < 0$, $\frac{dW^{PP}}{dc} = \frac{-8c\delta^2}{(16c-\mu^2)^2} < 0$, $\frac{dP^{PP}}{dc} = \frac{-12c\delta^2}{(16c-\mu^2)^2} < 0$, $\frac{dD^{PP}}{dc} = \frac{-4c\delta^2}{(16c-\mu^2)^2} < 0$, $\frac{\pi_s^{PP}}{dc} = \frac{-64c\delta^2\mu^2}{(16c-\mu^2)^3} < 0$, and $\frac{\pi_p^{PP}}{dc} = \frac{-\delta^2\mu^2}{(16c-\mu^2)^2} < 0$. This indicates a monotonically decreasing relationship. As a result, it can be inferred that an increase in the operational cost factor c leads to a decrease in several key variables: the level of logistics information traceability T^{PP}, wholesale and retail prices W^{PP} and P^{PP}, consumer demand D^{PP}, and the profits of both suppliers and the e-commerce platform π_s^{PP} and π_p^{PP}. This finding is significant as it highlights the sensitivity of these variables to changes in the operational costs of traceability services.

Conversely, the first derivatives of $T^{PP}, W^{PP}, P^{PP}, D^{PP}, \pi_s^{PP}$ and π_p^{PP} concerning consumer preference μ for logistics information traceability services are positive, namely, $\frac{dT^{PP}}{d\mu} = \frac{\delta\left(16c+\mu^2\right)}{(16c-\mu^2)^2} > 0$, $\frac{dW^{PP}}{d\mu} = \frac{16c\delta\mu}{(16c-\mu^2)^2} > 0$, $\frac{dP^{PP}}{d\mu} = \frac{24c\delta\mu}{(16c-\mu^2)^2} > 0$, $\frac{dD^{PP}}{d\mu} = \frac{8c\delta\mu}{(16c-\mu^2)^2} > 0$, $\frac{\pi_s^{PP}}{d\mu} = \frac{128\mu\delta^2c^2}{(16c-\mu^2)^3} > 0$, and $\frac{\pi_p^{PP}}{d\mu} = \frac{2c\mu\delta^2}{(16c-\mu^2)^2} > 0$. This suggests a monotonically increasing relationship. Therefore, an increase in consumer preference μ for logistics information traceability services correlates with an increase in the level of logistics information traceability T^{PP}, as well as in the wholesale and retail prices W^{PP} and P^{PP}. Additionally, this preference impacts consumer demand D^{PP} and elevates the profits of both suppliers and platforms π_s^{PP} and π_p^{PP}. This insight is particularly valuable for ecommerce platforms, emphasizing the importance of aligning logistics information traceability services with consumer preferences to optimize market outcomes.

3.2.3 *TS* model

Within the *TS* model framework, it is initially recognized that the supplier incurs an operational fee $c\left(T^{TS}\right)^2$ payable to a third-party logistics information traceability service provider. Following this, a commission is paid to the e-commerce platform, culminating in direct sales to consumers at a retail price P^{TS}. Hence, the profit function for the supplier is deduced in accordance with these operational procedures.

$$\pi_S^{TS}\left(W^{TS}, T^{TS}\right) = (1-e)P^{TS}D^{TS} - c\left(T^{TS}\right)^2 \tag{22}$$

The profit function for the e-commerce platform is similarly formulated:

$$\pi_p^{TS}\left(P^{TS}\right)=eP^{TS}D^{TS} \tag{23}$$

where, $D^{TS}=\delta-P^{TS}+\mu T^{TS}$.

The backward induction method is utilized for problem-solving. The computation of the partial derivative of π_S^{TS} with respect to P^{TS} and setting it to zero enables the determination of:

$$P_1^{TS}=\frac{\delta+\mu T^{TS}}{2} \tag{24}$$

Subsequently, upon substituting P_1^{TS} into π_S^{TS} and calculating the partial derivative of π_S^{TS} with respect to T^{TP} and setting to zero, the equilibrium level of logistics information traceability is ascertained:

$$T^{TP}=\frac{(1-e)\delta\mu}{4c-(1-e)\mu^2} \tag{25}$$

The equilibrium retail price is ascertained by integrating T^{TP} and W^{TP} into P_1^{TP} :

$$P^{TP}=\frac{2\delta c}{4c-(1-e)\mu^2} \tag{26}$$

Furthermore, by substituting T^{TP}, W^{TP} and P^{TP} into the demand function D^{TP}, supplier's profit function π_S^{TS}, and platform's profit function π_p^{TS} for the TS model, the outcomes are revealed:

$$D^{TP}=\frac{2\delta c}{4c-(1-\theta)\mu^2} \tag{27}$$

$$\pi_S^{TS}=\frac{(1-e)\mu\delta^2}{4c-(1-e)\mu^2} \tag{28}$$

$$\pi_p^{TS}=\frac{4e\delta^2c^2}{\left(4c-(1-e)\mu^2\right)^2} \tag{29}$$

It has been observed that the first derivatives of T^{TP}, P^{TP}, D^{TP}, π_S^{TS} and π_p^{TS} with respect to the operational cost factor c are negative, namely, $\frac{dT^{TP}}{dc}=\frac{-4\mu\delta(1-e)}{(4c-(1-e)\mu^2)^2}<0$, $\frac{dP^{TP}}{dc}=\frac{-2\delta\mu^2(1-e)}{(4c-(1-e)\mu^2)^2}<0$, $\frac{dD^{TP}}{dc}=\frac{-2\delta\mu^2(1-e)}{(4c-(1-e)\mu^2)^2}<0$, $\frac{d\pi_S^{TS}}{dc}=\frac{-\delta^2\mu^2(1-e)^2}{(4c-(1-e)\mu^2)^2}<0$, and $\frac{d\pi_p^{TS}}{dc}=\frac{-8ce\delta^2\mu^2(1-e)}{(4c-(1-e)\mu^2)^3}<0$, thereby indicating a monotonically decreasing relationship. This implies that an increase in the operational cost factor c for logistics information traceability service is associated with a decrease in several critical parameters: the level of logistics information traceability T^{TP}, retail price P^{TP}, consumer demand D^{TP}, and the profits of both suppliers and the platform π_S^{TS} and π_p^{TS}. This relationship is critical in understanding the economic dynamics of logistics information traceability services within e-commerce platforms.

Conversely, when considering consumer preference μ for logistics information traceability service, the first derivatives of these functions are positive, namely, $\frac{dT^{TP}}{d\mu}=\frac{\delta(1-e)\left(4c-(1-e)\mu^2\right)}{(4c-(1-e)\mu^2)^2}>0$, $\frac{dP^{TP}}{d\mu}=\frac{4\delta c\mu(1-e)}{(4c-(1-e)\mu^2)^2}>0$, $\frac{dD^{TP}}{d\mu}=\frac{4\delta c\mu(1-e)}{(4c-(1-e)\mu^2)^2}>0$, $\frac{d\pi_S^{TS}}{d\mu}=\frac{2c\mu\delta^2(1-e)^2}{(4c-(1-e)\mu^2)^2}>0$, and $\frac{d\pi_p^{TS}}{d\mu}=\frac{16\mu\delta^2c^2(1-e)}{(4c-(1-e)\mu^2)^3}>0$. This suggests a monotonically increasing relationship, indicating that enhanced consumer preference μ for logistics information traceability service results in an increase in the level of logistics information traceability T^{TP}. Furthermore, it leads to an increase in retail prices P^{TP}, consumer demand D^{TP}, and the profits accruing to both suppliers and the ecommerce platform π_S^{TS} and π_p^{TS}. This finding underscores the importance of aligning logistics traceability services with consumer preferences to optimize market outcomes and profitability.

3.2.4 *PS* model

In the *PS* model, the process commences with the supplier paying an operational fee f to a third-party logistics information traceability service provider. This is followed by payment of a commission to the platform, culminating in the supplier selling products directly to consumers at a retail price P^{PS}. Consequently, the profit function for the supplier is deduced based on these operational parameters.

$$\pi_S^{PS}\left(W^{PS},T^{PS}\right)=\left((1-e)P^{PS}-f\right)D^{PS} \tag{30}$$

The profit function for the e-commerce platform is similarly established:

$$\pi_p^{PS}\left(P^{PS}\right)=\left(eP^{PS}+f\right)D^{PS}-c\left(T^{PS}\right)^2 \tag{31}$$

where, $D^{PS}=\delta-P^{PS}+\mu T^{PS}$

Utilizing the backward induction method, the solution is derived by computing the partial derivative of π_S^{PS} with respect to P^{PS} and setting it to zero. This approach facilitates the determination of:

$$P_1^{PS}=\frac{f-(e-1)\left(\delta+\mu T^{PS}\right)}{2(1-e)} \tag{32}$$

Subsequently, upon substituting P_1^{PS} into π_p^{PS} and calculating the partial derivative of π_p^{PS} with respect to f and setting to zero, the equilibrium service fee for logistics information traceability is ascertained:

$$f_1=\frac{(1-e)^2\left(\delta+\mu T^{PS}\right)}{2-e} \tag{33}$$

The substitution of f_1 and P_1^{PS} into π_p^{PS} is followed by the calculation of the partial derivative of π_p^{PS} with respect to T^{PS}. This derivative is then set to zero, facilitating the derivation of the equilibrium level T^{PS} of logistics information traceability:

$$T^{PS}=\frac{\delta\mu}{4c(2-e)-\mu^2} \tag{34}$$

The equilibrium service fee f for logistics information traceability is ascertained by substituting T^{PS} into f_1 :

$$f=\frac{4\delta c(1-e)^2}{4c(2-e)-\mu^2} \tag{35}$$

The equilibrium retail price P^{PS} is then determined by integrating T^{PS} and f_1 into P_1^{PS} :

$$P^{PS}=\frac{2(3-2e)\delta\mu}{4c(2-e)-\mu^2} \tag{36}$$

Furthermore, by incorporating T^{PS}, f and P^{PS} into the demand function D^{PS}, supplier's profit function π_S^{PS}, and platform's profit function π_p^{PS} for the PS model, the outcomes are derived:

$$D^{TP}=\frac{2\delta\mu}{4c(2-e)-\mu^2} \tag{37}$$

$$\pi_S^{PS}=\frac{4(1-e)\delta^2\mu^2}{\left(4c(2-e)-\mu^2\right)^2} \tag{38}$$

$$\pi_p^{PS}=\frac{c\delta^2}{4c(2-e)-\mu^2} \tag{39}$$

The analysis shows that the first derivatives of T^{PS}, P^{TS}, D^{TS}, π_S^{PS} and π_p^{TS} with respect to the operational cost factor c are negative, namely, $\frac{dT^{TS}}{dc}=\frac{-4\delta\mu(2-e)}{(\mu^2+4c(e-2))^2}<0$, $\frac{dP^{TS}}{dc}=\frac{-2\delta\mu^2(3-2e)}{(\mu^2+4c(e-2))^2}<0$, $\frac{dD^{TS}}{dc}=\frac{-2\delta\mu^2}{(\mu^2+4c(e-2))^2}<0$, $\frac{df}{dc}=\frac{-4\delta\mu^2(e-1)^2}{(\mu^2+4c(e-2))^2}<0$, $\frac{d\pi_S^{PS}}{dc}=\frac{8c\delta^2\mu^2(1-e)}{(\mu^2+4c(e-2))^3}<0$, and $\frac{d\pi_p^{PS}}{dc}=\frac{-\delta^2\mu^2}{(\mu^2+4c(e-2))^2}<0$. This finding indicates a monotonically decreasing relationship, suggesting that an increase in the operational cost factor c associated with logistics information traceability services leads to a concurrent decrease in several key factors. These include the level T^{PS} of logistics information traceability, retail price P^{TS}, consumer demand D^{TS}, as well as the profits of both suppliers and the e-commerce platform π_S^{PS} and π_p^{TS}. This decline highlights the cost sensitivity of logistics traceability services and their impact on market dynamics and profitability.

Conversely, the analysis regarding consumer preference μ for logistics information traceability service yields a different relationship. The first derivatives of the examined functions with respect to this preference are positive, namely, $\frac{dT^{TS}}{d\mu}=\frac{\delta\left(\mu^2+8c-4ce\right)}{(\mu^2+4c(e-2))^2}>0$, $\frac{dP^{TS}}{d\mu}=\frac{4\delta c\mu(3-2e)}{(\mu^2+4c(e-2))^2}>0$, $\frac{dD^{TS}}{d\mu}=\frac{4\delta c\mu}{(\mu^2+4c(e-2))^2}>0$, $\frac{df}{d\mu}=\frac{8\delta c\mu(e-1)^2}{(\mu^2+4c(e-2))^2}>0$, $\frac{d\pi_S^{PS}}{d\mu}=\frac{16\mu\delta^2c^2(e-1)}{(\mu^2+4c(e-2))^3}>0$, and $\frac{d\pi_p^{PS}}{d\mu}=\frac{2c\mu\delta^2}{(\mu^2+4c(e-2))^2}>0$, revealing a monotonically increasing trend. This suggests that heightened consumer preference μ for logistics information traceability service is positively correlated with increases in the level T^{TP} of logistics information traceability. Furthermore, this increased preference also elevates retail prices P^{TP}, consumer demand D^{TP}, and the profits accruing to suppliers and e-commerce platforms π_S^{TS} and π_p^{TS}. This aspect of the research underscores the importance of consumer preference in shaping the market outcomes and the economic viability of logistics traceability services.

4 Operational Model Comparison

In this section, the impacts of the performance of logistics traceability services, denoted as $G = \frac{\mu^2}{c}$, on various operational metrics are scrutinized. The performance of these services, indicative of the return on investment, is directly proportional to the value of G, with a higher G signifying enhanced returns.

4.1 Comparison of Logistics Information Traceability Levels

An analytical comparison of logistics information traceability levels across four distinct operational models reveals insightful trends:

• In the scenario of platform operation, it is observed that the logistics information traceability level attains a higher value when third-party logistics information traceability is selected, i.e., $T^{TP} > T^{PP}$.

• Conversely, under the supplier direct operation model, the e-commerce platform's logistics information traceability exhibits a superior level of traceability, i.e., $T^{TS} < T^{PS}$.

• Among all models considered, the third-party logistics information traceability combined with platform operation model consistently demonstrates the highest logistics information traceability level, i.e., T^{TP}.

A comparative analysis between the *TP* and *PP* models concerning their respective logistics information traceability levels leads to the conclusion that the inequality $T^{TP} > T^{PP}$ consistently holds true.

$$T^{TP} - T^{PP} = \frac{\delta\mu}{8c - \mu^2} - \frac{\delta\mu}{16c - \mu^2} = \frac{8c\delta\mu}{(8c - \mu^2)(16c - \mu^2)} > 0 \tag{40}$$

Further comparison between the *TS* and *PS* models, focusing on their logistics information traceability levels, yields the finding that the inequality $T^{TS} < T^{PS}$ is invariably maintained.

$$T^{TS} - T^{PS} = \frac{\delta\mu}{(4c(e-2) + \mu^2)} - \frac{\delta\mu(e-1)}{(4c + (e-1)\mu^2)} = \frac{-4c\mu\delta\left(1 - 3e + e^2\right)}{(4c(e-2) + \mu^2)(4c + (e-1)\mu^2)} < 0 \tag{41}$$

Lastly, an evaluation of the *TP* and *TS* models in terms of their logistics information traceability levels deduces that the inequality $T^{TP} > T^{PS}$ remains consistently valid.

$$\mathrm{T^{TP}} - \mathrm{T^{PS}} = \frac{4\delta\mathrm{ce}\mu}{(8\mathrm{c} - \mu^2)(\mu^2 - 8\mathrm{c} + 4\mathrm{ce})} > 0 \tag{42}$$

4.2 Comparison of Retail Prices

The retail prices across the four models have been comparatively analyzed, leading to the following observations:

• In scenarios where the platform operates the model, it is observed that opting for third-party logistics information traceability correlates with higher retail prices, i.e., $P^{TP} > P^{PP}$.

• In contrast, under the supplier direct operation model, selecting the e-commerce platform's logistics information traceability results in higher prices, i.e., $P^{TS} < P^{PS}$.

• Notably, among all models, the combination of supplier direct operation and platform logistics information traceability consistently yields the highest retail prices, i.e., P^{PS}.

A detailed comparison of the retail prices in the *TP* and *PP* models reveals that the inequality $P^{TP} > P^{PP}$ holds true in every instance, indicating a consistent pattern.

$$P^{TP} - P^{PP} = \frac{3\delta\mu^2}{32c - 4\mu^2} - \frac{3\delta\mu^2}{64c - 4\mu^2} = \frac{6c\delta\mu^2}{(8c - \mu^2)(16c - \mu^2)} > 0 \tag{43}$$

When examining the retail prices in the *TS* and *PS* models, it is identified that for the function $f(G_0) = 2\delta c\left(\frac{-2c\left(3G^2C^2 - 4G\mu^2 + \mu^2\right)}{u^2}\right)$, where G equals $\frac{\mu^2}{c}$, the quadratic term's coefficient is negative, indicating a downwardopening quadratic function. The function's vertex is located at a specific coordinate $G_0 = \frac{2c}{3\mu^2} = \frac{2}{3G}$ and $f(G_0) = \frac{-4c^3}{3\mu^2} < 0$, and when G is less than G_0, $f(G)$ increases monotonically; conversely, when G exceeds this value, $f(G)$ decreases monotonically. Consequently, this inequality $P^{TS} < P^{PS}$ consistently holds true.

$$P^{TS} - P^{PS} = \frac{2\delta c\left(4c - \mu^2\left(2e^2 - 5e + 2\right)\right)}{(\mu^2 - 8c + 4ce)(4c + (e-1)\mu^2)} = \frac{2\delta c\left(\frac{-2c\left(3G^2C^2 - 4G\mu^2 + \mu^2\right)}{u^2}\right)}{(\mu^2 - 8c + 4ce)(4c + (e-1)\mu^2)} \tag{44}$$

Lastly, an assessment of the retail prices in the *TP* and *PS* models demonstrates that the inequality $P^{TP} < P^{PS}$ remains consistently valid.

$$P^{TP} - P^{PS} = \frac{-4\delta ce\left(2c - u^2\right)}{(8c - \mu^2)(\mu^2 + 4ce - 8\mathrm{c})} < 0 \tag{45}$$

4.3 Comparison of Market Demand

A comparative analysis of market demand across the four operational models has led to the following conclusions:

• In scenarios where the e-commerce platform operates the model, a higher market demand is discernibly associated with third-party logistics information traceability, i.e., $D^{TP} > D^{PP}$.

• In the context of supplier direct operation, the dynamics of market demand vary with the performance of logistics traceability services. Specifically, when the performance measure G is high, there is a greater demand for third-party logistics information traceability, i.e., $D^{TS} \geq D^{PS}$. In contrast, when G is low, the demand for ecommerce platform logistics information traceability services becomes more pronounced, i.e., $D^{TS} < D^{PS}$.

A detailed comparison of market demand in the *TP* and *PP* models reveals that the inequality $D^{TP} > D^{PP}$ holds true consistently, indicating a stable pattern in market demand preferences based on the operational model.

$$\mathrm{D^{TP}} - \mathrm{D^{PP}} = \frac{\delta\mu^2}{32\mathrm{c} - 4\mu^2} - \frac{\delta\mu^2}{64c - 4\mu^2} = \frac{2c\delta\mu^2}{(8c - \mu^2)(16c - \mu^2)} > 0 \tag{46}$$

Further examination of market demand in the *TS* and *PS* models shows that the relationship between market demand (M) and the performance of logistics traceability services (G) is dependent on certain conditions.

$$D^{TS} - D^{PS} = \frac{2\delta c\left(e\mu^2 - 4c + 4ce\right)}{(\mu^2 - 8c + 4ce)(4c + (e-1)\mu^2)} = \frac{2\delta c^2(eG - 4 + 4e)}{(\mu^2 - 8c + 4ce)(4c + (e-1)\mu^2)} \tag{47}$$

where, $G = \frac{\mu^2}{c}$, and $M = eG - 4 + 4e$, with M demonstrating a monotonically increasing trend in relation to G when a specific condition $e > 0$ is met. For $G \geq \frac{4(1-e)}{e}$, $D^{TS} \geq D^{PS}$. And for $G < \frac{4(1-e)}{e}$, $D^{TS} < D^{PS}$.

4.4 Comparative Analysis of Supplier Profits

An analysis of supplier profits within the four operational models has yielded insightful conclusions:

• When e-commerce platforms manage operations, suppliers opting for third-party logistics information traceability realize higher profits, i.e., $\pi_s^{TP} > \pi_s^{PP}$.

• Similarly, in models where suppliers manage direct operations, the choice of third-party logistics information traceability correlates with increased supplier profits, i.e., $\pi_s^{TS} > \pi_s^{PS}$.

Upon initial examination of supplier profits in the *TP* and *PP* models, it emerges that the inequality $\pi_s^{TP} > \pi_s^{TP}$ holds true consistently, underscoring a significant trend in profit margins based on the logistics information traceability approach.

$$\pi_s^{TP} - \pi_s^{TP} = \frac{c\delta^2\mu^4}{(8c - \mu^2)(16c - \mu^2)} > 0 \tag{48}$$

Further scrutiny of the *TS* and *PS* models reveals a complex interplay of factors impacting supplier profits. In this context, with G representing $\frac{\mu^2}{c}$, the analysis confirms the aforementioned pattern of profitability $\pi_s^{TS} > \pi_s^{PS}$.

$$\begin{aligned} \pi_s^{TS} - \pi_s^{PS} &= \frac{c\delta^2(1-e)\left(16c^2e^2 - 64c^2e + 48c^2 + 4ce\mu^2 - 12c\mu^2 + \mu^4\right)}{(\mu^2 - 8c + 4ce)(4c + (e-1)\mu^2)} \\ &= \frac{c\delta^2(1-e)\left(16c^2G^2\left(e^2 - 3\mu G\right)^2 + c\mu^2G^2(\mu G - 2e)^2\right)}{(\mu^2 - 8c + 4ce)(4c + (e-1)\mu^2)} > 0 \end{aligned} \tag{49}$$

4.5 Comparative Analysis of Platform Profits

A comparative analysis of platform profits across different operational models reveals noteworthy patterns:

• In scenarios where the platform operates independently, it is discerned that when the performance of logistics traceability services, denoted as G, reaches extreme levels (either very high or very low), opting for third-party logistics information traceability leads to an increase in platform profits. Specifically, when $G > 16$ or $G < 12$, the said outcome $\pi_P^{TP} > \pi_P^{PP}$ is observed. However, when G is at a moderate level, the adoption of e-commerce platform logistics information traceability is more profitable. Specifically, when $12 \leq G \leq 16$, the said outcome $\pi_P^{TP} \leq \pi_P^{PP}$ is observed.

• In the context of supplier direct operation models, the profitability dynamics differ. When G is high, selecting third-party logistics information traceability services is more lucrative, i.e., $\pi_P^{TS} > \pi_P^{PS}$. In contrast, when G is low, e-commerce platform logistics information traceability emerges as the more profitable option, i.e., $\pi_P^{TS} < \pi_P^{PS}$.

The initial comparative analysis between the *TP* and *PP* models in terms of platform profits indicates a consistent pattern with respect to the varying levels of G :

$$\pi_P^{TP} - \pi_P^{PP} = \frac{c\delta^2\mu^2\left(12c - \mu^2\right)}{\left(8c - \mu^2\right)^2\left(16c - \mu^2\right)} \tag{50}$$

When $G > 16$ or $G < 12$, then $\pi_P^{TP} > \pi_P^{PP}$ is achieved, and when $12 \leq G \leq 16$, then $\pi_P^{TP} \leq \pi_P^{PP}$ is met. Further comparative analysis between the TS and PS models regarding platform profits reveals:

$$\begin{aligned}\pi_P^{TS} - \pi_P^{PS} &= \frac{c\delta^2\left(16c^2e^2 - 32c^2e + 16c^2 + 12ce\mu^2 - 8c\mu^2 + \left(e^2 - 2e + 1\right)\mu^4\right)}{\left(\mu^2 - 8c + 4ce\right)\left(4c + (e-1)\mu^2\right)^2} \\ &= \frac{c\delta^2\left(c^2\left(e^2 - 2e + 1\right)G^2 + \left(12ec^2 - 8c^2\right)G + 16c^2e^2 - 32c^2e + 16c^2\right)}{\left(\mu^2 - 8c + 4ce\right)\left(4c + (e-1)\mu^2\right)^2}\end{aligned} \tag{51}$$

In these scenarios, with $G = \frac{\mu^2}{c}$, a distinct shift in profitability $\pi_P^{TS} \geq \pi_P^{PS}$ or $\pi_P^{TS} < \pi_P^{PS}$ is observed at specific thresholds of $G \geq 2\sqrt{1-e}$ or $G < 2\sqrt{1-e}$.

5 Conclusions and Future Directions

5.1 Conclusions

The findings of this study highlight intriguing aspects of logistics information traceability in the context of e-commerce platforms. It has been observed that under platform operation models, opting for third-party logistics information traceability services results in higher traceability levels than those achieved with e-commerce platform logistics. This outcome contrasts with the anticipated additive effect typically expected in such scenarios, exemplified by the case of JD Logistics in conjunction with the JD Platform. This deviation suggests that for e-commerce platforms, a dichotomy exists where focusing exclusively on either product sales or service provision is more beneficial than a combined approach.

In terms of profit maximization, both the platform operation and supplier direct operation models yield higher profits when employing third-party logistics information traceability, as detailed in the comparative analysis of supplier profits in Section 5. Interestingly, even when e-commerce platform logistics information traceability offers elevated traceability levels, it does not translate into increased profits for suppliers, thus diminishing their motivation to adopt e-commerce platform traceability.

Regarding e-commerce platform profitability, the study reveals that platform traceability is only advantageous when logistics traceability service performance aligns with industry averages. Section 5's profit comparisons indicate that in platform operation models, the utilization of e-commerce platform logistics information traceability is profitable only at moderate levels of service performance. Consequently, if third-party logistics information traceability services exhibit higher specialization, e-commerce platforms would benefit from prioritizing these services.

5.2 Future Directions

This research contributes to the field by applying Stackelberg game theory to the investigation of supplier-led supply chain information traceability, offering insights into supply chain pricing and information symmetry for e-commerce users. Nevertheless, the study encounters limitations, notably the absence of empirical data to corroborate the hypotheses and the reliance on a singular channel for traceability information services, which may influence supply chain pricing decisions.

Future inquiries could expand upon these findings by delving into the interplay of information sharing among suppliers, e-commerce platforms, and consumers. Utilizing empirical methodologies or big data analytics could offer deeper insights into these relationships, further enriching the understanding of supply chain dynamics in the e-commerce context.

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Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] A. Liu, T. Liu, J. Mou, and R. Wang, "A supplier evaluation model based on customer demand in blockchain tracing anti-counterfeiting platform project management," *J. Manage. Sci. Eng.*, vol. 5, no. 3, pp. 172–194, 2020. https://doi.org/10.1016/j.jmse.2020.06.001

[2] X. Pu, S. Sun, and J. Shao, "Direct selling, reselling, or agency selling? Manufacturer's online distribution strategies and their impact," *Int. J. Electron. Commer.*, vol. 24, no. 2, pp. 232–254, 2020. https://doi.org/10.1080/10864415.2020.1715530

[3] P. Chen, R. Zhao, Y. Yan, and X. Li, "Promotional pricing and online business model choice in the presence of retail competition," *Omega*, vol. 94, p. 102085, 2020. https://doi.org/10.1016/j.omega.2019.07.001

[4] X. Qin, Z. Liu, and L. Tian, "The optimal combination between selling mode and logistics service strategy in an e-commerce market," *Eur. J. Oper. Res.*, vol. 289, no. 2, pp. 639–651, 2021. https://doi.org/10.1016/j.ejor.2020.07.029

[5] X. Yu, H. Zhang, and J. Yu, "Luminescence anti-counterfeiting: From elementary to advanced," *Aggregate*, vol. 2, no. 1, pp. 20–34, 2021. https://doi.org/10.1021/acsaelm.0c01121.s001

[6] L. Meraviglia, "Technology and counterfeiting in the fashion industry: Friends or foes?" *Bus. Horizons*, vol. 61, no. 3, pp. 467–475, 2018. https://doi.org/10.1016/j.bushor.2018.01.013

[7] G. Liu, J. Zhang, and W. Tang, "Strategic transfer pricing in a marketing-operations interface with quality level and advertising dependent goodwill," *Omega*, vol. 56, pp. 1–15, 2015. https://doi.org/10.1016/j.omega.2015.01.004

[8] W. Liu, X. Yan, X. Li, and W. Wei, "The impacts of market size and data-driven marketing on the sales mode selection in an Internet platform based supply chain," *Transp. Res. E Logist. Transp. Rev.*, vol. 136, 2020. https://doi.org/10.1016/j.tre.2020.101914

[9] S.-H. Chin, C. Lu, P.-T. Ho, Y.-F. Shiao, and T.-J. Wu, "Commodity anti-counterfeiting decision in e-commerce trade based on machine learning and Internet of Things," *Comput. Stand. Interfaces*, vol. 76, 2021. https://doi.org/10.1016/j.csi.2020.103504

[10] C.-H. Sun, W.-Y. Li, C. Zhou, M. Li, Z.-T. Ji, and X.-T. Yang, "Anti-counterfeit code for aquatic product identification for traceability and supervision in China," *Food Control*, vol. 37, pp. 126–134, 2014. https://doi.org/10.1016/j.foodcont.2013.08.013

[11] Z. Liu and Z. Li, "A blockchain-based framework of cross-border e-commerce supply chain," *Int. J. Inf. Manage.*, vol. 52, p. 102059, 2020. https://doi.org/10.1016/j.ijinfomgt.2019.102059

[12] P. Dutta, T.-M. Choi, S. Somani, and R. Butala, "Blockchain technology in supply chain operations: Applications, challenges and research opportunities," *Transp. Res. E Logist. Transp. Rev.*, vol. 142, p. 102067, 2020. https://doi.org/10.1016/j.tre.2020.102067

[13] N. Z. Aitzhan and D. Svetinovic, "Security and privacy in decentralized energy trading through multi-signatures, blockchain and anonymous messaging streams," *IEEE Trans. Dependable Secure Comput.*, vol. 15, no. 5, pp. 840–852, 2018. https://doi.org/10.1109/tdsc.2016.2616861

[14] Y. Zhang, M. Jin, G. Zheng, and H. Li, "Design and application of product traceability blockchain-based platform," in *2020 3RD International Conference on Smart Blockchain (SmartBlock), Zhengzhou, China*, 2020, pp. 125–131. https://doi.org/10.1109/SmartBlock52591.2020.00030

[15] L. Tian and B. Jiang, "Effects of consumer-to-consumer product sharing on distribution channel," *Prod. Oper. Manag.*, vol. 27, no. 2, pp. 350–367, 2018. https://doi.org/10.2139/ssrn.2839101

[16] Y. Shi, L. Zhou, T. Qu, and Q. Qi, "Strategic introduction of the marketplace channel considering logistics costs and product information," *Procedia CIRP*, vol. 83, pp. 728–732, 2019. https://doi.org/10.1016/j.procir.2019.04.100

[17] A. Dumrongsiri, M. Fan, A. Jain, and K. Moinzadeh, "A supply chain model with direct and retail channels," *Eur. J. Oper. Res.*, vol. 187, no. 3, pp. 691–718, 2008. https://doi.org/10.1016/j.ejor.2006.05.044

[18] A. Hagiu and J. Wright, "Marketplace or reseller?" *Manag. Sci.*, vol. 61, no. 1, pp. 184–203, 2016. https://doi.org/10.1287/mnsc.2014.2042

[19] Q. Li, Q. Wang, and P. Song, "The effects of agency selling on reselling on hybrid retail platforms," *Int. J. Electron. Commer.*, vol. 23, no. 4, pp. 524–556, 2019. https://doi.org/10.1080/10864415.2019.1655209

[20] T.-M. Choi, L. Feng, and R. Li, "Information disclosure structure in supply chains with rental service platforms in the blockchain technology era," *Int. J. Prod. Econ.*, vol. 221, p. 107473, 2020. https://doi.org/10.1016/j.ijpe.2019.08.008

[21] Y. Wang, Z. Yu, and L. Shen, "Study on the decision-making and coordination of an e-commerce supply chain with manufacturer fairness concerns," *Int. J. Prod. Res.*, vol. 57, no. 9, pp. 2788–2808, 2019. https://doi.org/10.1080/00207543.2018.1500043

[22] M. Yang, T. Zhang, and C.-X. Wang, "The optimal e-commerce sales mode selection and information sharing strategy under demand uncertainty," *Comput. Ind. Eng.*, vol. 162, p. 107718, 2021. https://doi.org/10.1016/j.cie.2021.107718

[23] Z. Zhang, H. Xu, K. Chen, Y. Zhao, and Z. Liu, "Channel mode selection for an e-platform supply chain in the presence of a secondary marketplace," *Eur. J. Oper. Res.*, vol. 305, no. 3, pp. 1215–1235, 2023. https://doi.org/10.1016/j.ejor.2023.305.3.1215

[24] S. Bai, W. Yu, and M. Jiang, "Promoting the tripartite cooperative mechanism of e-commerce poverty alleviation: Based on the evolutionary game method," *Sustainability*, vol. 15, no. 1, p. 315, 2022. https://doi.org/10.3390/su15010315

[25] J. Lee and H. J. Lee, "Your expectation matters when you read online consumer reviews: The review extremity and the escalated confirmation effect," *Asia Pac. J. Inf. Syst.*, vol. 26, no. 3, pp. 449–476, 2020. https://doi.org/10.14329/apjis.2016.26.3.449

[26] C. G. Schmidt and S. M. Wagner, "Blockchain and supply chain relations: A transaction cost theory perspective," *J. Purch. Supply Manag.*, vol. 25, no. 4, p. 100552, 2019. https://doi.org/10.1016/j.pursup.2019.100552

[27] G. M. Hastig and M. S. Sodhi, "Blockchain for supply chain traceability: Business requirements and critical success factors," *Prod. Oper. Manag.*, vol. 29, no. 4, pp. 935–954, 2020. https://doi.org/10.2139/ssrn.3493418

[28] L. Dong, P. Jiang, and F. Xu, "Impact of traceability technology adoption in food supply chain networks," *Manag. Sci.*, vol. 69, no. 3, pp. 1518–1535, 2023. https://doi.org/10.1287/mnsc.2022.4440

[29] H. Ying, X. Peng, X. Zhao, and Z. Chen, "The effects of signaling blockchain-based track and trace on consumer purchases: Insights from a quasi-natural experiment," *Prod. Oper. Manag.*, 2023. https://doi.org/10.2139/ssrn.4349966

[30] X. Rueda, R. D. Garrett, and E. F. Lambin, "Corporate investments in supply chain sustainability: Selecting instruments in the agri-food industry," *J. Clean. Prod.*, vol. 142, pp. 2480–2492, 2017. https://doi.org/10.1016/j.jclepro.2016.11.026

[31] J. Y. Yeh, S. C. Liao, Y. T. Wang, and Y. J. Chen, "Understanding consumer purchase intention in a blockchain technology for food traceability and transparency context," in *2019 IEEE Social Implications of Technology (SIT) and Information Management (SITIM), Matsuyama, Japan*, 2019, pp. 1–6. https://doi.org/10.1109/sitim.2019.8910212

[32] A. R. Harish, X. Liu, M. Li, R. Y. Zhong, and G. Q. Huang, "Blockchain-enabled digital assets tokenization for cyber-physical traceability in E-commerce logistics financing," *Comput. Ind.*, vol. 150, p. 103956, 2023. https://doi.org/10.1016/j.compind.2023.103956

[33] D. Biswas, H. Jalali, A. H. Ansaripoor, and P. De Giovanni, "Traceability vs. sustainability in supply chains: The implications of blockchain," *Eur. J. Oper. Res.*, vol. 305, no. 1, pp. 128–147, 2023. https://doi.org/10.1016/j.ejor.2022.05.034

[34] J. Wu and J. Yu, "Blockchain's impact on platform supply chains: Transaction cost and information transparency perspectives," *Int. J. Prod. Res.*, vol. 61, no. 11, pp. 3703–3716, 2022. https://doi.org/10.1080/00207543.2022.2027037

[35] Z. Zhang, J. X. Li, and D. L. Zhang, "Research on supply chain information collaborative game based on alliance blockchain," *Comput. Appl. Res.*, vol. 38, no. 05, pp. 1314–1319, 2021. https://doi.org/10.19734/j.issn.1001-3695.2020.07.0090

[36] X. Liang and J. F. Xiao, "Research on pricing decision of dual channel supply chain based on blockchain technology application: Analysis of consumer sensitivity to product authenticity," *Price Theory Pract.*, no. 06, pp. 145–148+167, 2021. https://doi.org/10.19851/j.cnki.cn11-1010/f.2021.06.114

[37] L. Yan and L. Qin, "The openness of self-built logistics of the joint type B2C platform from the perspective of synergetic," *Logist. Sci-Tech*, vol. 40, no. 9, pp. 15–17, 2017.

[38] Y. Lou, L. Feng, S. He, Z. He, and X. Zhao, "Logistics service outsourcing choices in a retailer-led supply chain," *Transp. Res. Part E Logist. Transp. Rev.*, vol. 141, p. 101944, 2020. https://doi.org/10.1016/j.tre.2020.101944

[39] H. Liu, T. Xu, S. Jing, Z. Liu, and S. Wang, "The interplay between logistics strategy and platform's channel structure design in B2C platform market," *Eur. J. Oper. Res.*, vol. 310, no. 2, pp. 812–833, 2023. https://doi.org/10.1016/j.ejor.2023.02.043

[40] X. Qin, Z. Liu, and L. Tian, "The strategic analysis of logistics service sharing in an e-commerce platform,"

Omega, vol. 92, p. 102153, 2020. https://doi.org/10.1016/j.omega.2019.102153

[41] B. Niu, F. Xie, L. Chen, and X. Xu, "Join logistics sharing alliance or not? Incentive analysis of competing E-commerce firms with promised-delivery-time," *Int. J. Prod. Econ.*, vol. 224, no. 4, p. 107553, 2020. https://doi.org/10.1016/j.ijpe.2019.107553

[42] Z. Du, Z.-P. Fan, and G.-X. Gao, "Choice of O2O food delivery mode: Self-built platform or third-party platform? Self-delivery or third-party delivery?" *IEEE Trans. Eng. Manag.*, 2021. https://doi.org/10.1109/tem.2021.3069457

[43] Y. Zhang, M. Huang, L. Tian, D. Jin, and G. G. Cai, "Build or join a sharing platform? The choice of manufacturer's sharing mode," *Int. J. Prod. Econ.*, vol. 231, p. 107811, 2021. https://doi.org/10.1016/j.ijpe.2020.107811

[44] R. R. Sinkovics, O. Kuivalainen, and A. S. Roath, "Value co-creation in an outsourcing arrangement between manufacturers and third party logistics providers: Resource commitment, innovation and collaboration," *J. Bus. Ind. Mark.*, 2018. https://doi.org/10.1108/jbim-03-2017-0082