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STRATEGIC LOGISTICS SERVICE CHOICES FOR ONLINE PLATFORMS: SELF-OPERATED, THIRD-PARTY OR AGENCY LOGISTICS?

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Abstract. Self-operated and third-party products in platform retailing can be delivered by self-operated or third-party physical distribution. However, how choosing the best logistics service mode represents a difficult problem for online platforms and sellers in practice. This paper analyzes the strategic logistics service mode choices for retail sales on an online platform. Equilibrium strategies are derived by solving game models considering three logistics service modes: self-operated, third-party and agency. The results show that the platform has an incentive to provide self-operated physical distribution to the seller when the distribution commission exceeds a threshold. More specifically, it achieves a win–win situation with the seller in the self-operated logistics service mode when the distribution commission falls within a moderate range. The platform is unwilling to provide any logistics services with a sufficient low distribution commission. Except in the case of high distribution commission and low self-operated distribution quality, the seller would prefer to accept the platform's self-operated physical distribution. In addition, the third-party physical distribution company generally prefers the agency logistics service mode unless the self-operated distribution quality and commission are high.

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1. Introduction

With the rapid rise of platform economy and the continuous expansion of Internet users, retail sales on online platforms have experienced remarkable growth in the past decade. From 2011 to 2019, the total e-commerce transaction volume in China increased from RMB 6.09 trillion to RMB 34.81 trillion, and online retail sales increased from RMB 0.78 trillion to RMB 10.63 trillion, with an average annual growth rate of 38.6%. Based on a recent report from the US Department of Commerce, online sales came up to $602 billion in 2019, accounting for 11.4% of total sales, a 16.4% increase relative to 2018. This growth in online retail sales has changed the diversified retail and service modes and may create fierce e-commerce market competition problems. For online platforms, logistics services have been regarded as critical to gain competitive strength [18, 23]. In practice, some online platforms, such as Newegg, Amazon and JD, develop their self-operated physical distribution to

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Table 1. Summary of real-world examples.

Logistics service modes	Real-world examples
Purely self-operated logistics	Newegg, Best Buy, LightInTheBox
Self-operated and third-party logistics	Amazon, JD.com, Gome, Cdiscount
Self-operated and agency logistics	Dangdang

deliver products. By contrast, other online platforms, such as Wish, Taobao and eBay, outsource their services to third-party physical distribution [22].

Recent years have witnessed the emergence of a number of logistics service modes that have been adopted by online platforms and sellers in partnerships [23,33]. If an online platform has a self-operated physical distribution, then the platform always provides self-operated physical distribution to self-operated products. For third-party products, the platform may or may not provide self-operated physical distribution, or agency service by adopting a third-party physical distribution. Besides, some online platforms can outsource part of their distribution services to third-party physical distribution companies. That is, the third-party products are entrusted by the platform as an agent to purchase the third-party physical distribution. This service is referred as the agency logistics service. We summarize the above specific examples in Table 1 to illustrate the logistics service modes in real-world online platform retailing. These logistics service modes directly affect the profits of online platforms, sellers and third-party physical distribution companies. For example, JD, which has a powerful self-operated physical distribution, can promise next-day delivery in major cities and has gained a considerable advantage over competing e-tailers in China. Amazon delivers orders through different routes and modes, partially benefiting from the increasing efficiency of the e-commerce order fulfilment served by third-party physical distribution companies (*e.g.*, S.F. Express, STO Express and DHL).

However, many logistics service modes in platform retailing suffer from a highly immethodical physical distribution industry and low profit margins, despite the increasing demand for distribution services from e-commerce platforms [40]. According to a CNN report (CNN, 2013), more than 60% of consumer complaints Yihaodian.com due to its delivery service. Then the online retail firm of China is acquired by JD in 2016. The profits, service quality and word-of-mouth of platforms and sellers can be affected by the choice of logistics service modes. In 2020, JD.com's annual net revenue reached 745.8 billion yuan, of which the logistics service mode revenue exceeded 40.4 billion yuan, which was up 72% year-on-year. From 2017 to 2020, the proportion of JD.com's net service revenue from logistics service modes continued to rise, from 16.8% to 27.0%, 35.5% and 43.1%. Therefore, choosing a reasonable logistics service mode to achieve a win–win situation between platforms and sellers is of great importance to maintain and enhance a competitive advantage. Accordingly, our research aims to investigate the following questions.

- Which logistics service mode is preferred by the platform and the seller?
- Under what conditions can the platform offer the seller a self-operated or third-party logistics agency service? Under what conditions can the seller choose the platform's logistics service?
- How does the platform and seller adopt appropriate pricing strategies under different logistics service modes? Which factors influence the optimal decisions of online supply chain members?

To address the above questions, we develop game theoretic models to analyze a supply chain that consists of a platform, a seller and a third-party physical distribution company. We consider that the platform has a self-operated physical distribution to deliver self-operated products, and chooses from three logistics service modes to deliver third-party products. The first is the self-operated logistics service mode (mode LL), where the self-operated physical distribution is adopted by both the platform and seller. The second is the third-party logistics service mode (mode LT), where the platform adopts the self-operated physical distribution and the seller directly purchases a third-party physical distribution. The third is the agency logistics service mode (mode

LA), where the platform adopts the self-operated physical distribution and the seller entrusts the platform as an agent to purchase third-party physical distribution.

The main contributions of our research are as follows. First, we explore the impacts of different logistics service modes on online supply chain members' profits. A "win–win" situation exists that is a Pareto-optimal situation for the platform and the seller. Explicitly, the situation happens in mode LL with a moderate distribution commission under a not high self-operated distribution quality.

Next, we compare the profits of online supply chain members under different modes, and the results indicate that the platform is willing to provide self-operated physical distribution to the seller when the self-operated distribution quality is relatively low and the distribution commission is not sufficiently low. Expect in case of a high distribution commission and a low self-operated distribution quality, the seller would like to accept the platform's self-operated physical distribution.

Lastly, by analyzing the influences of significant parameters on price and profit in different modes, we find that in mode LL, the platform and the seller have great incentives to increase their retail prices when the distribution commission is high, the self-operated distribution quality is high, and the self-operated distribution cost is large. The platform should raise distribution commission and self-operated distribution quality to obtain a profit. In mode LT, as the self-operated distribution cost and third-party distribution cost increase, the platform's and seller's retail prices and the third-party physical distribution company's unit service price increase. The platform and the third-party physical distribution company have great incentives to reduce the self-operated distribution cost and the third-party distribution cost as much as possible. In mode LA, an increase in the distribution commission decreases unit price of third-party physical distribution company and increases retail prices of the platform and seller. The platform has a strong motivation to drive the distribution commission up, and the third-party physical distribution company is more willing to raise its distribution quality.

The remainder of this article is organized as follows. In Section 2, we provide a literature review, and we also give the summary and highlights of our study in this section. In Section 3, we present the modeling framework of this study. This is followed by equilibrium analysis in Section 4. In Section 5, we study service modes and make comparative discussions. Additionally, the main managerial implications are provided in Section 6. The conclusions are summarized in Section 7. All the proofs are presented in the appendix.

2. Literature review

Our research is related to three streams of literature: (i) logistics service supply chain, (ii) strategic business mode choices, and (iii) online platform-based retailing.

2.1. Research on logistics service supply chain

The analysis of strategic logistics service choices in supply chains is an important research topic and has drawn considerable research attention. Most works focus on the impact on distribution quality [17]. For example, Yan *et al.* [36] study the channel structure and pricing of a two-echelon supply chain, considering the impact of distribution quality on consumer channel choices, and analyzing the performance of each member of the supply chain through the consumer utility function and four game models. Therefore, retailer and manufacturer know how to weigh distribution costs and profits. Chen *et al.* [6] examine how the government can influence the price, demand and profit of railway logistics suppliers and shippers through subsidies. The research shows that the logistics suppliers can obtain the highest government subsidies under an optimal transportation time. When the customer's demand is uncertain, the degree of fluctuation of customer demand and the risk attributes of logistics providers will affect the size of government subsidies. Considering a logistics service supply chain, Liu *et al.* [15] use four game models to evaluate the performance of supply chain members, and analyze the influencing factors of cost sharing and the interaction of customization. The order fulfillment problem is constructed by Li and Jia [10] as a mixed integer programming model, a Benders decomposition algorithm is developed to solve this model, and the performance of the decomposition algorithm is evaluated through the actual electronic platform case. In the logistics service process of cross-border e-commerce, transfer service is an aspect that is different from traditional physical distribution [27]. Xu *et al.* [34] study the procurement strategies of e-retailers under different physical distribution systems. Ren *et al.* [24] establish an inventory optimization model that determines orders through dynamic transportation and logistics capacity allocation demand. In addition, Yu *et al.* [39] establish the three Stackelberg game models to investigate the optimal choice of e-tailers' delivery strategies. By adopting the game models, Niu *et al.* [20] study the impacts of Physical Internet on the logistics service supply chains. Similar to Qin *et al.* [22] and Yu *et al.* [39], our research analyzes a supply chain with platform and seller, where the platform not only acts as an online retailer, but also provides logistics service for the seller. Nonetheless, compared with the study of Qin *et al.* [22], who consider the logistics service sharing between platform and seller, our work aims to reveal the trade-offs among a platform, a seller and a third-party physical distribution company. Our research analyzes the impact of self-operated distribution quality, self-operated distribution cost, third-party distribution quality, third-party distribution cost and distribution commission on the prices and profits of supply chain members.

2.2. Research on strategic business mode choices

Our research is also related to the literature on strategic business mode choices. Tian *et al.* [30] develop e-commerce game models in which the platform can choose the optimal strategy among a reseller, a marketplace and hybrid sales. Order fulfillment costs and competition intensity are important factors in the choice of mode. By establishing a game theory model, Abhishek *et al.* [1] solve the mode choice problem regarding under which conditions e-retailers should adopt the mode of agency sales or wholesale sales. The study found that when electronic channels have a negative impact on the demand for traditional channels, e-retailers will choose agency sales, otherwise, they will choose wholesale sales. Shen *et al.* [28] establish a channel selection model for manufacturers. The model takes into account the existence of an online platform that charges fixed commissions and unit sales commissions, and at the same time the manufacturer decides the channel through which the products are sold. Mantin *et al.* [19] introduce channels for third-party sellers on the platform, and discuss the game relationship and equilibrium model between the platform and third-party sellers, so as to enhance the bargaining power of the platform and sellers. Li *et al.* [11] investigate the problem of service channel selection. The research establishes four service channels and studies the impact of service costs on channel selection. Pal and Sarkar [21] study a dual-channel green supply chain problem and propose optimal strategies with recycling under retailer promotional effort. Through the study of Yang *et al.* [37], one manufacturer is selling products through two retailers, under what conditions the manufacturer provides the same service, and how the retailer chooses the level of service to compete with competitors. In addition, Liu *et al.* [16] explore the operating strategies that manufacturers and retailers can choose to open online or offline omni-channel supply chains. Li *et al.* [13] develop an analysis model to discuss whether the manufacturer OEM chooses P2P platform or B2C platform. By considering the different power structures of the supply chain, Shi *et al.* [29] study the dual-channel supply chain which composed of manufacturers, online retailers and physical stores, the study shows that the profit sharing rate is an important factor in decision-making. Li and Ai [9] discuss the question of how competing suppliers and retailers choose sales models in a supply chain composed of two suppliers and two e-retailers. Zolfani *et al.* [44] present a hybrid multi-criteria decision-making methodology to study the resource recovery business mode. By adopting a game theoretic model, Yu *et al.* [38] consider four different business modes to investigate the strategic interactions between an e-commerce platform and two brand manufacturers. Their research findings provide the managerial implications for the e-commerce platform and brand manufacturers. Unlike the aforementioned studies, our work focuses on exploring the logistics service mode choices of an online platform and a seller. To be precise, a hybrid structure is focused where the platform and the seller can choose alternative logistics service modes.

2.3. Research on online platform-based retailing

The last stream of literature is related to online platform-based retailing. In the literature, a number of studies emphasize the strategic pricing of online platforms (*e.g.*, [25, 31, 32]). Lin *et al.* [14] investigate the platforms' pricing and product bundling strategy. In competition, the decision to bind or not have a great impact on platforms' profits. In addition, Li *et al.* [12] study the pricing strategy of the platform under a pure duopoly, and examine how information transmission affects pricing decisions in the word-of-mouth market. Chen *et al.* [4] study a company and e-retailer formulate promotional pricing strategies on the platform, and explore how a company and e-retailer conduct strategic promotions under the reseller and agency sales model. Based on the research background of online platform retailing, Zhou *et al.* [42, 43] separately examine the impact of recommender systems on brand competition and the impact of fairness concerns on the competition between e-platforms and third-party sellers. In addition, other works regarding online platforms discuss determinant factors such as third-party information [8], spillover effects [35], review information [41] and promotional prices [5]. Our work is based on online platform settings, and price competition is considered in the supply chain. Contrary to the above research, we focus on the impact of price competition on the choice of logistics service mode, and compare the profits of supply chain members under different modes to identify a Pareto-optimal situation.

2.4. Summary and highlights

From the above literature review, we can see that the existing studies examining logistics service supply chain issues mainly focus on the impacts of distribution quality and most studies only investigate the platform and the physical distribution company's logistics service strategies in the e-commerce supply chain. Moreover, the review of the related literature suggests that the impact of logistics service mode choice on the online platform-based retailing is becoming an important topic for recent operations management research. However, there are very few studies that bring the platform's logistics service choices into logistics service supply chain. Moreover, there are very few studies that discuss different logistics service modes to investigate the equilibrium strategies among a platform, a seller, and a third-party physical distribution company. To fill the gap, we consider a logistics service mode choices problem in online supply chain. The main difference between this paper and the previous literature is listed in Table 2.

The contributions of our study are listed as follows. (1) Our work contributes to filling the research gap of logistics service mode choices problem in online supply chain, and providing management insights for platforms, sellers and third-party physical distribution companies. (2) We develop three service modes to consider the logistics service mode choices problem, namely, the self-operated logistics service mode, the third-party logistics service mode and the agency logistics service mode. By comparing the optimal solutions of these modes, we investigate how choosing the best logistics service mode for online platforms and sellers. (3) We further examine how different logistics service modes will influence the optimal decisions of online supply chain members. The findings of our study have significant implications for online platforms, sellers and third-party physical distribution companies.

3. Modelling framework

Consider an online supply chain that consists of a platform (he), a seller (she), and a third-party physical distribution company (denoted as "3PC"). The platform sells a self-operated product at a unit price p_e, and the seller sells a third-party product on the platform at a unit price p_r by paying a certain revenue-sharing fee ρ. There are two types of online logistics services available, *i.e.*, the self-operated physical distribution of platform, the third-party physical distribution of 3PC. Specifically, the distribution qualities of the platform and 3PC are denoted by s_e and s_t, respectively. This paper analyses the logistics service mode choices among the platform, the seller and the 3PC. Meanwhile, we examine the effects of the distribution cost, distribution quality and distribution commission on these members' optimal decisions and logistics service mode choices. Table 3 lists the parameters and variables used in this paper.

Given that both the self-operated and third-party products are substitutable, we formulate the demand functions D_e and D_r as follows.

$$D_e = a - p_e + \alpha p_r + \beta s_i - \gamma s_j, \tag{1}$$

TABLE 2. A summary of main literature.

Paper	Logistics service supply chain	Strategic business mode choices	Online platform-based retailing
Liu *et al.* [15]	✓		
Xu *et al.* [34]	✓		
Qin *et al.* [22]	✓		✓
Liu *et al.* [17]	✓		
Yu *et al.* [39]	✓		✓
Niu *et al.* [20]	✓		
Tian *et al.* [30]		✓	✓
Shen *et al.* [28]		✓	✓
Yang *et al.* [37]		✓	
Pal and Sarkar [21]		✓	
Yu *et al.* [38]	✓	✓	
Zolfani *et al.* [44]		✓	
Kwark *et al.* [8]			✓
Yan *et al.* [35]			✓
Li *et al.* [12]			✓
Chen *et al.* [4]		✓	✓
Chen *et al.* [5]		✓	✓
Zhou *et al.* [42]			✓
Zhou *et al.* [43]			✓
Our work	✓	✓	✓

TABLE 3. Parameters and variables.

Notation	Descriptions
p_e, p_r	Unit prices of the self-operated and third-party products
s_e, s_t	Distribution qualities of the platform and the 3PC
c_e, c_t	Distribution costs of the platform and the 3PC
D_e, D_r	Demands of the self-operated and third-party products
π_e, π_r, π_t	Profits of platform, seller and 3PC
ρ	Revenue-sharing ratio charged by the platform
f	Unit distribution commission offered by the platform
w	Unit logistics service price offered by 3PC
a	Market potential
α	Sensitivity of the cross-price
β	Sensitivity of the platform/seller's demand to his/her own distribution quality
γ	Sensitivity of the platform/seller's demand to his/her rival's distribution quality

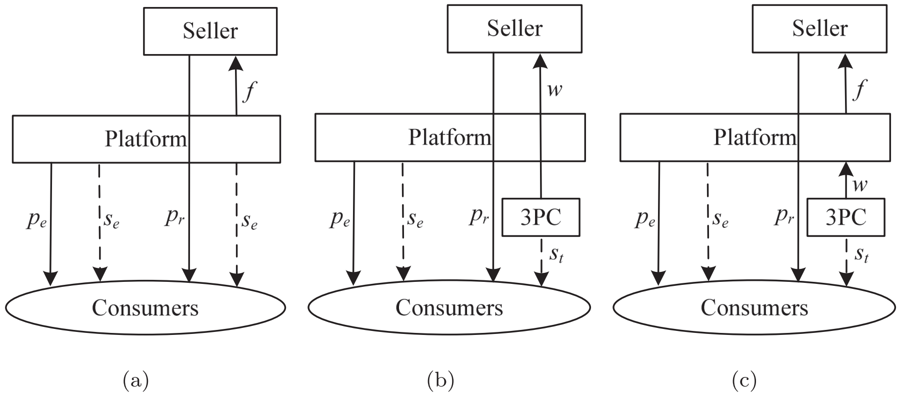


FIGURE 1. Mode structures for the online supply chain. (a) Mode LL. (b) Mode LT. (c) Mode LA.

$$D_r = a - p_r + \alpha p_e + \beta s_j - \gamma s_i, \tag{2}$$

where $i, j \in \{e, t\}$, a is the market potential, and p_e and p_r are the retail prices of self-operated and third-party products, respectively. The sensitivity of the cross-price is denoted by α, which reflects the price competition between the two products. Given that $0 < \alpha < 1$, it can be shown that the self-operated product price has a greater impact on the platform's demand than the third-party product price. In addition, the third-party product price has a greater impact on the seller's demand than the self-operated product price. Furthermore, we assume that $\sigma = \frac{\gamma}{\beta} < 1$ measures the cross-channel logistics service sensitivity. These demand functions have been widely utilized in the marketing and operations management literature [2, 3, 22, 26].

The platform has a self-operated physical distribution to deliver its self-operated products. For third-party products, the platform and seller can choose three alternative logistics service modes as follows.

– Mode LL: the platform and seller adopt the self-operated logistics service mode, where the seller adopts the self-operated physical distribution by paying the platform with a distribution commission f. The platform and the seller determine retail prices p_e and p_r simultaneously.
– Mode LT: the platform and seller adopt the third-party logistics service mode, where the seller directly purchases third-party physical distribution from the 3PC at a unit price w. The 3PC first set the seller a service price w; then, the platform and the seller determine retail prices p_e and p_r simultaneously.
– Mode LA: the platform and seller adopt the agency logistics service mode, where the seller chooses a third-party physical distribution from the platform with a distribution commission f, and the platform purchases a logistics service from the 3PC at a unit price w. The 3PC first sets the platform a unit price w; subsequently, the platform and the seller determine retail prices p_e and p_r simultaneously.

Note that when the seller sells a third-party product on the platform, both the platform and the seller share the sales revenue according to an allocation ratio $\rho \in (0, 1)$. Specifically, when the product is sold by the seller at price p_r, the platform retains revenue ρp_r and allocates the remaining amount $(1 - \rho)p_r$ to the seller. The platform charges the seller a distribution commission f when he shares the self-operated physical distribution or provides the logistics agency service to the seller. To be consistent with practice, we assume that the revenue-sharing ratio ρ and distribution commission f are determined by the platform and are exogenous parameters. According to the practice of the logistics industry, the platform plays the leading role of Stackelberg in whether he will choose the seller's logistics service mode. The seller, as a follower, accepts or rejects the offer from the platform. When determining the equilibrium result, for each available mode, under which conditions the seller will accept the platform's service mode choices are clearly included. Assuming that each mode exists, the interaction between online supply chain members is shown in the Figure 1.

4. Equilibrium analysis

The equilibrium outcomes are characterized under three service modes, *i.e.*, mode LL, mode LT, and mode LA. Then, we provide a sensitivity analysis and comparative results for these modes and draw managerial insights.

4.1. Mode LL

In mode LL, the platform provides a self-operated physical distribution for both the seller and himself. The demand functions of the platform and the seller are $D_e = a - p_e + \alpha p_r + \beta s_e - \gamma s_e$ and $D_r = a - p_r + \alpha p_e + \beta s_e - \gamma s_e$, respectively. The profit functions of the platform and seller are calculated as $\pi_e = (p_e - c_e)D_e + (\rho p_r + f - c_e)D_r$ and $\pi_r = (p_r - \rho p_r - f)D_r$, respectively. Given the platform's distribution commission f, distribution quality s_e, the platform and seller determine their retail prices p_e, p_r simultaneously by maximizing their individual profit functions. Therefore, we solve the problem backwardly and obtain the results of the following proposition.

Proposition 1. *In mode LL, the platform and the seller's optimal retail prices are given as follows:*

$$\begin{aligned} p_e^{LL} = {} & \frac{1}{(1-\rho)(4-\alpha^2(1+\rho))}[(2+\alpha-\alpha\rho^2-2\rho)a + (\beta-\gamma)(2+\alpha-\alpha\rho^2-2\rho)s_e \\ & + 2(1-\rho)(1-\alpha)c_e + \alpha(3-\rho)f], \end{aligned} \tag{3}$$

$$\begin{aligned} p_r^{LL} = {} & \frac{1}{(1-\rho)(4-\alpha^2(1+\rho))}[(2+\alpha)(1-\rho)a + (\beta-\gamma)(2+\alpha)(1-\rho)s_e \\ & + (1-\rho)(1-\alpha)\alpha c_e + (2+\alpha^2-\alpha^2\rho)f]. \end{aligned} \tag{4}$$

4.2. Mode LT

In mode LT, the platform adopts his self-operated physical distribution, and the seller directly purchases the third-party physical distribution. The platform's and seller's demand functions are $D_e = a - p_e + \alpha p_r + \beta s_e - \gamma s_t$ and $D_r = a - p_r + \alpha p_e + \beta s_t - \gamma s_e$, respectively. The profit functions of the platform, seller, and 3PC are given as $\pi_e = (p_e - c_e)D_e + \rho p_r D_r$, $\pi_r = (p_r - \rho p_r - w)D_r$, and $\pi_t = (w - c_t)D_r$, respectively. We exogenously give the platform and the 3PC's distribution qualities s_e and s_t. The sequence of events for mode LT operation is as follows. The 3PC first decides service price w by maximizing its π_t. Then, the platform and seller determine retail prices p_e, p_r by simultaneously maximizing their respective profit functions.

Proposition 2. *In mode LT, the platform's and the seller's optimal retail prices and the 3PC's service price are given as follows:*

$$\begin{aligned} p_e^{LT} = {} & \frac{1}{2(1-\rho)(2-\alpha^2(1+\rho))(4-\alpha^2(1+\rho))}[(1-\rho)(8+6\alpha(1+\rho)-2(1+\rho)^2\alpha^3-3\alpha^2(1+\rho))a \\ & + (1-\rho)(8\beta+2\gamma\alpha^3(1+\rho)^2-(3\beta\alpha^2+6\gamma\alpha)(1+\rho))s_e + (1-\rho)((3\gamma\alpha^2+6\beta\alpha)(1+\rho) \\ & - 2(1+\rho)^2\alpha^3\beta-8\gamma)s_t + (1-\rho)(8-3\alpha^2(1+\rho))c_e + (1+\rho)(2\alpha-\alpha^3(1+\rho))c_t], \end{aligned} \tag{5}$$

$$\begin{aligned} p_r^{LT} = {} & \frac{1}{2(1-\rho)(2-\alpha^2(1+\rho))(4-\alpha^2(1+\rho))}[(1-\rho)(\alpha+2)(3-(1+\rho)\alpha^2)a \\ & + (1-\rho)(\alpha\beta-2\gamma)(3-(1+\rho)\alpha^2)s_e + (1-\rho)(2\beta-\alpha\gamma)(3-\alpha^2(1+\rho))s_t \\ & + (2-\alpha^2(1+\rho))c_t + \alpha(1-\rho)(3-\alpha^2(1+\rho))c_e], \end{aligned} \tag{6}$$

$$\begin{aligned} w^{LT} = {} & \frac{1}{2(2-\alpha^2(1+\rho))}[(1-\rho)(\alpha+2)a + (1-\rho)(\alpha\beta-2\gamma)s_e \\ & + (1-\rho)(2\beta-\alpha\gamma)s_t + (2-\alpha^2(1+\rho))c_t + \alpha(1-\rho)c_e]. \end{aligned} \tag{7}$$

4.3. Mode LA

In this mode, the platform adopts his self-operated physical distribution, the seller entrusts the platform as an agency to purchase third-party physical distribution. Therefore, the platform's and seller's demand functions are $D_e = a - p_e + \alpha p_r + \beta s_e - \gamma s_t$ and $D_r = a - p_r + \alpha p_e + \beta s_t - \gamma s_e$, respectively. The profit functions of the platform, seller, and 3PC are $\pi_e = (p_e - c_e)D_e + (\rho p_r + f - w)D_r$, $\pi_r = (p_r - \rho p_r - f)D_r$, and $\pi_t = (w - c_t)D_r$, respectively. We exogenously give the platform's and the 3PC's distribution qualities s_e and s_t and the platform's distribution commission f. The sequence of events for mode LA is shown below. The 3PC first sets service price w by maximizing its π_t. Then, the platform and seller determine retail prices p_e, p_r by simultaneously maximizing their individual profit functions.

Proposition 3. *In mode LA, the platform's and the seller's optimal retail prices and the 3PC's service price are given as follows:*

$$\begin{aligned} p_e^{LA} = {} & \frac{1}{(1-\rho)\alpha(4-\alpha^2(1+\rho))}[(1-\rho)(\alpha+(1-\rho)\alpha^2-2)a \\ & + (2+\alpha^2-\alpha^2\rho)f + (1-\rho)\alpha c_e - \alpha^2(1-\rho)c_t + (1-\rho)(\alpha\beta+2\gamma-\gamma(1+\rho)\alpha^2)s_e \\ & + (1-\rho)(\beta(1+\rho)\alpha^2 - \alpha\gamma - 2\beta)s_t], \end{aligned} \tag{8}$$

$$\begin{aligned} p_r^{LA} = {} & \frac{1}{2(1-\rho)(4-\alpha^2(1+\rho))}[(1-\rho)(\alpha+2)a + (6-2\alpha^2\rho)f + (1-\rho)\alpha c_e \\ & - \alpha^2(1-\rho)c_t + (\alpha\beta-2\gamma)(1-\rho)s_e + (2\beta-\alpha\gamma)(1-\rho)s_t], \end{aligned} \tag{9}$$

$$\begin{aligned} w^{LA} = {} & \frac{1}{2\alpha^2(1-\rho)}[(1-\rho)(\alpha+2)a - 2(1-\alpha^2)f + \alpha^2(1-\rho)c_t + (1-\rho)\alpha c_e \\ & + (\alpha\beta-2\gamma)(1-\rho)s_e + (2\beta-\alpha\gamma)(1-\rho)s_t]. \end{aligned} \tag{10}$$

5. Strategic choices among service modes

In this section, we conduct a sensitivity analysis under modes LL, LT and LA. Under the three logistics service modes, we aim to analyze the effects of distribution commission and distribution quality on optimal prices and profits and examine the optimal logistics service mode.

Proposition 4. *p_e^{LL} and p_r^{LL} are increasing in s_e, c_e and f.*

Proposition 4 shows that both the self-operated product price and the third-party product price increase with s_e, c_e and f. This occurs because product demand increases as the self-operated distribution quality increases. Then, the platform and the seller boost their retail prices to maximize the profit. An increase in the self-operated distribution cost decreases the platform's profit; thus, the platform makes up for the loss of profit by increasing his retail price. Because of price competition, the seller also increases her retail price accordingly. The increase in the distribution commission forces the seller to increase her retail price. Therefore, the platform also raises his retail price due to price competition.

Proposition 5. *We obtain the following results:*

(i) *p_e^{LT} is increasing (decreasing) in s_e when $\sigma < \theta$ ($\sigma > \theta$). p_r^{LT} and w^{LT} are increasing (decreasing) in s_e when $\sigma < \alpha/2$ ($\sigma > \alpha/2$).*
(ii) *p_e^{LT} is increasing (decreasing) in s_t when $\sigma < 1/\theta$ ($\sigma > 1/\theta$). p_r^{LT} and w^{LT} are increasing in s_t.*
(iii) *p_e^{LT}, p_r^{LT}, and w^{LT} are increasing in c_e and c_t.*

Note that $\theta = [8 - 3\alpha^2(1+\rho)]/[6\alpha(1+\rho) - 2\alpha^3(1+\rho^2)]$. Proposition 5(i) indicates that if σ is less than a threshold θ, the self-operated product price increases with s_e, but the price decreases with s_e if σ is greater than the threshold θ. When σ is less than $\alpha/2$, the third-party product price and the 3PC's unit price increase with

s_e. In contrast, when σ is greater than $\alpha/2$, the third-party product price and the 3PC's unit price decrease with s_e. The reason is that when the cross-channel logistics service sensitivity is sufficiently low, the market demand is less affected by the cross channel. The platform raises his retail price as the self-operated distribution quality increases, and the seller and 3PC also raise the retail price and unit price, respectively. In contrast, the market demand is greatly affected by the cross channel with a high cross-channel logistics service sensitivity. As the self-operated distribution quality increases, the seller and the 3PC reduce the retail price and unit service price, respectively, and the platform also decreases his retail price.

We learn from Proposition 5(ii) that both the third-party product price and the 3PC's unit price increase with s_t. If σ is less than a threshold $1/\theta$, then the self-operated product price increases with s_t; otherwise, the self-operated product price decreases with s_t. As the 3PC's distribution quality increases, the 3PC raises its unit price, and the seller has to increase her retail price accordingly. When the cross-channel logistics service sensitivity is low, the market demand is less affected by the cross channel, and the platform increases his retail price. Moreover, when the cross-channel logistics service sensitivity is high, the market demand is greatly affected by the cross channel and the platform decreases his retail price to increase demand.

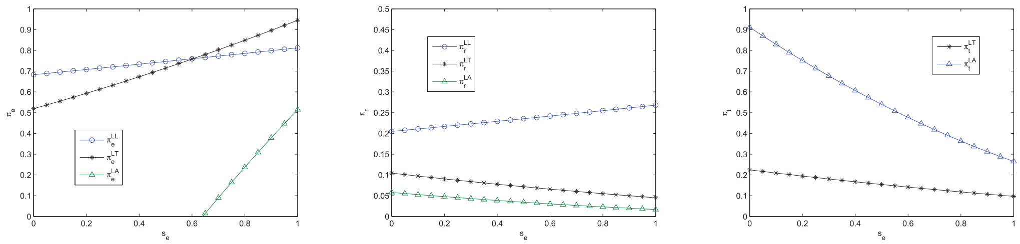
Proposition 5(iii) indicates that as the self-operated distribution cost increases, the platform increases his retail price to maintain his profit. The seller and 3PC also increase the retail price and unit price, respectively, because of price competition. The increase in the 3PC's distribution cost results in a higher retail price for the seller, and the platform increases his retail price accordingly.

Proposition 6. *In mode LA, regarding the impacts of the distribution commission and distribution quality on the optimal retail prices, we obtain the following results:*

(i) p_e^{LA} *is increasing in* s_e. p_r^{LA} *and* w^{LA} *are increasing (decreasing) in* s_e *when* $\sigma < \alpha/2$ $(\sigma > \alpha/2)$.
(ii) p_r^{LA} *and* w^{LA} *are increasing in* s_t, *and* p_e^{LA} *is decreasing in* s_t.
(iii) p_e^{LA}, p_r^{LA} *and* w^{LA} *are increasing in* c_e.
(iv) w^{LA} *is increasing in* c_t, *and* p_e^{LA} *and* p_r^{LA} *are decreasing in* c_t.
(v) p_e^{LA} *and* p_r^{LA} *are increasing in* f, *and* w^{LA} *is decreasing in* f.

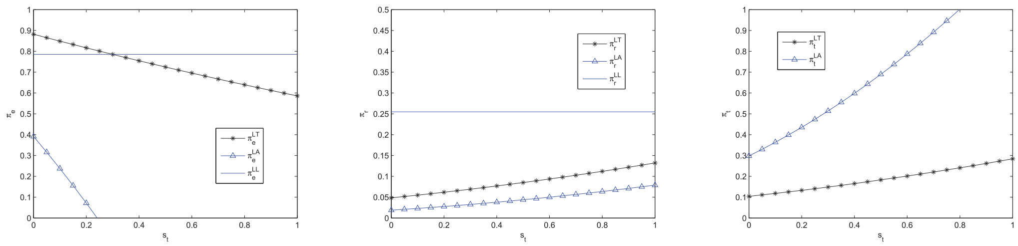
As shown in Proposition 6(i), the platform's retail price increases with s_e. If σ is less than $\alpha/2$, then both the third-party product price and the 3PC's unit price increase with s_e; otherwise, the third-party product price and the 3PC's unit price decrease with s_e. As the self-operated distribution quality increases, the self-operated product price increases. When the cross-channel logistics service sensitivity is sufficiently low, the market demand is less affected by the cross channel, and the seller and 3PC increase the retail price and unit price, respectively, to maximize their profits. Besides, the market demand is greatly affected by the cross channel with a sufficiently high cross-channel logistics service sensitivity; to expand market demand, the seller and 3PC decrease the retail price and unit price, respectively. Proposition 6(ii) indicates that the market demand of third-party product increases with the 3PC's distribution quality. Afterwards, the 3PC's unit price and seller's retail price increase accordingly. In response, the platform decreases his retail price to promote market demand. From Proposition 6(iii), an increase in the self-operated distribution cost reduces the platform's profit, and the platform tends to increase his retail price to offset his profit loss. Because of price competition, both the third-party product retail price and the 3PC's unit price also increase. Proposition 6(iv) shows that the 3PC increases unit price with its distribution cost, which compresses the platform's profit margins in the third-party channel. To maximize profit, the platform increases market demand by decreasing his retail price. In response, the seller decreases her retail price accordingly. Proposition 6(v) indicates that the increase in distribution commission reduces the seller's profit margins. Thus, the seller increases her retail price to maximize her profit. Due to price competition, the platform also increases his retail price. Moreover, the 3PC expects to avoid the decline in the retailer's market demand by reducing the unit price.

Through a numerical analysis, we explore the effects of the self-operated and third-party distribution qualities, distribution costs and distribution commission on profits under the three modes. The basic parameter values on numerical studies are set as follows: $a = 1$, $\alpha = 0.5$, $\beta = 0.7$, $\gamma = 0.6$, and $\rho = 0.05$. Furthermore, all of the numerical results are presented in Figures 2–6.



(a) (b) (c)

FIGURE 2. Effects of s_e on the profits of supply chain members in modes LL, LT, and LA ($s_t = 0.1$, $c_e = 0.1$, $c_t = 0.1$, $f = 0.5$). (a) Platform. (b) Seller. (c) 3PC.

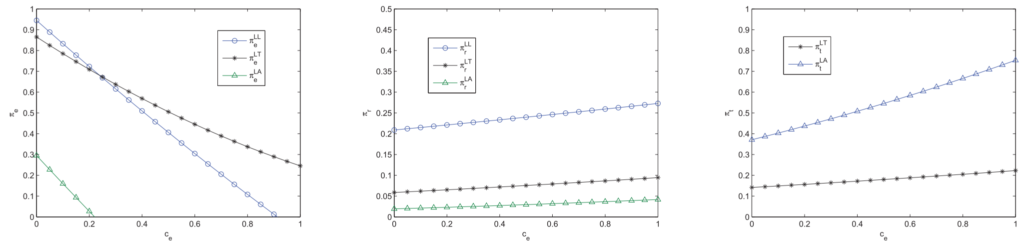


(a) (b) (c)

FIGURE 3. Effects of s_t on the profits of supply chain members in modes LL, LT, and LA ($s_e = 0.8$, $c_e = 0.1$, $c_t = 0.1$, $f = 0.5$). (a) Platform. (b) Seller. (c) 3PC.

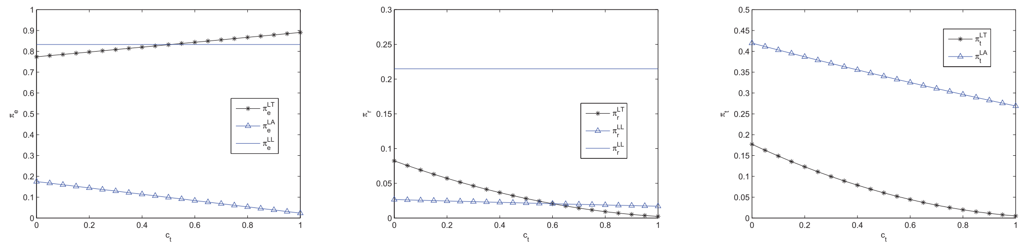
Figure 2 shows that under mode LL, an improvement in the self-operated distribution quality promotes the value of self-operated and third-party products, which increases their retail prices and demands. Therefore, the profits of both platform and seller increase. Under mode LT, because $\sigma < \theta$, the cross-channel distribution quality has a small influence on the platform. As the self-operated distribution quality increases, the value of the self-operated product increases, and the platform raises his retail price. As the cross-channel logistics service has a strong influence on a seller with $\sigma > \alpha/2$, an improvement in the self-operated distribution quality leads to a decrease in the demand for the third-party product, and the seller's and 3PC's profits decrease. To compensate for the loss of profits, the seller and 3PC increase demand by reducing the third-party product price and unit price, respectively. Under mode LA, an improvement in the self-operated distribution quality increases the retail price and the demand of the self-operated product and thus increases the platform's profit. Because $\sigma > \alpha/2$, the cross-channel distribution quality has a strong influence on the seller, which reduces the demand of the third-party product and the profits of the seller and 3PC. Therefore, the seller increases demand by lowering her retail price.

As indicated by Figure 3, in mode LT, because $\sigma > 1/\theta$, the cross-channel distribution quality has a strong influence on the platform. As the 3PC's distribution quality improves, the platform reduces his retail price, and his profit also decreases accordingly. To increase profits, the seller and 3PC increase the retail price and unit price, respectively. At this time, the platform and seller show opposite preferences with respect to the distribution quality of 3PC. Based on the consideration of channel competition, the platform expects the 3PC to have a lower distribution quality, while the seller hopes that the distribution quality is sufficiently high to increase her demand. Under mode LA, an improvement in the 3PC's distribution quality increases the demand of the seller and 3PC, the seller's retail price and the 3PC's unit price rise accordingly, and both members' profits



(a) (b) (c)

FIGURE 4. Effects of c_e on the profits of supply chain members in modes LL, LT, and LA ($s_e = 0.8,\ s_t = 0.3,\ c_t = 0.1,\ f = 0.6$). (a) Platform. (b) Seller. (c) 3PC.

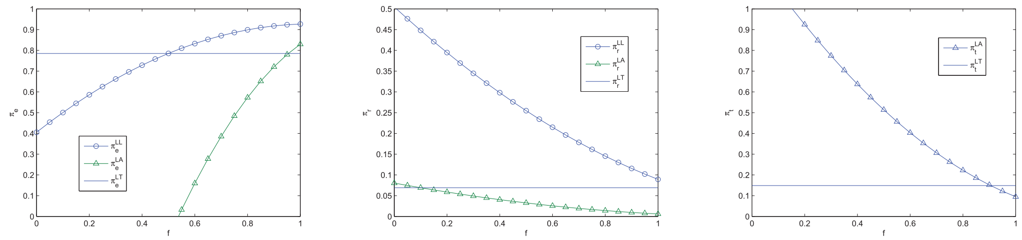


(a) (b) (c)

FIGURE 5. Effects of c_t on the profits of supply chain members in modes LL, LT, and LA ($s_e = 0.8,\ s_t = 0.3,\ c_e = 0.1,\ f = 0.6$). (a) Platform. (b) Seller. (c) 3PC.

increase. As the demand for the platform decreases, the profit decreases. To reduce profit loss, the platform increases demand by reducing his retail price.

As shown in Figure 4, an increase in the self-operated distribution cost compresses the platform's profit margins under mode LL. The platform compensates for the profit loss by increasing his retail price. Due to competition, the seller also increases her retail price accordingly. However, under the condition of a constant distribution commission, the seller may not be impacted by the rising self-operated distribution cost. The price increment of the third-party product is lower than that of the self-operated product. As a result, the seller has a competitive advantage over the platform and realizes an increase in demand and profit. Furthermore, the demand and profit of the platform decrease. Under mode LT, an increase in the self-operated distribution cost reduces the platform's profit margins, which increases the self-operated product's price. Although the seller also increases her price, the retail price increment of third-party product is less than that of self-operated product under the condition that the service price of the 3PC remains unchanged. The competitive advantage may produce an increase in demand of third-party product, while the demand of self-operated product declines. Finally, the profit of the platform decreases, whereas the profits of the seller and 3PC increase. Under mode LA, an increase in the self-operated distribution cost leads to an increase in the platform's retail price. The seller and 3PC correspondingly raise the retail price and unit price. However, the rise in self-operated distribution cost has no impact on the seller; thus, the retail price increment of third-party product is less than that of self-operated product. Therefore, the seller has a competitive advantage over the platform and realizes an increase in demand. Moreover, the demand of the platform decreases. As a result, the platform's profit decreases, while the seller's and 3PC's profits increase.



(a) (b) (c)

FIGURE 6. Effects of f on the profits of supply chain members in modes LL, LT, and LA ($s_e = 0.8$, $s_t = 0.3$, $c_e = 0.1$, $c_t = 0.1$). (a) Platform. (b) Seller. (c) 3PC.

Figure 5 reveals that an increase in the 3PC's distribution cost gives rise to an increase in the 3PC's unit price under mode LT, and the third-party product's price also rises. Due to price competition, the self-operated product price also increases. However, since the platform is not affected by the increase in unit price, the price increment of self-operated product is less than that of third-party product. Therefore, the platform's demand increases, while the seller's demand decreases. Finally, the profit of platform increases, while the profits of seller and 3PC decrease. In mode LA, an increase in the 3PC's distribution cost increases the 3PC's service price, which compresses the profit margins of the platform. To maximize profit, the platform increases demand by reducing his retail price. However, due to price competition, the seller also reduces her retail price, and the platform still cannot compete with the seller when demand increases. It follows that the profits of the platform, seller and 3PC all decrease in this scenario.

Figure 6 shows that under mode LL, an increase in the distribution commission forces the seller to increase the third-party product's price to compensate for the profit loss. Although the platform also increases the self-operated product's price because of price competition, the price increment for the self-operated product is less than that for the third-party product. Because of the competitive advantage, the demand for the self-operated product increases, while the demand for the third-party product decreases. Accordingly, the platform's profit increases, while the seller's profit decreases. Under mode LA, an increase in the distribution commission reduces the seller's profit. The seller makes up for the profit loss by increasing her retail price. Due to price competition, the platform also increases his retail price. However, the price of self-operated product increases less than that of third-party product. Thus, the platform's profit increases because of the increased self-operated product demand, while the seller's profit decreases due to the decline in the third-party product's demand. The 3PC is affected by the decline in the third-party product's demand and decides to reduce the third-party product's price by reducing the unit price to increase the demand. However, the 3PC's unit price decreases without improving the demand; thus, the 3PC's profit decreases.

For convenience, the impacts of different parameters on the price and profit of online supply chain members in modes LL, LT, and LA are summarized in Table 4.

From Figures 2, 3, 4, 5 and 6, we can obtain the following managerial implications. First, the platform's profit under mode LL or LT is always larger than that under mode LA. This result implies that the platform hopes that the seller will use the self-operated physical distribution or purchase a third-party physical distribution directly and is not willing to act as a third-party logistics agency for the seller. Second, the seller's profit under mode LL is always larger than that under modes LT and LA unless the value of f is sufficiently high. This finding implies that when the platform sets a moderate distribution commission, the seller is willing to use the self-operated physical distribution. Third, the 3PC's profit under mode LA is always larger than that under mode LT unless the value of f is sufficiently high. This result means that when the platform sets a moderate distribution commission, the 3PC provides the third-party physical distribution to the platform rather than to the seller.

TABLE 4. Impacts of different parameters on prices and profits in modes LL, LT, and LA.

Mode	Parameters	Price			Profit		
		Platform	Seller	3PC	Platform	Seller	3PC
Mode LL	s_e	↗	↗	–	↗	↗	–
	c_e	↗	↗	–	↘	↗	–
	f	↗	↗	–	↗	↘	–
Mode LT	s_e	↗	↘	↘	↗	↘	↘
	s_t	↗	↗	↗	↘	↗	↗
	c_e	↗	↗	↗	↘	↗	↗
	c_t	↗	↗	↗	↗	↘	↘
Mode LA	s_e	↗	↘	↘	↗	↘	↘
	s_t	↘	↗	↗	↘	↗	↗
	c_e	↗	↗	↗	↘	↗	↗
	c_t	↘	↘	↗	↘	↘	↘
	f	↗	↗	↘	↗	↘	↘

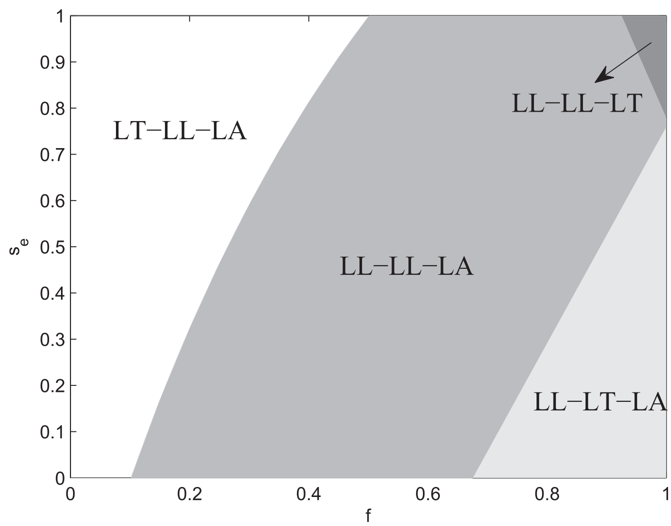


FIGURE 7. Equilibrium service mode with self-operated logistics.

Finally, we examine how the third-party distribution quality and the distribution commission affect the equilibrium mode and investigate the optimal logistics service mode. To provide a more intuitive presentation, the results are further illustrated in Figure 7. Note that "LT-LL-LA", "LL-LL-LA", "LL-LL-LT" and "LL-LT-LA" represent the areas of online supply chain members' preferred logistics service mode combinations. For example, "LL-LL-LA" means that the platform and the seller are better off in mode LL, while the 3PC is well fixed in mode LA. Typically, the platform and the seller would reach a consensus in areas "LL-LL-LA" or "LL-LL-LT".

We learn from Figure 7 that when the distribution commission is low, mode LT is beneficial to the platform regardless of the self-operated distribution quality. As the distribution commission increases, if the self-operated distribution quality is high, then the platform is better off in mode LT. If the self-operated distribution quality is low, then mode LL is beneficial to the platform. As the distribution commission continues to increase, the platform is willing to provide the self-operated physical distribution to the seller, regardless of the self-operated distribution quality. When the distribution commission charged by the platform to the seller is low or the self-operated distribution quality is high, the distribution expenditure of the platform is higher than the distribution commission. As a result, the profit of the platform generated by providing no logistics service is higher than that when providing a logistics service. For the seller, only when the distribution commission is high and the self-operated distribution quality is not excessively high in mode LT is beneficial to the seller; otherwise, the seller is better off in mode LL. This is because under the condition that the distribution commission is low or moderate, the seller's distribution expenditure of using the self-operated physical distribution is smaller than that of directly purchasing the third-party physical distribution, and the profit of the seller in mode LL is larger than that in mode LT. When both the distribution commission and the self-operated distribution quality are high, the operation cost of the seller increases. However, the improvement in the self-operated distribution quality increases the demand for the third-party product. Finally, the seller's profit in mode LL is larger than that in mode LT. When the distribution commission is excessive and the self-operated distribution quality is not high, the lower self-operated distribution quality cannot increase the product demand. Therefore, the seller chooses to purchase the third-party physical distribution directly. Furthermore, the platform should set a reasonable distribution commission and improve the self-operated distribution quality, to achieve a win–win situation for the platform and seller in mode LL. For the 3PC, only when both the self-operated distribution quality and distribution commission are very high is mode LT beneficial to the 3PC; otherwise, mode LA is beneficial to the 3PC. This is because the demand for the third-party product in mode LT is greater than that in mode LA only when the self-operated distribution quality and distribution commission are sufficiently high.

6. Managerial implications

In this section, we consider the discussions and findings of this paper, and provide some crucial managerial insights to explore the practical value of these findings.

There are two key factors which would improve operations managers' logistics service choice decisions. When the managers plan to adopt an appropriate logistics service mode, in addition to the distribution commission factor, they also need to take their own and competitor's distribution qualities into consideration. Specifically, our findings suggest that logistics operations managers of the platform have an incentive to provide self-operated physical distribution to the seller when the distribution commission is sufficiently high or the distribution commission and distribution quality are relatively low. Furthermore, when the distribution commission is sufficient low, logistics operations managers of the platform should adopt the third-party logistics service mode. When the distribution commission is moderate and the self-operated distribution quality is not sufficiently high, the self-operated logistics service mode is beneficial to logistics operations managers of the platform and achieve a win–win outcome with the seller. Expect in case of a high distribution commission and a low self-operated distribution quality, the seller would like to accept the platform's self-operated physical distribution. Therefore, although potential conflicts of interests exist, the platform and the seller could establish a long-term and stable cooperative relationship. In addition, our study also suggests that managers of the 3PC need to consider the self-operated distribution quality and commission when making physical distribution strategy decisions. Specifically, managers of the 3PC always prefer the agency logistics service mode if the self-operated distribution quality and commission are not high. These results imply that distribution commission and distribution quality are critical elements that influence the platform's distribution service choices, and logistics operations managers should pay more attention to it.

In general, the issue of e-commerce logistics service choices is a critical point of logistics management [7]. We analyze this issue in an online supply chain that includes a platform, a seller, and a 3PC. Moreover, we further explore the strategic logistics service mode choices for the platform, which has a self-operated physical distribution. If the platform provides self-operated physical distribution to the seller, the managers of the platform should choose a moderate distribution commission and self-operated distribution quality. Therefore, our managerial insights make for clarifying the manager's decision choice in physical distribution practice. Our work also offers managerial insights to managers of the platform and the 3PC to adopt an appropriate logistics service strategy.

7. Conclusion

In this paper, we consider an online supply chain that consists of a platform, a seller and a 3PC. By analyzing three logistics service modes, we investigate the optimal logistics service mode and further explore the impacts of different service modes on supply chain members' profits.

The findings of our work have significant implications for the platform, seller, and 3PC. When the platform provides self-operated physical distribution to the seller, it should set a distribution commission higher than a threshold. If the platform wants to achieve a win–win situation with the seller, then it should set a distribution commission within a moderate range. If the distribution commission is sufficiently low, the platform should not provide self-operated or agency physical distribution. Except in the case of a high distribution commission and low self-operated distribution quality, the seller should accept the platform's self-operated physical distribution. Furthermore, the 3PC should cooperate with the platform to offer the agency logistics service unless both the self-operated distribution quality and commission are relatively large.

We then analyze the influence of significant parameters on prices and profits in different modes. The results indicate that in the self-operated logistics service mode, the platform and the seller have great incentives to increase their retail prices when the self-operated distribution quality is high, the self-operated distribution cost is large, and the distribution commission is high. The platform should raise the self-operated distribution quality and the distribution commission for a higher profit. In the third-party logistics service mode, as the self-operated distribution cost and third-party distribution cost increase, the platform's and seller's retail prices and the 3PC's unit price increase. The platform is willing to reduce the self-operated distribution cost as much as possible. Meanwhile, the 3PC is willing to reduce the third-party distribution cost. In the agency logistics service mode, an increase in the distribution commission decreases the 3PC's unit price and increases the platform's and seller's retail prices. The platform has a strong motivation to increase the distribution commission, and the 3PC raises the third-party distribution quality.

The current research has certain limitations, and several future research directions are still worth studying. First, we assume that this model is static under different logistics service modes. It could be interesting to incorporate the dynamic decision in the logistics service mode choice problem. We leave it to future research to observe the new managerial insights. Second, we consider that there is only one 3PC to selected by the platform and the seller. Considering the competition among different 3Ps in platform supply chain is a future research direction. Finally, it is also interesting to study the impact of blockchain technology on the online platforms' strategic logistics service.

Appendix A.

Proof of Proposition 1. In mode LL, the profit function of the platform and the seller are defined as follows:

$$\begin{aligned}\pi_e = &(p_e - c_e)(a - p_e + \alpha p_r + \beta s_e - \gamma s_e)\\ &+ (\rho p_r + f - c_e)(a - p_r + \alpha p_e + \beta s_e - \gamma s_e)\end{aligned} \tag{A.1}$$

$$\pi_r = (p_r - \rho p_r - f)(a - p_r + \alpha p_e + \beta s_e - \gamma s_e). \tag{A.2}$$

Using equations (A.1) and (A.2), the following derivatives of π_e to p_e and π_r to p_r can be shown as:

$$\frac{\partial \pi_e}{\partial p_e} = -2p_e + (\alpha + \alpha\rho)p_r + a + (\beta - \gamma)s_e + (1 - \alpha)c_e + \alpha f. \tag{A.3}$$

$$\frac{\partial \pi_r}{\partial p_r} = -2(1 - \rho)p_r + (1 - \rho)(\alpha + \alpha p_e + (\beta - \gamma)s_e) + f. \tag{A.4}$$

By setting equations (A.3) and (A.4) to zero and solving them simultaneously, we obtain

$$p_e^{LL} = \frac{1}{(1-\rho)(4-\alpha^2(1+\rho))}[(2+\alpha-\alpha\rho^2-2\rho)a+(\beta-\gamma)(2+\alpha-\alpha\rho^2-2\rho)s_e + 2(1-\rho)(1-\alpha)c_e+\alpha(3-\rho)f]. \tag{A.5}$$

$$p_r^{LL} = \frac{1}{(1-\rho)(4-\alpha^2(1+\rho))}[(2+\alpha)(1-\rho)a+(\beta-\gamma)(2+\alpha)(1-\rho)s_e + (1-\rho)(1-\alpha)\alpha c_e+(2+\alpha^2-\alpha^2\rho)f]. \tag{A.6}$$

□

Proof of Proposition 2. In mode LT, the profit function of the platform, the seller and the 3PC are defined as follows:

$$\pi_e = (p_e-c_e)(a-p_e+\alpha p_r+\beta s_e-\gamma s_t)+\rho p_r(a-p_r+\alpha p_e+\beta s_t-\gamma s_e) \tag{A.7}$$

$$\pi_r = (p_r-\rho p_r-w)(a-p_r+\alpha p_e+\beta s_t-\gamma s_e) \tag{A.8}$$

$$\pi_t = (w-c_t)(a-p_r+\alpha p_e+\beta s_t-\gamma s_e). \tag{A.9}$$

Using equations (A.7) and (A.8), the following derivatives of π_e to p_e and π_r to p_r can be shown as:

$$\frac{\partial \pi_e}{\partial p_e} = -2p_e+(\alpha+\alpha\rho)p_r+a+\beta s_e-\gamma s_t+c_e \tag{A.10}$$

$$\frac{\partial \pi_r}{\partial p_r} = -2(1-\rho)p_r+(1-\rho)(a+\alpha p_e+\beta s_t-\gamma s_e)+w. \tag{A.11}$$

By setting equations (A.10) and (A.11) to zero and solving them simultaneously, we obtain

$$p_e = \frac{1}{(1-\rho)(4-\alpha^2(1+\rho))}(2c_e+2a+\alpha a-2c_e\rho-2a\rho+\alpha w+2\beta s_e-2\gamma s_t+\alpha\beta s_t - \alpha\gamma s_e+\alpha\rho w-2\beta\rho s_e+2\gamma\rho s_t-\alpha a\rho^2-\alpha\beta\rho^2 s_t+\alpha\gamma\rho^2 s_e) \tag{A.12}$$

$$p_r = \frac{1}{(1-\rho)(4-\alpha^2(1+\rho))}(2a+2w+\alpha c_e+\alpha a-2a\rho+2\beta s_t-2\gamma s_e-\alpha c_e\rho-\alpha a\rho + \alpha\beta s_e-\alpha\gamma s_t-2\beta\rho s_t+2\gamma\rho s_t-\alpha\beta\rho s_e+\alpha\gamma\rho s_t). \tag{A.13}$$

Substituting equations (A.12) and (A.13) into equation (A.9), setting $\frac{\partial \pi_t}{\partial w}$ to zero and solving it, we have

$$w^{LT} = \frac{1}{2(2-\alpha^2(1+\rho))}[(1-\rho)(\alpha+2)a+(1-\rho)(\alpha\beta-2\gamma)s_e + (1-\rho)(2\beta-\alpha\gamma)s_t+(2-\alpha^2(1+\rho))c_t+\alpha(1-\rho)c_e]. \tag{A.14}$$

Substituting equation (A.14) to equations (A.12) and (A.13), we have

$$p_e^{LT} = \frac{1}{2(1-\rho)(2-\alpha^2(1+\rho))(4-\alpha^2(1+\rho))}[(1-\rho)(8+6\alpha(1+\rho)-2(1+\rho)^2\alpha^3-3\alpha^2(1+\rho))a + (1-\rho)(8\beta+2\gamma\alpha^3(1+\rho)^2-(3\beta\alpha^2+6\gamma\alpha)(1+\rho))s_e+(1-\rho)((3\gamma\alpha^2+6\beta\alpha)(1+\rho) - 2(1+\rho)^2\alpha^3\beta-8\gamma)s_t+(1-\rho)(8-3\alpha^2(1+\rho))c_e+(1+\rho)(2\alpha-\alpha^3(1+\rho))c_t] \tag{A.15}$$

$$p_r^{LT} = \frac{1}{2(1-\rho)(2-\alpha^2(1+\rho))(4-\alpha^2(1+\rho))}[(1-\rho)(\alpha+2)(3-(1+\rho)\alpha^2)a + (1-\rho)(\alpha\beta-2\gamma)(3-(1+\rho)\alpha^2)s_e+(1-\rho)(2\beta-\alpha\gamma)(3-\alpha^2(1+\rho))s_t + (2-\alpha^2(1+\rho))c_t+\alpha(1-\rho)(3-\alpha^2(1+\rho))c_e]. \tag{A.16}$$

□

Proof of Proposition 3. In mode LA, the profit function of the platform, the seller and the 3PC are defined as follows:

$$\pi_e = (p_e - c_e)(a - p_e + \alpha p_r + \beta s_e - \gamma s_t) + (\rho p_r + f - w)(a - p_r + \alpha p_e + \beta s_t - \gamma s_e) \tag{A.17}$$
$$\pi_r = (p_r - \rho p_r - f)(a - p_r + \alpha p_e + \beta s_t - \gamma s_e) \tag{A.18}$$
$$\pi_t = (w - c_t)(a - p_r + \alpha p_e + \beta s_t - \gamma s_e). \tag{A.19}$$

With equations (A.17) and (A.18), the following derivatives of π_e to p_e and π_r to p_r can be shown as:

$$\frac{\partial \pi_e}{\partial p_e} = -2p_e + (\alpha + \alpha\rho)p_r + a + \beta s_e - \gamma s_t + c_e + \alpha f - \alpha w \tag{A.20}$$
$$\frac{\partial \pi_r}{\partial p_r} = -2(1-\rho)p_r + (1-\rho)(a + \alpha p_e + \beta s_t - \gamma s_e) + f. \tag{A.21}$$

By setting equations (A.20) and (A.21) to zero and solving them simultaneously, we obtain

$$p_e = \frac{1}{(1-\rho)(4-\alpha^2(1+\rho))}(2c_e + 2a + \alpha a + 3\alpha f - 2c_e\rho - 2a\rho - 2\alpha w$$
$$+ 2\beta s_e - 2\gamma s_t - \alpha\rho f + \alpha\beta s_t - \alpha\gamma s_e + 2\alpha\rho w - 2\beta\rho s_e + 2\gamma\rho s_t - \alpha a\rho^2 - \alpha\beta\rho^2 s_t + \alpha\gamma\rho^2 s_e) \tag{A.22}$$
$$p_r = \frac{1}{(1-\rho)(4-\alpha^2(1+\rho))}(2a + 2f + \alpha c_e + \alpha a - 2a\rho + 2\beta s_t - 2\gamma s_e + \alpha^2 f$$
$$- \alpha^2 w - \alpha c_e\rho - \alpha a\rho\alpha\beta s_e - \alpha\gamma s_t - 2\beta\rho s_t + 2\gamma\rho s_e - \alpha^2\rho w - \alpha\beta\rho s_e + \alpha\gamma\rho s_t). \tag{A.23}$$

Substituting equations (A.22) and (A.23) into equation (A.19), setting $\frac{\partial \pi_t}{\partial w}$ to zero and solving it, we have

$$w^{LA} = \frac{1}{2\alpha^2(1-\rho)}[(1-\rho)(\alpha+2)a - 2(1-\alpha^2)f + \alpha^2(1-\rho)c_t + (1-\rho)\alpha c_e$$
$$+ (\alpha\beta - 2\gamma)(1-\rho)s_e + (2\beta - \alpha\gamma)(1-\rho)s_t]. \tag{A.24}$$

Substituting equation (A.24) to equations (A.22) and (A.23), we have

$$p_e^{LA} = \frac{1}{(1-\rho)\alpha(4-\alpha^2(1+\rho))}[(1-\rho)(\alpha + (1-\rho)\alpha^2 - 2)a + (2 + \alpha^2 - \alpha^2\rho)f + (1-\rho)\alpha c_e$$
$$- \alpha^2(1-\rho)c_t + (1-\rho)(\alpha\beta + 2\gamma - \gamma(1+\rho)\alpha^2)s_e + (1-\rho)(\beta(1+\rho)\alpha^2 - \alpha\gamma - 2\beta)s_t] \tag{A.25}$$
$$p_r^{LA} = \frac{1}{2(1-\rho)(4-\alpha^2(1+\rho))}[(1-\rho)(\alpha+2)a + (6 - 2\alpha^2\rho)f + (1-\rho)\alpha c_e - \alpha^2(1-\rho)c_t$$
$$+ (\alpha\beta - 2\gamma)(1-\rho)s_e + (2\beta - \alpha\gamma)(1-\rho)s_t]. \tag{A.26}$$

□

Proof of Proposition 4.

$$\frac{\partial p_e^{LL}}{\partial s_e} = \frac{(\beta-\gamma)(2+\alpha(1+\rho))}{4-\alpha^2(1+\rho)} > 0 \tag{A.27}$$
$$\frac{\partial p_e^{LL}}{\partial c_e} = \frac{2(1-\alpha)}{4-\alpha^2(1+\rho)} > 0 \tag{A.28}$$
$$\frac{\partial p_e^{LL}}{\partial f} = \frac{\alpha(3-\rho)}{(1-\rho)(4-\alpha^2(1+\rho))} > 0 \tag{A.29}$$
$$\frac{\partial p_r^{LL}}{\partial s_e} = \frac{(\beta-\gamma)(2+\alpha)}{4-\alpha^2(1+\rho)} > 0 \tag{A.30}$$

$$\frac{\partial p_r^{LL}}{\partial c_e} = \frac{\alpha(1-\alpha)}{4-\alpha^2(1+\rho)} > 0 \tag{A.31}$$

$$\frac{\partial p_r^{LL}}{\partial f} = \frac{2+\alpha^2(1-\alpha)}{(1-\rho)(4-\alpha^2(1+\rho))} > 0. \tag{A.32}$$

□

Proof of Proposition 5.
(i)

$$\frac{\partial p_e^{LT}}{\partial s_e} = \frac{8\beta + 2\gamma\alpha^3(1+\rho)^2 - (3\beta\alpha^2 + 6\gamma\alpha)(1+\rho)}{2(2-\alpha^2(1+\rho))(4-\alpha^2(1+\rho))}. \tag{A.33}$$

Let $\sigma = \frac{\gamma}{\beta}$ and $\theta = (8-3\alpha^2(1+\rho))/(6\alpha(1+\rho) - 2\alpha^3(1+\rho^2))$. If $\sigma < \theta$, it is obvious that $8\beta + 2\gamma\alpha^3(1+\rho)^2 - (3\beta\alpha^2 + 6\gamma\alpha)(1+\rho) > 0$, and thus, $\frac{\partial p_e^{LT}}{\partial s_e} > 0$; otherwise, $\frac{\partial p_e^{LT}}{\partial s_e} \leq 0$.

$$\frac{\partial p_r^{LT}}{\partial s_e} = \frac{(\alpha\beta - 2\gamma)(3-(1+\rho)\alpha^2)}{2(2-\alpha^2(1+\rho))(4-\alpha^2(1+\rho))}. \tag{A.34}$$

If $\sigma = \frac{\gamma}{\beta} < \frac{\alpha}{2}$, $\frac{\partial p_r^{LT}}{\partial s_e} > 0$; otherwise $\frac{\partial p_r^{LT}}{\partial s_e} \leq 0$.

$$\frac{\partial w^{LT}}{\partial s_e} = \frac{(\alpha\beta - 2\gamma)(1-\rho)}{2(2-\alpha^2(1+\rho))}. \tag{A.35}$$

If $\sigma = \frac{\gamma}{\beta} < \frac{\alpha}{2}$, $\frac{\partial w^{LT}}{\partial s_e} > 0$; otherwise $\frac{\partial w^{LT}}{\partial s_e} \leq 0$.
(ii)

$$\frac{\partial p_e^{LT}}{\partial s_t} = \frac{(3\gamma\alpha^2 + 6\beta\alpha)(1+\rho) - 2(1+\rho)^2\alpha^3\beta - 8\gamma}{2(2-\alpha^2(1+\rho))(4-\alpha^2(1+\rho))}. \tag{A.36}$$

Let $\sigma = \frac{\gamma}{\beta}$ and $\theta = (8-3\alpha^2(1+\rho))/(6\alpha(1+\rho) - 2\alpha^3(1+\rho^2))$. If $\sigma < \frac{1}{\theta}$, it is obvious that $(3\gamma\alpha^2 + 6\beta\alpha)(1+\rho) - 2(1+\rho)^2\alpha^3\beta - 8\gamma > 0$, and thus, $\frac{\partial p_e^{LT}}{\partial s_t} > 0$; otherwise, $\frac{\partial p_e^{LT}}{\partial s_t} \leq 0$.

$$\frac{\partial p_r^{LT}}{\partial s_t} = \frac{(2\beta - \alpha\gamma)(3-(1+\rho)\alpha^2)}{2(2-\alpha^2(1+\rho))(4-\alpha^2(1+\rho))} > 0 \tag{A.37}$$

$$\frac{\partial w^{LT}}{\partial s_t} = \frac{(2\beta - \alpha\gamma)(1-\rho)}{2(2-\alpha^2(1+\rho))} > 0. \tag{A.38}$$

(iii)

$$\frac{\partial p_e^{LT}}{\partial c_e} = \frac{8-3\alpha^2(1+\rho)}{2(2-\alpha^2(1+\rho))(4-\alpha^2(1+\rho))} > 0 \tag{A.39}$$

$$\frac{\partial p_r^{LT}}{\partial c_e} = \frac{\alpha(3-(1+\rho)\alpha^2)}{2(2-\alpha^2(1+\rho))(4-\alpha^2(1+\rho))} > 0 \tag{A.40}$$

$$\frac{\partial w^{LT}}{\partial c_e} = \frac{2(1-\rho)}{2(2-\alpha^2(1+\rho))} > 0 \tag{A.41}$$

$$\frac{\partial p_e^{LT}}{\partial c_t} = \frac{\alpha(1+\rho)}{2(1-\rho)(4-\alpha^2(1+\rho))} > 0 \tag{A.42}$$

$$\frac{\partial p_r^{LT}}{\partial c_t} = \frac{1}{2(1-\rho)(4-\alpha^2(1+\rho))} > 0 \tag{A.43}$$

$$\frac{\partial w^{LT}}{\partial c_t} = \frac{1}{2} > 0\cdot \tag{A.44}$$

□

Proof of Proposition 6.
(i)

$$\frac{\partial p_e^{LA}}{\partial s_e} = \frac{\alpha\beta + 2\gamma - \gamma(1+\rho)\alpha^2}{\alpha(4-\alpha^2(1+\rho))} > 0 \tag{A.45}$$

$$\frac{\partial p_r^{LA}}{\partial s_e} = \frac{\alpha\beta - 2\gamma}{2(4-\alpha^2(1+\rho))} > 0 \tag{A.46}$$

$$\frac{\partial w^{LA}}{\partial s_e} = \frac{\alpha\beta - 2\gamma}{2\alpha^2}\cdot \tag{A.47}$$

If $\sigma = \frac{\gamma}{\beta} < \frac{\alpha}{2}$, $\frac{\partial w^{LA}}{\partial s_e} > 0$; otherwise $\frac{\partial w^{LA}}{\partial s_e} \leq 0$.
(ii)

$$\frac{\partial p_e^{LA}}{\partial s_t} = \frac{-\beta(2-(1+\rho)\alpha^2) - \alpha\gamma}{\alpha(4-\alpha^2(1+\rho))} < 0 \tag{A.48}$$

$$\frac{\partial p_r^{LA}}{\partial s_t} = \frac{2\beta - \alpha\gamma}{2(4-\alpha^2(1+\rho))} > 0 \tag{A.49}$$

$$\frac{\partial w^{LA}}{\partial s_t} = \frac{2\beta - \alpha\gamma}{2\alpha^2} > 0. \tag{A.50}$$

(iii)

$$\frac{\partial p_e^{LA}}{\partial c_e} = \frac{1}{4-\alpha^2(1+\rho)} > 0 \tag{A.51}$$

$$\frac{\partial p_r^{LA}}{\partial c_e} = \frac{\alpha}{2(4-\alpha^2(1+\rho))} > 0 \tag{A.52}$$

$$\frac{\partial w^{LA}}{\partial c_e} = \frac{1}{2\alpha} > 0. \tag{A.53}$$

(iv)

$$\frac{\partial p_e^{LA}}{\partial c_t} = \frac{-1}{4-\alpha^2(1+\rho)} < 0 \tag{A.54}$$

$$\frac{\partial p_r^{LA}}{\partial c_t} = \frac{-\alpha^2}{2(4-\alpha^2(1+\rho))} < 0 \tag{A.55}$$

$$\frac{\partial w^{LA}}{\partial c_t} = \frac{1}{2} > 0. \tag{A.56}$$

(v)

$$\frac{\partial p_e^{LA}}{\partial f} = \frac{2+(1-\rho)\alpha^2}{(1-\rho)\alpha(4-\alpha^2(1+\rho))} > 0 \tag{A.57}$$

$$\frac{\partial p_r^{LA}}{\partial f} = \frac{6-2\alpha^2\rho}{2(1-\rho)(4-\alpha^2(1+\rho))} > 0 \tag{A.58}$$

$$\frac{\partial w^{LA}}{\partial f} = \frac{\alpha^2 - 1}{\alpha^2(1-\rho)} < 0. \tag{A.59}$$

□

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