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Service selection strategic analysis for self-operated e-commerce platforms under settlement

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ABSTRACT

In order to study whether e-commerce platforms carry out service cooperation after settlement in-depth, this paper focuses on service selection strategic analysis for agent channels on some self-operated e-commerce platforms settled in hybrid e-commerce platforms. We present multi-leader-follower models in two different scenarios with the platforms as leaders and the manufacturers as followers and give some numerical experiments to analyze the impacts of service selection strategies for self-operated platforms on all supply chain members. Our finding shows that if the service cost efficiency is moderate or low, the self-operated platform prefers to provide its service for the agent; otherwise, its selection mainly depends on the unit product service fee. In addition, fierce service competition and high unit service fee are unfavorable to all members, while high service cost efficiency may hurt both the platform and the manufacturer.

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1. Introduction

With the rise of the Internet economy, online retailing has experienced remarkable growth in recent years. From 2017 to 2021, the overall scale of global retail sales-maintained growth, and the transaction scale of the global e-commerce market exceeds 5.3 trillion dollars in 2021. The global Internet penetration rate increased from 16.8% in 2005 to 53.6% in 2019. From 2005 to 2019, the number of Internet users increased by an average of 10% per year. In China, many online retailing markets have developed rapidly since 2011, but the growth rate has been slowing down gradually from 53.7% in 2011 to 10.9% in 2020. Therefore, in response to this change, e-commerce platforms should increase their efforts to obtain more market shares for themselves. In the retail market, self-operated e-commerce platforms adopt the self-operated mode, which means a platform wholesales products from merchants, determines the price and sells them to consumers, and makes a profit by earning the difference (Li et al., 2022). Hybrid e-commerce platforms (open e-commerce platforms) include both self-operated and agency modes (Zhao & Luo, 2022). Agency

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mode means merchants enter the platform by paying commissions to sell their products, and the price is determined by the merchant (Hagiu & Wright, 2015). Some e-commerce platforms like Amazon.com, JD.com, etc. have enabled a large number of manufacturers and retailers to settle in and have completed their transformations from self-operated platforms to hybrid platforms (Song et al., 2021; Sun & Liu, 2021). At the same time, self-operated e-commerce platforms like Gome.com, Suning.com, etc. have a chance to settle in these hybrid e-commerce platforms to open up agency channels to seek more market shares (Fan et al., 2020; Ryan et al., 2012; Song et al., 2021; Sun & Liu, 2021). Undoubtedly, the settlement selections are not only beneficial to self-operated e-commerce platforms, but also pave a way for hybrid e-commerce platforms to gain more profits.

As an important factor besides price, platform service is highly valued by consumers and e-commerce platforms (Hasiloglu & Kaya, 2021; Panda et al., 2020). Many platforms provide convenient services on online retailing channels to promote platform sales. Especially since the COVID-19 pandemic, online retailing has shown strong resilience and becomes an important force driving consumption. Affected by the COVID-19 pandemic, offline consumption has been blocked. At the same time, online consumption is effectively promoting consumption replenishment. Relevant data show that China's online retail sales were 5,150.1 billion yuan, a year-on-year increase of 7.3% in the first half of 2020. Among them, the online retail sales of physical goods reached 4,348.1 billion yuan, an increase of 14.3%. For example, in China, due to less face-to-face contact appealed by governments, high-quality and diversified services in retail have become a focus of consumers. In such circumstances, many platforms provide convenient services on online retailing channels to promote platform sales (e.g. JD.com has built JD Logistics to provide consumers with efficient and fast services delivered in next day; Vipshop.com has provided convenient services for door-to-door return and exchange). High-quality services provided by e-commerce platforms can not only enhance their images but also enhance their sales volumes of products and thereby increase their profits. Therefore, to stabilize and strengthen good cooperation, hybrid e-commerce platforms are willing to provide services for settled merchants.

Quite a few e-commerce platforms such as Gome.com, Taobao.com, JD.com, Suning.com, and Vipshop.com have the ability to provide services. In reality, Gome.com selected to settle in JD.com to form a horizontal cooperation in 2020. This channel can provide after-sales and logistics services of JD.com or its own services. Gome.com can also expand market demand through the quality services of other parties. Other examples include the cases of Suning.com settling in Taobao.com, Vipshop.com settling in JD.com, and Gome.com settling in Pinduoduo.com. These new channels generally have the problem of service selection. On the basis of this settlement strategy, there are also competition and cooperation relationships in terms of services among e-commerce platforms. So far, there are few types of research on service competition and cooperation, especially on service selection under the premise of the settlement strategy. Therefore, how to choose services for e-commerce platforms is worth studying.

In this paper, we consider a supply chain consisting of one hybrid e-commerce platform called the large platform, one self-operated platform called the small platform, and one manufacturer. The small platform enters the large platform based on an original self-operated channel to generate an agent channel and sells products through the large platform. Suppose that both platforms are self-operated and can provide services for the agent. We mainly focus on the following two issues: (1) How should the self-operated e-commerce platform choose its optimal service strategy? (2) How do different service selections affect the coordination with other members in the supply chain? Note that current literatures on settlement strategies mainly focus on the impact of prices only (Fan et al., 2020; Ryan et al., 2012; Song et al., 2021; Sun & Liu, 2021), while various services have also become important affect factors. Based on this observation, in this paper, we add service level to demands and consider its impact on demand changes in the settlement situation through multi-leader-follower game models. Furthermore, we investigate the small platform's service selection for the agent and analyze the cooperation and competition behaviors of the e-commerce platforms in service strategy.

Some valuable insights and contributions can be stated as follows: Firstly, the increase of unit product service cost or service competition intensity may lead to the small platform being more inclined to choose its own service. To be specific, when the service cost efficiency of the small platform is moderate or low, the small platform prefers to provide its own service for the agent channel; when the service cost efficiency of the small platform is high, it should choose the large platform to provide service in the case that the unit service fee is low or in the case that the unit service cost is moderate/high and the service cost efficiency of the large platform is much lower than the small platform. Secondly, about the impact of the service strategy on supply chain members, fierce service competition and high unit product service cost are unfavorable to each member, and high service cost efficiency may have a negative impact on profits for the platforms themselves and be detrimental to the manufacturer. In addition, fierce competition is not conducive to the coordinated development of the supply chain in any scenario.

Note that most existing literatures on e-commerce platforms mainly focus on prices and selling modes (Abhishek et al., 2016; Fan et al., 2020; Mantin et al., 2014; Ryan et al., 2012; Song et al., 2021; Sun & Liu, 2021). In this paper, we take multi-leader-follower game models into consideration in the service competition and cooperation between two sides when the e-commerce platforms have formed a settlement cooperation. We uncover the effects of key parameters such as service cost efficiency, service competition intensity, unit service fee parameters, etc. on service selection and supply chain members. Our findings may not only deepen prior research but also provide managerial insights for e-commerce platforms in service selection.

The remainder of this paper is organized as follows. In Section 2, we review the relevant literature. In Section 3, we present our models. We give a solution analysis for the model in Section 4 and report some numerical experiments in Section 5. Finally, in Section 6, we make some conclusions with a summary of the key findings and future research directions. All proofs are presented in Appendix.

2. Literature review

This research is closely related to e-commerce platforms' strategic analysis, coopetition of supply chain members, and service levels.

2.1. E-commerce platforms strategic analysis

Our research mainly focuses on strategic analysis for e-commerce platforms. In the literature, there has been a list of publications on strategic selling modes for e-commerce platforms. In particular, Mantin et al. (2014) investigated strategic rationale for retailers by introducing a 3 P marketplace and studied how a 3 P marketplace alters the outcome of the bargaining game between a manufacturer and retailers. They explored a dual-format model and proved that retailers can improve their bargaining positions in negotiations with manufacturers through 3 P marketplace. Abhishek et al. (2016) constructed selection models for e-commerce platforms to study when the platforms should use an agency selling format instead of the conventional reselling format. Their results showed that sales in the electronic channel can influence strategic selling modes. On this basis, Han et al. (2018) considered two operational patterns (other-organization e-pattern and self-organization e-pattern) to study the influence of commission charge and found that fixed commission has an effect on the total profits of manufacturers only, but the variable commission may influence prices of the others. Zennyo (2020) considered two competing suppliers to select a wholesale contract or agency contract by examining strategic contracts between a monopoly platform and suppliers and showed that the platform can offer a low royalty rate to induce the suppliers to adopt the agency contract as long as the product substitutability is low enough. Li and Ai (2021) investigated what type of selling format e-retailers should choose under horizontal competition and showed that the selling format choice of e-retailers depends on channel competition and revenue sharing. Liu et al. (2021) studied contract choice strategies for a monopoly manufacturer facing two competing downstream online retail platforms and found that the competition intensity between the two platforms and the order-fulfillment costs critically moderate the choice decision. Wei et al. (2021) used a stylized theoretical model to study how to choose reselling or agency selling format for e-tailers and showed that e-tailers' best choice depends on their referral fees and the difference among their market shares. Zhang and Hou (2022) considered manufacturers' sales mode selection problem when e-retailers introduce private label products and found that manufacturers should adopt agency selling when the percentage fees are low. There are some works related to e-commerce platforms to discuss order fulfillment (Acimovic & Graves, 2015; Song et al., 2021), online product reviews (Garnefeld et al., 2021; Kwark et al., 2014), promotion (Chen et al., 2020; Huang & Bai, 2021; Kurata & Liu, 2007), and demand information sharing (Yang et al., 2021; Zhang & Zhang, 2020).

On the basis of the above works, our study considers a hybrid e-commerce structure, where one platform not only works as a retailer but also offers online marketplace services to sellers and another platform not only works as a retailer but also settles in the above platform as a seller. Different from the above papers, our objective is to examine the impact of different service levels in the hybrid mode under multi-channel coopetition and the equilibrium scenario choices in e-commerce markets.

2.2. Coopetition of supply chain members

Our work is closely related to coopetition among channel members. In general, coopetition occurs in cases where there are homogeneous products among more firms in the same markets (Bengtsson & Kock, 2000). Ryan et al. (2012) considered a firm facing an independent retailer and selling products through its own website. The firm may also choose to sell products as a 3 P seller on another retailer's marketplace to cooperate. The authors analyzed the optimal decisions for both the retailer and the firm. Chakraborty et al. (2015) considered a supply chain consisting of two competing manufacturers to analyze the integrated effect of competitive and cooperative pricing behaviors in supply chains. Their results showed that revenue sharing contracts can enable supply chain coordination. Zhu and Lin (2019) focused on pricing strategies in stable advertising cooperation under a market power structure and found that platforms would reduce their income commission to attract more advertisers to cooperate. Pi et al. (2019) studied pricing and service strategies with retailers' competition and cooperation in a dual-channel supply chain consisting of one manufacturer and two retailers. The numerical experiments showed that the retailers' cooperation enhances each retailer's performance, but reduces the profits of the manufacturer and the whole system. Chen et al. (2019) discussed the dynamics of coopetition and the effects of coopetition strategies on firms' operational decisions when rival firms participate in market competition. Their results showed that coopetition eases competition intensity in the cooperating area. Fan et al. (2020) studied the influence of horizontal cooperation between two competing online retailers and showed that horizontal cooperation may promote channel coordination.

On the base of the above works, our study aims at studying coopetition in an e-commerce market and especially investigates the implications of service selection between two platforms under both channel coopetition and service coopetition.

2.3. Service levels

This research is also related to service levels in an inter-organizational relationship. There are some literatures on service competition. In particular, Ding et al. (2018) studied service competition in the context of inventory and environmental constraints and showed that service time is an important factor in competition, while service competition becomes fierce when consumers are increasingly sensitive to service time. Zhao et al. (2019) studied the combination of mode selection and service competition strategies and found that, when a supplier's service efficiency is relatively high, the service elastic coefficient is high or the price elastic coefficient is low, to select the consignment mode is an equilibrium strategy.

There also are some literatures to consider the influence brought about by service choices. For example, Qin et al. (2020) analyzed the strategic and economic impacts of logistics service sharing and found that, as both the third-party logistics' service level and the market potential increase, the equilibrium mode may evolve from no-service-sharing to service-sharing. Subsequently, Qin et al. (2021) presented an analytical model to examine how selling mode choice interacts with logistics service strategy and showed that the supplier's preference aligns with the improvement of the logistics service level.

Different from these works, our study focuses on how the self-operated platforms' service choices interact with each other, especially, we are interested in finding an optimal combination between the two platforms' service coopetition.

In summary, this study may offer two contributions to the existing literature. Firstly, there is no published work to examine the optimization of service selection under settlement strategy in supply chains with multi-channel structures. To enrich the service selection literature, we focus on the interactions between service levels and coopetition in a multi-channel structure. Secondly, we investigate the impact of service selection on supply chain members to find some managerial insights to help firms determine their strategy under different service selections and provide optimal service strategies for platforms.

3. Model framework

In this section, we present model descriptions in two scenarios, which include the scenario that the small platform provides services for the agent and the scenario that the large platform provides services for the agent.

In real life, such as Taobao.com, JD.com, Amazon, etc., as the main e-commerce platforms in the market, have a strong market position. Then have absolute advantages and voice when negotiating with manufacturers, and have a significantly dominant position. Therefore, similarly to Zhao et al. (2019) and Wei et al. (2020), the platforms are leaders and the manufacturer is the follower. This paper has two platforms, and both of them are leaders, so it is a multi-leader-follower model. E-commerce platforms make decisions first as leaders, and then manufacturers make decisions as followers.

3.1. Model descriptions

We consider a market consisting of one hybrid e-commerce platform called the large platform, one self-operated platform called the small platform, and a manufacturer. The small platform enters the large platform as a flagship store with a settlement fee k and a commission rate δ so as to create an agency channel. The platforms wholesale the same products from the manufacturer, but they determine their own service levels and unit prices by themselves. Moreover, the small platform can provide its own service in the agent channel or choose the large platform's service to promote the sales of products through the agent channel.

If the small platform chooses its own service (denoted by R), it needs to determine its own retail price p_{RL} and service level s_{RL} in both self-operated and agent channels, while the large platform needs to determine its own retail price p_{RB} and service level

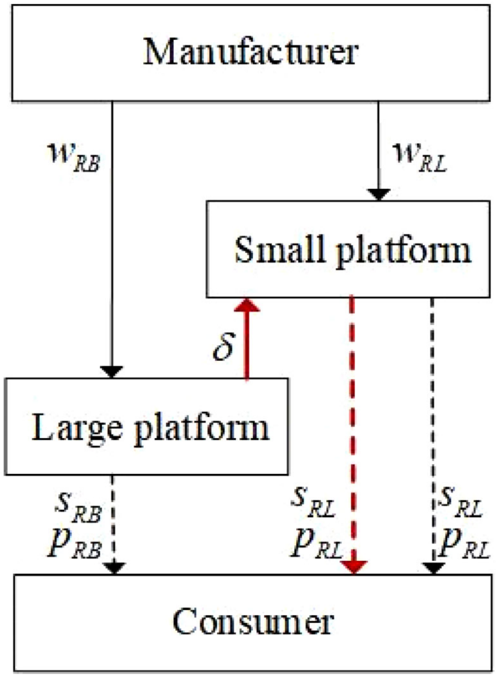

Figure 1. Small platform provides services (*R*).
Source: own research by Visio.

s_{RB} in the self-operated channel, as shown in Figure 1. We assume that the small platform sells products at the same price in different channels (Fan et al., 2020).

If the small platform chooses the large platform's service (denoted by H), it needs to pay a product service fee m per unit to the large platform and determine its own retail price p_{HL} in both self-operated and agent channels. Similarly as in Qiu and Yang (2022), the service fee m means that, for a unit of product sold on the large platform, the small platform will pay the service fee to the large platform. The large platform needs to determine the service level s_{HB} in both self-operated channels and its own retail price p_{HB}, as shown in Figure 2. The notations used later on are summarized in Table 1.

3.2. Demand functions

As is known to us, various linear demand functions have been extensively used in Yue and Liu (2006), Dan et al. (2012), Ma et al. (2017), Yan et al. (2019), Pi et al. (2019), Shen et al. (2019) and Qin et al. (2020). In our settings, since the order demands decrease with the rise of prices and increase with the rise of service levels, we refer to the references (Pi et al., 2019; Qin et al., 2020; Yue & Liu, 2006) to adopt linear demand functions to characterize demand changes caused by prices and services. If the small platform chooses its own service for the agent channel, the demands are respectively given by

$$D_{RL} = (1-\lambda)d - p_{RL} + \alpha(p_{RB} + p_{RL}) + s_{RL} - \beta(s_{RL} + s_{RB}), \tag{1}$$

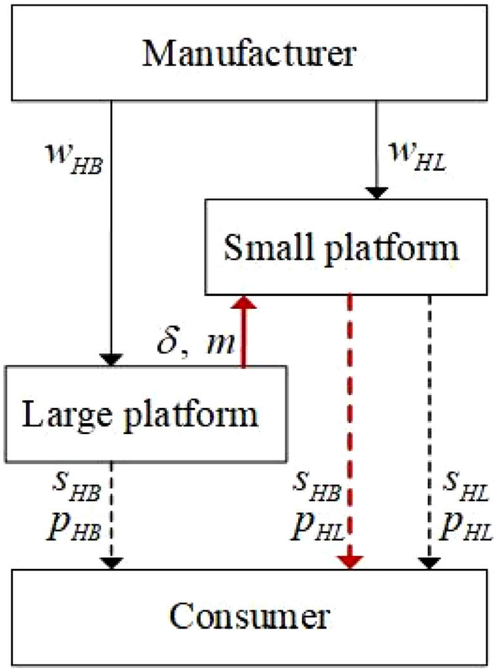

Figure 2. Large platform provides services (H).
Source: own research by Visio.

$$D_{RB} = \theta\lambda d - p_{RB} + \alpha(p_{RL} + p_{RL}) + s_{RB} - \beta(s_{RL} + s_{RB}), \tag{2}$$

$$D_{R} = (1-\theta)\lambda d - p_{RL} + \alpha(p_{RB} + p_{RL}) + s_{RL} - \beta(s_{RL} + s_{RB}). \tag{3}$$

If the small platform chooses the large platform's service for the agent channel, the demands are respectively given by

$$D_{HL} = (1-\lambda)d - p_{HL} + \alpha(p_{HB} + p_{H}) + s_{HL} - \beta(s_{HB} + s_{HB}), \tag{4}$$

$$D_{HB} = \theta\lambda d - p_{HB} + \alpha(p_{HL} + p_{HL}) + s_{HB} - \beta(s_{HL} + s_{HB}), \tag{5}$$

$$D_{H} = (1-\theta)\lambda d - p_{H} + \alpha(p_{HB} + p_{HL}) + s_{HB} - \beta(s_{HL} + s_{HB}). \tag{6}$$

Here, $D_{ij}(i \in \{R, H\},\ j \in \{B, L\})$ denotes the demand in the self-operated channel of the platform j in mode i; D_i denotes the demand of the small platform's agent channel in mode i; the parameters d, λ, θ refer to the potential market demand, the potential market share of the large platform, and the proportion of remaining consumers for the distribution channel respectively; α means the perfect substitution, which is a cross-price sensitivity reflecting the price competition among different channels (as α increases, the price competition is getting more intense among the channels and $\alpha \in [0, 0.5]$ can ensure the profitability of the self-operated products of the large platform (Fan et al., 2020)); β stands for the sensitivity of service level of the other platform.

Table 1. Notations.

Notation	Description
I	Scenario set $i \in I = \{R, H\}$: R represents the case that the small platform provides service, H represents the case that the large platform provides service
J	Market players $j \in J = \{B, L\}$: B represents the large platform and L denotes the small platform
k	Platform settlement fee
δ	Commission rate (charge according to the transaction volume), $\delta \in [0, 1]$
m	Unit product service fee paid by the small platform to the large platform
d	Potential market demand
λ	Market share of the large platform, $\lambda \in [0.5, 1]$
α	Price competition intensity, $\alpha \in [0, 0.5]$
β	Service competition intensity, $\beta \in [0, \alpha]$
θ	Customer loyalty to the self-operated products on the large platform, $\theta \in [0, 1]$
η_j	Service cost efficiency for the platform j
π_{ij}	Profit for the platform j in mode i
π_{iM}	Profit for the manufacturer in mode i
D_{ij}	Self-operated channel market demand for the platform j in mode i
D_i	Agent channel market demand for the small platform in mode i
$c(s_{ij})$	Product cost of service for the platform j in mode i
$\bar{s}_j$, $\underline{s}_j$	Boundaries of service level for the platform j
w_{ij}	Wholesale price for the platform j in mode i
p_{ij}	Retail price of the platform j in mode i
s_{ij}	Service level of the platform j in mode i

Source: own research by Matlab.

Similarly as in Gurnani et al. (2007), Lu and Liu (2013), Ma et al. (2017), and Pi et al. (2019), we suppose the service cost to be given by $c(s_{ij}) = \eta_j (s_{ij})^2/2$, where $\eta_j (j \in J)$ represents the service cost efficiency of the platform j. High service level means that the driver group costs more to reach the desired service level and so small η_j means more cost-effective service.

3.3. Formulations for scenario R

In the scenario R, the small platform provides services for the agent channel. The small platform and the large platform determine their respective product prices and service levels. Then the manufacturer determines wholesale prices based on the decisions of the e-commerce platform. A multi-leader-follower model (I) can be established as

$$\max_{p_{RL},\ s_{RL}} \pi_{RL} = (p_{RL} - w_{RL})(D_{RL} + D_R) - \delta p_{RL} D_R - 2c(s_{RL}) - k \tag{7}$$

$$\text{s.t.} \quad p_{RL} \geq w_{RL}, \quad \underline{s}_L \leq s_{RL} \leq \bar{s}_L \tag{8}$$

$$\max_{w_R \geq 0} \pi_{RM} = w_{RL}(D_{RL} + D_R) \ + w_{RB} D_{RB} \tag{9}$$

$$\max_{p_{RB},\ s_{RB}} \pi_{RB} = (p_{RB} - w_{RB}) D_{RB} + \delta p_{RL} D_R - c(s_{RB}) + k \tag{10}$$

$$\begin{aligned} \text{s.t.} \quad & p_{RB} \geq w_{RB}, \quad \underline{s}_B \leq s_{RB} \leq \bar{s}_B \\ & \max_{w_R \geq 0} \pi_{RM} = w_{RL}(D_{RL} + D_R) \ + w_{RB} D_{RB} \end{aligned} \tag{11}$$

Here, $w_R = (w_{RL}, w_{RB})$ is the wholesale price vector determined by the manufacturer in mode R; (7)-(9) are the small platform's model, where (7) represents its profit function, (8) represents the constraints on prices and service levels, and (9) represents the manufacturer's model; (9)-(11) are the large platform's model, where (10) represents its profit function and (11) represents the constraints on prices and service levels.

3.4. Formulations for scenario H

In the case that the large platform provides service, a multi-leader-follower model (II) can be established as

$$\max_{p_{HL},\ s_{HL}} \pi_{HL} = (p_{HL} - w_{HL})(D_{HL} + D_H) - (\delta p_{HL} + m)D_H - c(s_{HL}) - k \tag{12}$$

$$\text{s.t.} \quad p_{HL} \geq w_{HL}, \quad \underline{s}_L \leq s_{HL} \leq \bar{s}_L \tag{13}$$

$$\max_{w_H \geq 0} \pi_{HM} = w_{HL}(D_{HL} + D_H) + w_{HB}D_{HB} \tag{14}$$

$$\max_{p_{HB},\ s_{HB}} \pi_{HB} = (p_{HB} - w_{HB})D_{HB} + (\delta p_{HL} + m)D_H - 2c(s_{HB}) + k \tag{15}$$

$$\begin{aligned} \text{s.t.} \quad & p_{HB} \geq w_{HB}, \quad \underline{s}_B \leq s_{HB} \leq \bar{s}_B \\ & \max_{w_H \geq 0} \pi_{HM} = w_{HL}(D_{HL} + D_H) + w_{HB}D_{HB} \end{aligned} \tag{16}$$

Where $w_H = (w_{HL}, w_{HB})$ denotes the wholesale price vector determined by the manufacturer in mode H, (12)-(14) are the small platform's model, and (14)-(16) are the large platform's model.

4. Theoretical analysis and results

The multi-leader-follower models given in the last section are very difficult to solve directly due to their hierarchical structures. We use a popular way to deal with the hierarchical models, that is, at the first stage, we solve the lower-level models and then, in the second stage, we substitute them into the upper-level models. Noting that both lower-level and upper-level models are constrained optimization problems, in order to solve them, we first obtain some stationarity points of their objective functions and then find conditions satisfying the constraints. Since stationarity points of a convex optimization model must be its globally optimal solutions, we need to discuss the convexity of each model involved.

4.1. Solution and analysis for scenario R

We introduce the auxiliary variables $\tau_{ij} = p_{ij} - w_{ij}$ ($i \in \{R, H\}, \ j \in \{B, L\}$) to simplify the model. We first discuss the manufacturer's decision in model (I). It can be shown in Proposition 1 that, if $\alpha \in [0, 0.5]$, π_{RM} is concave in w_R.

Proposition 1. *If $\alpha \in [0, 0.5]$, the manufacturer's model Eq. (9) is a convex optimization problem with respect to w_R. The optimal wholesale prices of two platforms are*

$$w_{RL}^* = \frac{1}{4}(X_1 + 2Y_1 s_{RL} + 2Y_2 s_{RB} - 2\tau_{RL}), w_{RB}^* = \frac{1}{2}(X_2 + 2Y_2 s_{RL} + Y_3 s_{RB} - \tau_{RB}).$$

See the appendix for proof of Proposition 1, where X_1, X_2, Y_1, …, Y_3 are defined in Table A1 in Appendix.

From Proposition 1, it can be seen that the optimal solutions exist for the manufacturer in the model (I) when $\tau_{RL} \le \tau_{1L}^*$, $\tau_{RB} \le \tau_{1B}^*$, where $\tau_{1L}^* = X_1/2 + Y_1 \underline{s}_L + Y_2 \underline{s}_B$, $\tau_{1B}^* = X_2 + 2Y_2 \underline{s}_L + Y_3 \underline{s}_B$, $\underline{s}_L$ and $\underline{s}_B$ represent the lower limits of the service levels. $\tau_{RL} \le \tau_{1L}^*$, $\tau_{RB} \le \tau_{1B}^*$ mean that the retail prices cannot be too high and, under this condition, the manufacturer can guarantee a better wholesale price, which indicates that the manufacturer's wholesale price is subject to the upper variables. Moreover, the manufacturer's wholesale prices are also relevant with s_{RL}, s_{RB}, which means that the manufacturer's wholesale price is affected by the service levels of the platforms. The higher the service levels, the higher the wholesale prices. In addition, w_{Rj}^* is relevant with τ_{Rj}, which means that the manufacturer's wholesale price is not affected by the retail prices in other channels.

By taking w_{RL}^* and w_{RB}^* into the upper-level models, we can find that π_{Rj} is concave in τ_{Rj}, s_{Rj} and then we can get each member's optimal solutions, as summarized in Proposition 2.

Proposition 2. *If $\alpha \in [0, 0.5)$, $\beta \in [0, \alpha]$, $\lambda \in [0.5, 1]$, $\theta \in [0, 1]$, $\delta \in [0, 1]$, $\eta_L \ge \eta_{1L}$, $\eta_B \ge \eta_{1B}$, the small platform's model is a convex optimization problem with respect to τ_{RL}, s_{RL} and the large platform's model is a convex optimization problem with respect to τ_{RB}, s_{RB}. Two platforms' optimal retail prices, optimal service levels and the manufacturer's optimal wholesale price are*

$$\begin{aligned}
s_{RL}^* &= (N_3N_4 - N_1N_6)/(N_2N_6 - N_3N_5), \\
s_{RB}^* &= (N_1N_5 - N_2N_4)/(N_2N_6 - N_3N_5), \\
w_{RL}^* &= (X_1 - E_1 + 2(Y_1 - E_2)s_{RL}^* + 2(Y_2 - E_3)s_{RB}^*)/4, \\
w_{RB}^* &= (X_2 - E_4 + (2Y_2 - E_5)s_{RL}^* + (Y_3 - E_6)s_{RB}^*)/2, \\
p_{RL}^* &= (X_1 + E_1 + 2(Y_1 + E_2)s_{RL}^* + 2(Y_2 + E_3)s_{RB}^*)/4, \\
p_{RB}^* &= (X_2 + E_4 + (2Y_2 + E_5)s_{RL}^* + (Y_3 + E_6)s_{RB}^*)/2,
\end{aligned}$$

where $\eta_{1L} = \frac{((4-\delta)(1-\beta) - Y_1\delta(1-\alpha))^2}{16(4-\delta)(1-\alpha)}$, $\eta_{1B} = \frac{(2+\alpha\delta Y_2)^2 - 8\beta\delta Y_2}{16}$.

See the appendix for proof of Proposition 2, where E_1, …, E_6, N_1, …, N_6 are given in Table A2 in Appendix.

From Proposition 2, it can be seen that the optimal service levels involve a variety of parameters, which reveals that the actual service levels are limited by various factors. In addition to the basic parameter setting (α, β, θ, λ, δ), we find that the unit service costs also need to meet certain conditions $\eta_L \ge \eta_{1L}$, $\eta_B \ge \eta_{1B}$. This indicates that the unit service cost of the small platform should be higher than η_{1L} to meet the basic service standards of consumers and, when an enterprise cannot meet the corresponding service standards, it should choose the services of other platforms. As for the large platform, it is also necessary to achieve the corresponding service level to attract small platforms to settle. It can also be observed that, when $N_4(N_3+N_2) > N_1(N_5+N_6)$, the small platform has better services and, at this time, small platforms may be more suitable for development through their high-quality services; otherwise, the services provided by large platforms are better. In addition, both the retail prices of the platforms and the wholesale price of the manufacturer are affected by the service level.

By substituting the above solutions into the profit functions, the optimal profits of the two platforms and the manufacturer are respectively

$$\pi^*_{RL} = \left(\frac{1}{2}E_1 + E_2 s^*_{RL} + E_3 s^*_{RB}\right)(D^*_{RL} + D^*_R) - \frac{\delta}{4}(X_1 + E_1 + 2(Y_1 + E_2)s^*_{RL} + 2(Y_2 + E_3)s^*_{RB})D^*_R - \eta_L (s^*_{RL})^2 - k,$$

$$\pi^*_{RB} = (E_4 + E_5 s^*_{RL} + E_6 s^*_{RB})D^*_{RB} + \frac{\delta}{4}(X_1 + E_1 + 2(Y_1 + E_2)s^*_{RL} + 2(Y_2 + E_3)s^*_{RB})D^*_R - \frac{\eta_B}{2}(s^*_{RB})^2 + k,$$

$$\pi^*_{RM} = \frac{1}{4}(X_1 - 4E_1 + 2(Y_1 - 2E_2)s^*_{RL} + 2(Y_2 - 2E_3)s^*_{RB})(D^*_{RL} + D^*_R) + \frac{1}{2}(X_2 - E_4 + (2Y_2 - E_5)s^*_{RL} + (Y_3 - E_6)s^*_{RB})D^*_{RB}.$$

Where $D^*_{RL} = \frac{1}{4}(X_3 - 2(1-\alpha)\tau^*_{RL} + 2\alpha\tau^*_{RB} + 2(1-\beta)s^*_{RL} - 2\beta s^*_{RB})$, $D^*_{RB} = \frac{1}{2}(X_4 + 2\alpha\tau^*_{RL} - \tau^*_{RB} - 2\beta s^*_{RL} + s^*_{RB})$, $D^*_R = \frac{1}{4}(X_5 - 2(1-\alpha)\tau^*_{RL} + 2\alpha\tau^*_{RB} + 2(1-\beta)s^*_{RL} - 2\beta s^*_{RB})$, and $X_3, \ldots, X_5$ are given in Table A1 in Appendix.

4.2. Solution and analysis for scenario H

Similarly to Subsection 4.1, by introducing the auxiliary variables $\tau_{ij} = p_{ij} - w_{ij}$ $(i \in \{R, H\},\ j \in \{B, L\})$, we can show that, if $\alpha \in [0, 0.5]$, π_{HM} is concave in w_H, which is summarized in Proposition 3 and proved in the appendix.

Proposition 3. *If $\alpha \in [0, 0.5]$, the manufacturer's model Eq. (14) is a convex optimization problem with respect to w_H. The optimal wholesale prices are respectively*

$$w^*_{HL} = \frac{1}{4}(X_1 + Y_1 s_{HL} + Y_4 s_{HB} - 2\tau_{HL}), w^*_{HB} = \frac{1}{2}(X_2 + Y_2 s_{HL} + Y_1 s_{HB} - \tau_{HB}),$$

Where $Y_4 = (1 + 2\alpha - 2\alpha\beta - 3\beta)/A$.

From Proposition 3, it is seen that, when $\tau_{HL} \le \tau^*_{2L}$, $\tau_{HB} \le \tau^*_{2B}$, the optimal solutions exist for the manufacturer in the model (II), where $\tau^*_{2L} = (X_1 + Y_1 \underline{s}_L + Y_4 \underline{s}_B)/2$ and $\tau^*_{2B} = X_2 + Y_2 \underline{s}_L + Y_1 \underline{s}_B$. It can also be found that the manufacturer's wholesale prices are relevant with s_{HL}, s_{HB}, which means that the manufacturer's wholesale price is affected by the service levels of the platforms in each scenario. The higher service the levels, the higher the wholesale prices. Moreover, w^*_{Hj} is relevant with τ_{Hj}, which means the manufacturer's wholesale price is not affected by the retail prices in other channels in the scenario H.

Substituting the above solutions into the upper-level models of model (II), Then, We can find that π_{Hj} is concave in τ_{Hj}, s_{Hj}, and we can get each member's optimal solutions which are summarized in Proposition 4, whose proofs are given in Appendix. $T_1, \ldots, T_6, Q_1, \ldots, Q_6$ are given in Table A3 in Appendix.

Proposition 4. *If* $\alpha \in [0, 0.5)$, $\beta \in [0, \alpha]$, $\lambda \in [0.5, 1]$, $\theta \in [0, 1]$, $\delta \in [0, 1]$, $\eta_L \geq \eta_{2L}$, $\eta_B \geq \eta_{2B}$ *the small platform's model is a convex optimization problem with respect to* τ_{HL}, s_{HL} *and the large platform's model is a convex optimization problem with respect to* τ_{HB}, s_{HB}. *Two platforms' optimal retail prices, optimal service levels and the manufacturer's optimal wholesale price are respectively*

$$\begin{aligned}
s^*_{HL} &= (T_3T_4 - T_1T_6)/(T_2T_6 - T_3T_5),\\
s^*_{HB} &= (T_1T_5 - T_2T_4)/(T_2T_6 - T_3T_5),\\
w^*_{HL} &= (X_1 - Q_1 + (Y_1 - Q_2)s^*_{HL} + (Y_4 - Q_3)s^*_{HB})/4,\\
w^*_{HB} &= (X_2 - Q_4 + (Y_2 - Q_5)s^*_{HL} + (Y_1 - Q_6)s^*_{HB})/2,\\
p^*_{HL} &= (X_1 + Q_1 + (Y_1 + Q_2)s^*_{HL} + (Y_4 + Q_3)s^*_{HB})/4,\\
p^*_{HB} &= (X_2 + Q_4 + (Y_2 + Q_5)s^*_{HL} + (Y_1 + Q_6)s^*_{HB})/2,
\end{aligned}$$

where $\eta_{2L} = \frac{\delta Y_1(1+3\beta)}{8} + \frac{(4(1-\beta)+Y_1\delta(1-\alpha)+\delta(1+3\beta))^2}{32(4-\delta)(1-\alpha)}$, $\eta_{2B} = \frac{\delta(3-\beta)Y_4}{16} + \frac{(4(1-\beta)+\alpha\delta Y_4)^2}{128}$.

From Proposition 4, it can be seen that the unit service costs need to meet certain conditions $\eta_L \geq \eta_{2L}$, $\eta_B \geq \eta_{2B}$, while the e-commerce platforms have low limits on unit service costs, which indicates that services can only be formed if the service costs reach certain levels. This is consistent with the actual situation. In the scenario R, if $T_4(T_3 + T_2) > T_1(T_5 + T_6)$, the small platform has better services and, at this time, small platforms may be more suitable for development through their own high-quality services; otherwise, the services provided by large platforms are better.

By substituting the above solutions into the profit functions, the optimal profits of the two platforms and the manufacturer are respectively

$$\begin{aligned}
\pi^*_{HL} &= \frac{1}{2}(Q_1 + Q_2s^*_{HL} + Q_3s^*_{HB})(D^*_{HL} + D^*_H) - (\frac{\delta}{4}(X_1 + Q_1 + (Y_1 + Q_2)s^*_{HL} + (Y_4 + Q_3)s^*_{HB}) + m)D^*_H\\
&\quad - \frac{\eta_L}{2}(s^*_{HL})^2 - k,\\
\pi^*_{HB} &= (Q_4 + Q_5s^*_{HL} + Q_6s^*_{HB})D^*_{HB} + (\frac{\delta}{4}(X_1 + Q_1 + (Y_1 + Q_2)s^*_{HL} + (Y_4 + Q_3)s^*_{HB}) + m)D^*_H\\
&\quad - \eta_B(s^*_{HB})^2 + k,\\
\pi^*_{HM} &= \frac{1}{4}(X_1 - Q_1 + 2(Y_1 - Q_2)s^*_{HL} + (Y_4 - Q_3)s^*_{HB})(D^*_{HL} + D^*_H) + \frac{1}{2}(X_2 - Q_4 + (Y_2 - Q_5)s^*_{HL}\\
&\quad + (Y_1 - Q_6)s^*_{HB})D^*_{HB}.
\end{aligned}$$

Where $D^*_{HB} = \frac{1}{2}(X_4 + 2\alpha\tau^*_{HL} - \tau^*_{HB} - \beta s^*_{HL} + (1-\beta)s^*_{HB})$,
$D^*_H = \frac{1}{4}(X_5 - 2(1-\alpha)\tau^*_{HL} + 2\alpha\tau^*_{HB} - (1+3\beta)s^*_{HL} + (3-\beta)s^*_{HB})$,
$D^*_{HL} = \frac{1}{4}(X_3 - 2(1-\alpha)\tau^*_{HL} + 2\alpha\tau^*_{HB} + (3+\beta)s^*_{HL} - (1+5\beta)s^*_{HB})$.

5. Numerical analysis

In this section, we report our numerical experiments by employing MATLAB 9.9.0 to analyze the impact of main parameters on service selections and members in the supply chain. The first class of parameters is the service cost efficiency $\eta_L, \ \eta_B$ since the small platform needs to weigh the benefits and service costs to choose an appropriate mode. The second class includes the service competition intensity β by comparing the changes in service competition caused by different services so that the small platform can weigh the impact of demand variation on profits. The third class includes the unit service fee m because its variation charged by the large platform may affect the small platform's profits and hence it is necessary to weigh its impact on revenues. The reference parameters were set in our experiments as $d = 10, \ k = 0, \ \lambda = 0.6, \ \theta = 0.5, \ \delta = 0.1, \ \alpha = 0.3$.

5.1. Service selection analysis

By comparing the profit difference between two service scenarios, we can analyze service selection strategies for the small platform to get some management enlightenment. We analyzed the selection strategies under different services $\eta_L, \ \eta_B$ by changing the unit product service fee m= 2, 5, 9 and the service competitive intensity $\beta = 0.1, 0.2, 0.3$, as shown in Figure 3, where region R denotes the region where the

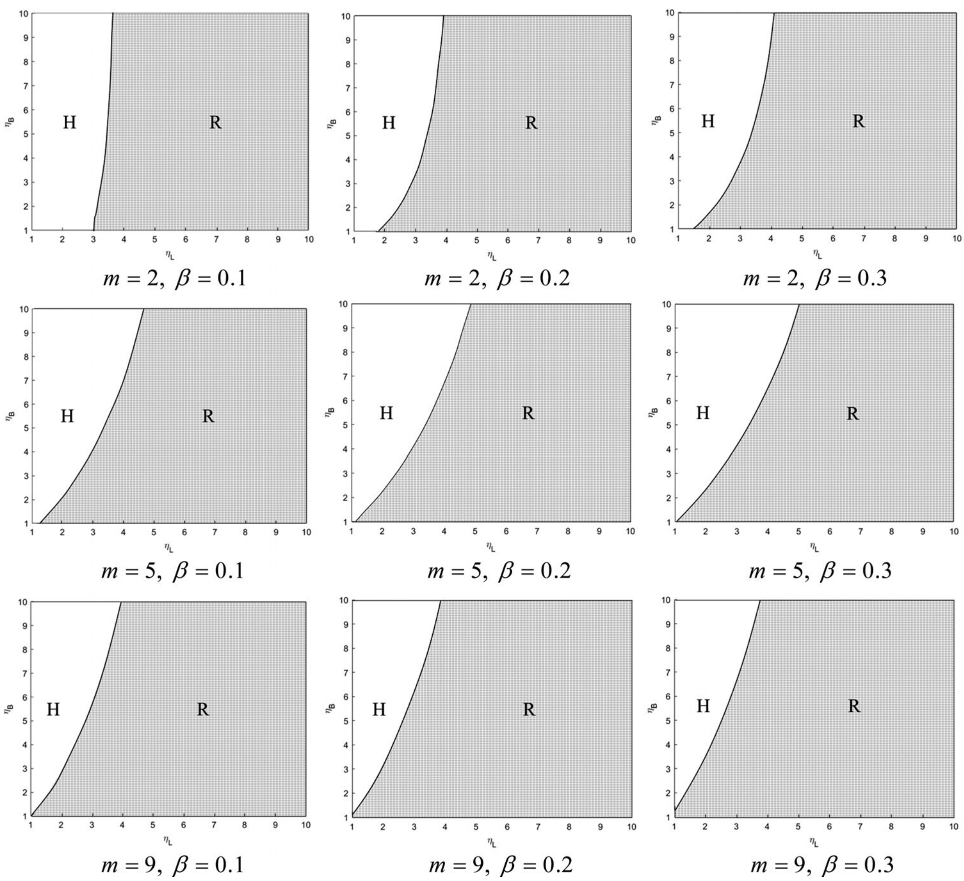

Figure 3. Service selection analysis.
Source: own research by Matlab.

service provided by the small platform is the optimal choice and region H denotes the region where the service provided by the large platform is the optimal choice.

From Figure 3, we observed that, if the unit product service cost is fixed, the small platform prefers to choose its own service as the service competition intensity increases. In particular, when the service competition intensity is low, it may promote service cooperation between two platforms to obtain high profits. Moreover, if the service competition intensity remains unchanged, by analyzing the impact of the small platform's unit product service cost, we found that, as the service cost increases, the area that the small platform chooses its own service expands, which indicates that the increase of unit service fee may compel the small platform to select its own services to avoid excessive expenditure.

We also investigated the service cost efficiencies of two platforms and found that, when the service cost efficiency of the small platform is moderate or low (namely, η_L is high), the impacts of unit product service fee, service competition intensity, and service cost efficiency of the large platform can be ignored and the small platform prefers to provide its own service for the agent. This may be because, when η_L is high, it needs to invest high in service so that the small platform has to set relatively high unit product price to gain more profits. Moreover, when the service cost efficiency of the small platform is high (namely, η_L is low), the small platform prefers to choose the large platform's service in the case that the unit service fee is low or the case that the unit service fee is moderate and the service cost efficiency of the large platform is much lower than the small platform; otherwise, the small platform prefers to provide its own service. This may be because, when the service cost efficiency of the small platform is high, it can reduce costs and have a high-level service. Hence, when the unit service fee is low, the small platform can pay a low cost to the large platform to obtain service for the agent to attract consumers to the self-operated channel; when the unit service fee is moderate or high, if the service cost efficiency of the large platform is low, it means that its service level is good and then it should choose the large platform's service for the agent channel.

5.2. Impact on supply chain members

We investigated the impact of service selection strategies of the small platform on supply chain members by setting the parameters $\eta_L = 5,\ \eta_B = 5,\ \beta = 0.1,\ m = 2,$ as shown in Figures 4–7.

The experimental results on the service cost efficiency of the small platform are shown in Figure 4. It can be observed that, for the small platform, its profit in two modes is monotonically decreasing as η_L increases, which reveals that, no matter what mode, low service cost efficiency may cause excessive capital expenditure to decrease profits, especially in the scenario H, the small platform not only has to pay capital to ensure sufficient service level in the self-operated channel, but also needs to pay service fee to the large platform. For the large platform, as η_L increases, it is getting more profitable to provide service by the large platform. For the manufacturer, its profit in both modes is decreasing as η_L increases and, to compare two modes, its profit is higher in the scenario R.

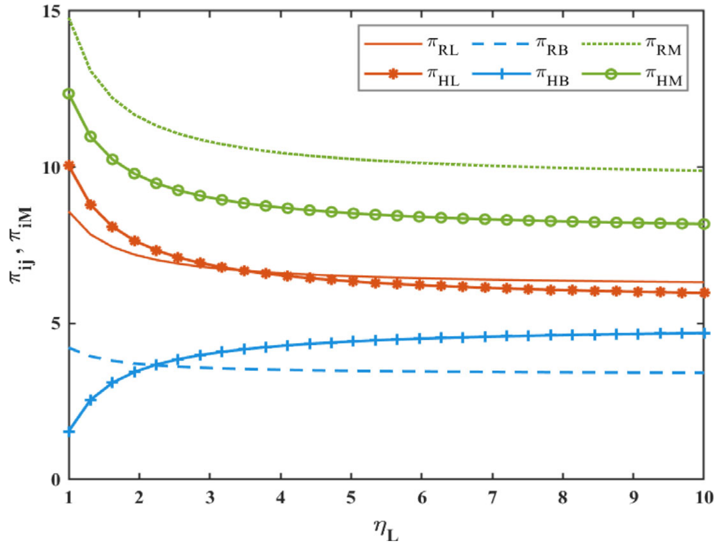

Figure 4. Combination of π_{ij} and η_L.
Source: own research by Matlab.

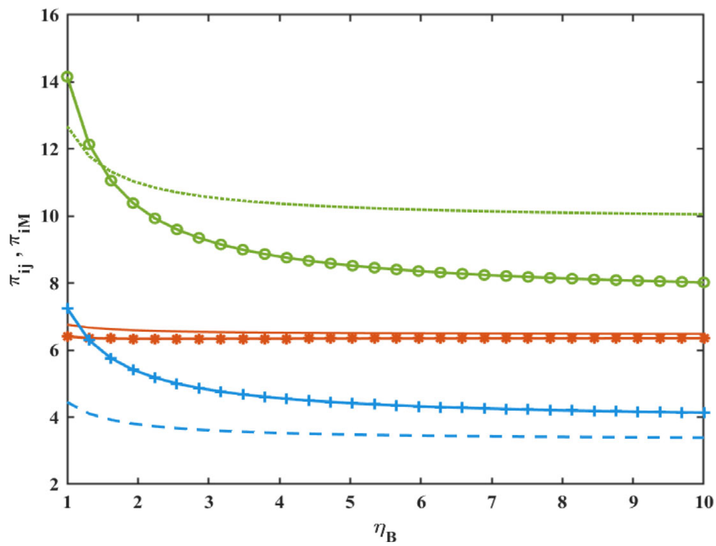

Figure 5. Combination of π_{ij} and η_B.
Source: own research by Matlab.

The experimental results on service cost efficiency of the large platform are shown in Figure 5. It can be observed that, for the small platform, as η_B increases, its profit in the scenario H grows fast, which indicates that the small platform can attract more customers to the agent channel through the large platform's services, but the scenario R can make the small platform obtain high profit. For the large platform, due to the impact of its own service cost efficiency, its profit in both scenarios is decreasing, which shows that low service cost efficiency is unfavorable and reduction of service efficiency may affect its profit. For the manufacturer, although its profit in both modes is decreasing, its profit is higher than the two platforms, which indicates that

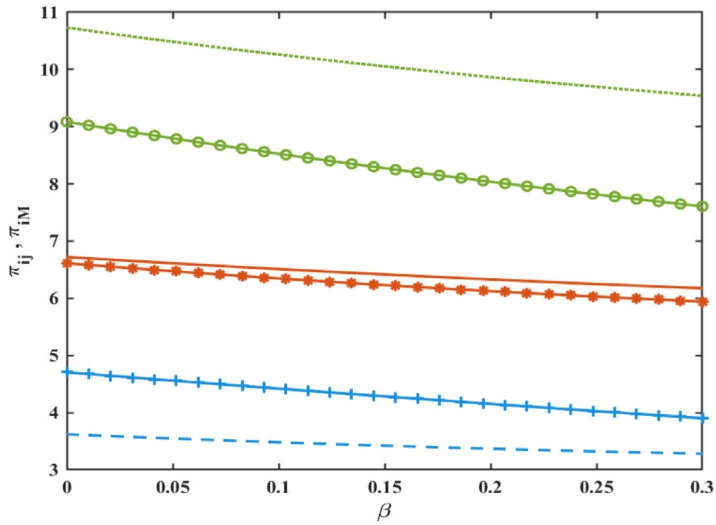

Figure 6. Combination of π_{ij} and β.
Source: own research by Matlab.

the reduction of service cost efficiency of the large platform also has a negative impact on the manufacturer.

The experimental results on service competition intensity are shown in Figure 6. It can be observed that, no matter what scenarios, each supply chain member's profit is decreasing as the service competition intensity increases, which indicates that fierce service competition is unfavorable to each member. Particularly, high service competition has the greatest impact on the manufacturer by significantly reducing its profit. This means that the platforms as leaders are fiercely competitive so that the demands decrease, while the manufacturer as a follower can only reduce the wholesale price to sell products, which results in decreasing the manufacturer's profit. In addition, we find that in either scenario, fierce competition is not conducive to the coordinated development of the supply chain.

The experimental results on unit service fee are shown in Figure 7. It can be observed that, in the scenario R, the profit of each member is not related to the unit service fee, while the profits of the small platform and the manufacturer are decreasing as m increases and the profit of the large platform is increasing firstly and decreasing after as m increases. This shows that, for the small platform, the increase of service expenditure may lead to the decrease of profit and, for the large platform, high service fee may reduce its profit. The manufacturer is more affected by the small platform because excessive service fee may lead to less demand for the small platform, which further makes it difficult for the manufacturer to sell more products.

In summary, we can find that the profits of each member in the supply chain are affected by service-related parameters. Fierce service competition and high unit service fee are detrimental to members, and higher service cost efficiency will have a negative impact on the platform's own profits, while adversely affecting manufacturers. Contrary to the conclusion of Fan et al. (2020) about price competition, it shows that strong price competition promotes supply chain coordination, while

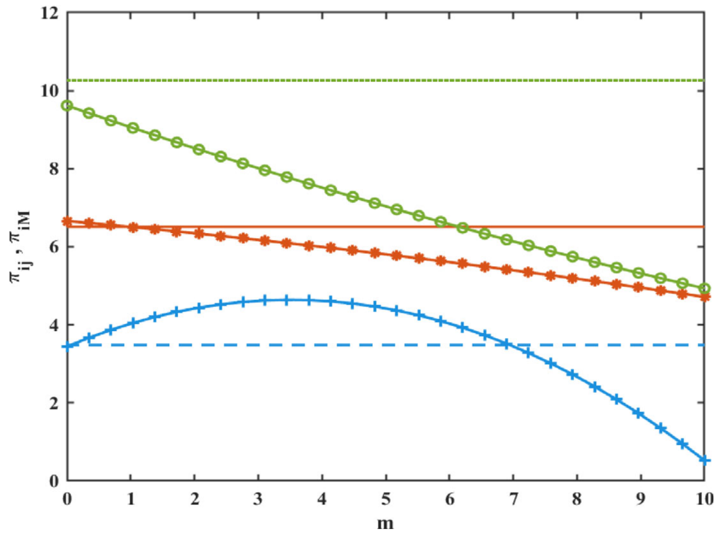

Figure 7. Combination of π_{ij} and m.
Source: own research by Matlab.

service competition is the opposite. Our results explain that reducing service competition and improving service cooperation can promote supply chain coordination.

6. Conclusions

We have studied the service selection strategies for the small platform settled in the large platform by constructing multi-leader-follower models in two scenarios with the platforms as leasers and the manufacturer as a follower. In order to solve the models effectively, we have discussed the convexity conditions for each model involved and, based on these theoretical results, the platforms and the manufacturer's optimal retail prices and the optimal service levels have been derived. We have further made numerical experiments to analyze the impacts of different service strategy choices on supply chain members.

Our numerical analysis shows that the increase in unit product service cost or service competition intensity may lead to the small platform being more inclined to choose its own service; when the service cost efficiency of the small platform is moderate or low, the small platform prefers to provide its own service for the agent channel; when the service cost efficiency of the small platform is high, it should choose the large platform to provide service in the case that the unit service fee is low or in the case that the unit service cost is moderate/high and the service cost efficiency of the large platform is much lower than the small platform. In addition, fierce service competition and high unit product service cost are unfavorable to each supply chain member, and high service cost efficiency may have a negative impact on profits for the platform itself and be detrimental to the manufacturer. And fierce competition is not conducive to the coordinated development of the supply chain in either scenario.

Our findings provide some managerial insights for e-commerce platforms that face service selection and channel coopetition in multi-channel coopetition supply chains. In the highly competitive e-commerce market, more and more e-commerce platforms are looking for cooperation. This paper provides an effective way to deepen cooperation between e-commerce platforms. And through the analysis of the conditions of service cooperation, our findings provide management opinions for further service selection of self-operated e-commerce platforms or merchants who have settled in hybrid e-commerce platforms and have their own platforms. However, there are several limitations to this research. For the theoretical study, the relevant assumptions were too strict, such as prices setting, if we take different pricing decision for the self-operated e-commerce platform, the theoretical model analysis could be more applicable; however, it would be much more difficult to analyse. Furthermore, our assumption of e-commerce platforms is limited, if we could study the several platforms' coopetition, the conclusion would be more general.

There are still some scopes for future research. Our first target focuses on using some famous e-commerce platforms to analyze their coopetition mechanism. In addition, service strategies under different power structures are also worth studying. In particular, when manufacturers are in leading positions or equal positions, comprehensive studies can provide references for enterprises.

Disclosure statement

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Appendix

Tables A1–A3 list the mathematical expressions of some key notations.

Table A1. Notations for Proposition 1–4.

Notation	Notation
$A = 1 - \alpha - 2\alpha^2$	$X_1 = (1 - \theta\lambda + 2\alpha\theta\lambda)d/A$
$Y_1 = (1 - \beta - 2\alpha\beta)/A$	$X_2 = (\alpha + \theta\lambda - 2\alpha\theta\lambda)d/A$
$Y_2 = (\alpha - \beta)/A$	$X_3 = (3 - 4\lambda + \theta\lambda)d$
$Y_3 = (1 - \alpha - 2\alpha\beta)/A$	$X_4 = \theta\lambda d$
$Y_4 = (1 + 2\alpha - 2\alpha\beta - 3\beta)/A$	$X_5 = (4\lambda - 3\theta\lambda - 1)d$

Table A2. Notations for Proposition 1–2.

Notation
$Z = (4 - \delta)(8(1 - \alpha) - \alpha^2(4 + \delta))$
$E_1 = (4(\delta(1 - \alpha)X_1 + 2X_3 + \alpha(4 - \delta)X_4 + (2 - \delta)X_5) + \alpha^2\delta(4 - \delta))/Z$
$E_2 = ((-\alpha^2\delta^2 + 4\delta(1 - \alpha + \alpha^2))Y_1 + 4(4 - \delta)(1 - \beta - \alpha\beta))/Z$
$E_3 = ((-\alpha^2\delta^2 + 4\delta(1 - \alpha + \alpha^2))Y_2 + 2(4 - \delta)(\alpha - 2\beta))/Z$
$E_4 = (\alpha(4 + \delta)E_1 + \alpha\delta X_1 + 4X_4)/8$
$E_5 = (\alpha(4 + \delta)E_2 + \alpha\delta Y_1 - 4\beta)/4$
$E_6 = (\alpha(4 + \delta)E_3 + \alpha\delta Y_2 + 2)/4$
$N_1 = (-2\alpha\delta Y_1 E_4 + (\delta(1 - \alpha)Y_1 + (4 - \delta)(1 - \beta))E_1 - \delta X_5 Y_1 - \delta(1 - \beta)X_1)/8$
$N_2 = (-\alpha\delta Y_1 E_5 + (\delta(1 - \alpha)Y_1 + (4 - \delta)(1 - \beta))E_2 - 2\delta(1 - \beta)Y_1 - 8\eta_L)/4$
$N_3 = (-\alpha\delta Y_1 E_6 + (\delta(1 - \alpha)Y_1 + (4 - \delta)(1 - \beta))E_3 - \delta(1 - \beta)Y_2 + \beta\delta Y_1)/4$
$N_4 = (2(2 + \alpha\delta Y_2)E_4 - (\delta Y_2(1 - \alpha) + \beta\delta)E_1 + \delta X_5 Y_2 - \beta\delta X_1)/8$
$N_5 = ((2 + \alpha\delta Y_2)E_5 - (\delta Y_2(1 - \alpha) + \beta\delta)E_2 + \delta(1 - \beta)Y_2 - \beta\delta Y_1)/4$
$N_6 = ((2 + \alpha\delta Y_2)E_6 - (\delta Y_2(1 - \alpha) + \beta\delta)E_3 - 2\beta\delta Y_2 - 4\eta_B)/4$

Table A3. Notations for Proposition 3–4.

Notation
$Q_1 = ((-\alpha^2\delta^2 + 4\delta(1 - \alpha + \alpha^2))X_1 + 8X_3 + 4\alpha(4 - \delta)X_4 + 4(2 - \delta)X_5 + 4m(-\alpha^2\delta + 4(1 - \alpha + \alpha^2)))/Z$
$Q_2 = ((-\alpha^2\delta^2 + 4\delta(1 - \alpha + \alpha^2))Y_1 - 4\alpha\beta(4 - \delta) + 16(1 - \beta) + 4\delta(1 + 3\beta))/Z$
$Q_3 = ((-\alpha^2\delta^2 + 4\delta(1 - \alpha + \alpha^2))Y_4 + 4\alpha(4 - \delta)(1 - \beta) + 16(1 - 3\beta) - 4\delta(3 - \beta))/Z$
$Q_4 = (\alpha(4 + \delta)Q_1 + \alpha\delta X_1 + 4(X_4 + \alpha m))/8$
$Q_5 = (\alpha(4 + \delta)Q_2 + \alpha\delta Y_1 - 4\beta)/8$
$Q_6 = (\alpha(4 + \delta)Q_3 + \alpha\delta Y_4 + 4(1 - \beta))/8$
$T_1 = (-2\alpha\delta Y_1 Q_4 + (\delta(1 - \alpha)Y_1 + \delta(1 + 3\beta) + 4(1 - \beta))Q_1 - \delta X_5 Y_1 + (\delta X_1 + 4m)(1 + 3\beta))/16$
$T_2 = (-2\alpha\delta Y_1 Q_5 + (\delta(1 - \alpha)Y_1 + \delta(1 + 3\beta) + 4(1 - \beta))Q_2 + 2\delta(1 + 3\beta)Y_1 - 16\eta_L)/16$
$T_3 = (-2\alpha\delta Y_1 Q_6 + (\delta(1 - \alpha)Y_1 + \delta(1 + 3\beta) + 4(1 - \beta))Q_3 + \delta(1 + 3\beta)Y_4 - \delta(3 - \beta)Y_1)/16$
$T_4 = (2(\alpha\delta Y_4 + 4(1 - \beta))Q_4 + (\delta(3 - \beta) - \delta(1 - \alpha)Y_4)Q_1 + \delta X_5 Y_4 + (\delta X_1 + 4m)(3 - \beta))/16$
$T_5 = (2(\alpha\delta Y_4 + 4(1 - \beta))Q_5 + (\delta(3 - \beta) - \delta(1 - \alpha)Y_4)Q_2 + \delta(3 - \beta)Y_1 - \delta(1 + 3\beta)Y_4)/16$
$T_6 = (2(\alpha\delta Y_4 + 4(1 - \beta))Q_6 + (\delta(3 - \beta) - \delta(1 - \alpha)Y_4)Q_3 + 2(\delta(3 - \beta)Y_4 - 16\eta_B))/16$

Next, we present the proofs of all propositions in the main paper.

Proof of Proposition 1. The Hessian matrix of π_{RM} with respect to w_R is

$$H = \begin{bmatrix} -4 + 4\alpha & 4\alpha \\ 4\alpha & -2 \end{bmatrix}.$$

This matrix is negative semidefinite when $\alpha \in [0, 0.5]$ and hence the lower-level objective function π_{RM} is concave in w_R. Since the lower-level constraints are linear, the lower-level model (9) is a convex optimization problem, which means that the stationary points of its objective function must be globally optimal solutions as long as the constraints are satisfied. By solving $\nabla_{\mathbf{w_R}} \pi_{RM} = 0$, we get a unique stationary point

$$w_{RL}^* = \frac{1}{4}(X_1 + 2Y_1 s_{RL} + 2Y_2 s_{RB} - 2\tau_{RL}),$$
$$w_{RB}^* = \frac{1}{2}(X_2 + 2Y_2 s_{RL} + Y_3 s_{RB} - \tau_{RB}).$$

If $\alpha \in [0, 0.5)$ and $\alpha \geq \beta$, we have Y_1-$Y_3 \geq 0$. To ensure the nonnegative conditions $w_{RL}^* \geq 0$ and $w_{RB}^* \geq 0$, it is sufficient to satisfy

$$\tau_{RL} \leq \tau_{1L}^* = \frac{X_1}{2} + Y_1 \underline{s}_L + Y_2 \underline{s}_B,$$
$$\tau_{RB} \leq \tau_{1B}^* = X_2 + 2Y_2 \underline{s}_L + Y_3 \underline{s}_B.$$

This completes the proof.

Proof of Proposition 2. The Hessian matrix of π_{RL} with respect to τ_{RL}, s_{RL} is

$$H = \begin{bmatrix} -\frac{(4-\delta)(1-\alpha)}{2} & \frac{(4-\delta)(1-\beta) + Y_1\delta(1-\alpha)}{4} \\ \frac{(4-\delta)(1-\beta) + Y_1\delta(1-\alpha)}{4} & -\frac{Y_1\delta(1-\beta)}{2} - 2\eta_L \end{bmatrix}$$

and the Hessian matrix of π_{RB} with respect to τ_{RB}, s_{RB} is

$$H = \begin{bmatrix} -1 & \frac{2 + \alpha\delta Y_2}{4} \\ \frac{2 + \alpha\delta Y_2}{4} & -\frac{\beta\delta Y_2}{2} - \eta_B \end{bmatrix}.$$

If $\alpha \in [0, 0.5)$, $\beta \in [0, \alpha]$, $\delta \in [0, 1]$, $\eta_B \geq \eta_{1B} = ((2 + \alpha\delta Y_2)^2 - 8\beta\delta Y_2)/16$, $\eta_L \geq \eta_{1L} = ((4-\delta)(1-\beta) - Y_1\delta(1-\alpha))^2/16(4-\delta)(1-\alpha)$, both of the above matrices are negative semidefinite and hence π_{RL} is concave in τ_{RL}, s_{RL} and π_{RB} is concave in τ_{RB}, s_{RB}. Since the constraints in both the small and the large platforms' models are linear, these two models are both convex optimization problems. Letting $\nabla\pi_{RL} = 0$, $\nabla\pi_{RB} = 0$, we obtain their stationary points

$$s_{RL}^* = (N_3N_4 - N_1N_6)/(N_2N_6 - N_3N_5), \qquad s_{RB}^* = (N_1N_5 - N_2N_4)/(N_2N_6 - N_3N_5),$$
$$\tau_{RL}^* = \frac{1}{2}E_1 + E_2 s_{RL}^* + E_3 s_{RB}^*, \qquad \tau_{RB}^* = E_4 + E_5 s_{RL}^* + E_6 s_{RB}^*.$$

The condition $Y_2(2\underline{s}_L + \underline{s}_B) \geq \max\{(E_1 - X_1)/2 + E_2 s_{RL}^* + E_3 s_{RB}^*,\ E_4 - X_2 + E_5 s_{RL}^* + E_6 s_{RB}^*\}$ can ensure their feasibility and so they are all globally optimal solutions. Substituting τ_{Rj}^*, s_{Rj}^* into w_{RL}^*, w_{RB}^*, we can get the optimal wholesale prices and, furthermore, we can get p_{RL}^*, p_{RB}^* by $p_{Rj} = w_{Rj} + \tau_{Rj}$. This completes the proof.

Proof of Proposition 3. The Hessian matrix of π_{HM} with respect to variables w_H is

$$H = \begin{bmatrix} -4 + 4\alpha & 4\alpha \\ 4\alpha & -2 \end{bmatrix}.$$

If $\alpha \in [0, 0.5)$, the above matrix is negative semidefinite and so π_{HM} is concave in w_H. Since the lower-level constraints are linear, the lower-level model (14) is a convex optimization problem. Solving $\nabla_{\mathbf{w_H}} \pi_{HM} = 0$, we obtain a stationary point

$$w_{HL}^* = \frac{1}{4}(X_1 + Y_1 s_{HL} + Y_4 s_{HB} - 2\tau_{HL}),$$
$$w_{HB}^* = \frac{1}{2}(X_2 + Y_2 s_{HL} + Y_1 s_{HB} - \tau_{HB}).$$

If $\alpha \geq \beta$, we have $Y_4 \geq 0$. To ensure the nonnegative conditions $w_{HL}^* \geq 0$, $w_{HB}^* \geq 0$, it is sufficient to satisfy

$$\tau_{HL} \leq \tau_{2L}^* = (X_1 + Y_1 \underline{s}_L + Y_4 \underline{s}_B)/2,$$
$$\tau_{HB} \leq \tau_{2B}^* = X_2 + Y_2 \underline{s}_L + Y_1 \underline{s}_B.$$

This completes the proof.

Proof of Proposition 4. The Hessian matrix of π_{HL} with respect to τ_{HL}, s_{HL} is

$$H = \begin{bmatrix} -\frac{(4-\delta)(1-\alpha)}{2} & \frac{4(1-\beta) + \delta((1-\alpha)Y_1 + (1+3\beta))}{8} \\ \frac{4(1-\beta) + \delta((1-\alpha)Y_1 + (1+3\beta))}{8} & \frac{\delta(1+3\beta)Y_1}{8} - \eta_L \end{bmatrix}$$

and the Hessian matrix of π_{HB} with respect to τ_{HB}, s_{HB} is

$$H = \begin{bmatrix} -1 & \frac{4(1-\beta) + \alpha\delta Y_4}{8} \\ \frac{4(1-\beta) + \alpha\delta Y_4}{8} & -2\eta_B + \frac{\delta(3-\beta)Y_4}{8} \end{bmatrix}.$$

If $\eta_L \geq \eta_{2L} = \delta Y_1(1+3\beta)/8 + (4(1-\beta) + Y_1\delta(1-\alpha) + \delta(1+3\beta))^2/32(4-\delta)(1-\alpha)$, $\alpha \in [0, 0.5)$, $\beta \in [0, \alpha]$, $\delta \in [0, 1]$, $\eta_B \geq \eta_{2B} = \delta(3-\beta)Y_4/16 + (4(1-\beta) + \alpha\delta Y_4)^2/128$, both of the above matrices are negative semidefinite and hence π_{HL} is concave in τ_{HL}, s_{HL} and π_{HB} is concave in τ_{HB}, s_{HB}. Since the constraints in both the small and the large platforms' models are linear, these two models are both convex optimization problems. Solving $\nabla \pi_{HL} = 0$, $\nabla \pi_{HB} = 0$, we obtain their stationary points

$$s_{HL}^* = (T_3 T_4 - T_1 T_6)/(T_2 T_6 - T_3 T_5), \qquad s_{RB}^* = (T_1 T_5 - T_2 T_4)/(T_2 T_6 - T_3 T_5),$$
$$\tau_{HL}^* = \frac{1}{2}(Q_1 + Q_2 s_{HL}^* + Q_3 s_{HB}^*), \qquad \tau_{HB}^* = Q_4 + Q_5 s_{HL}^* + Q_6 s_{HB}^*.$$

The condition $Y_2 \underline{s}_L + Y_1 \underline{s}_B \geq \max\{Q_1 - X_1 + Q_2 s_{RL}^* + Q_3 s_{RB}^*,\ Q_4 - X_2 + Q_5 s_{RL}^* + Q_6 s_{RB}^*\}$ can ensure their feasibility and so they are all globally optimal solutions. Substituting τ_{Hj}^*, s_{Hj}^* into w_{HL}^*, w_{HB}^*, we can get the optimally wholesale prices and, furthermore, we can get p_{HL}^*, p_{HB}^* by $p_{Hj} = w_{Hj} + \tau_{Hj}$. This completes the proof.