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Nash-stackelberg game perspective on pricing strategies for ride-hailing and aggregation platforms under bundle mode

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A B S T R A C T

The growing popularity of aggregation platforms has attracted widespread attention in the ride-hailing market in recent years. In order to obtain additional orders by charging commissions and slotting fees, many ride-hailing platforms choose to bundle with aggregation platforms. Unlike traditional reseller electronic channels, the bundle channels may affect pricing of platforms, service levels of drivers, market demands and they may further impact on profits. These different attitudes raise an interesting and key question about the influence of bundle channels in ride-hailing platforms. In this paper, we propose an analytical framework for pricing strategies of ride-hailing and aggregation platforms under bundle mode and analyze their pricing process from the perspective of Nash and Stackelberg games, where the platforms serve as leaders to determine optimal prices through Nash equilibrium and the drivers serve as followers to provide optimal service levels. Through sensitivity analysis of service levels and costs, we capture the distribution trends of profits between the platforms. Based on some numerical examples and results analysis, some interesting managerial insights on pricing of ride-hailing and aggregation platforms are gained.

1. Introduction

With the rise of aggregation platforms in recent years, the shared mobility ecosystem is expected to be reinvented and the ride-hailing platforms are gradually shifting to technology investment to promote platform upgrades, improve user experience, and bring back their business essence. Through aggregating ride-hailing services, rather than operating new platforms, the aggregation platform can avoid head-on competition with these ride-hailing platforms and therefore significantly reduce costs as it does not need to invest everlasting capital to attract users. Using these bundle services in aggregation platforms, users no longer need to download, install and register multiple ride-hailing apps. Embedding a one-click function in the display page of a ride-hailing platform and making multi-platform multi-mode calls at the same time can help users call faster and thereby reduce their waiting times. Nowadays, ride-hailing service aggregation platforms are becoming a trend and gaining prominence during peak hours.

Some Chinese companies firstly set examples in the ride-hailing market. DiDi Chuxing and Amap (Alibaba-owned AutoNavi) have built aggregation platforms through their information capabilities and technical background. Amap aggregates more than 40 suppliers such as DiDi, Shenzhou, Shouqi and Caocao, and provides a variety of models and vehicle types across the country. As the first travel platform with over 100 million daily active users in China, Amap is able to provide extensive user access for ride-hailing platforms and boost their online refinement operations. DiDi Chuxing is both a ride-hailing platform and an aggregation platform that can access some services like Landao Chuxing, Liangzi Chuxing, and Henghao Yongche. The aggregation platform gives riders the possibility to go shopping around at the best price. Before making an order, riders

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can first compare prices through Amap and then choose the most preferred one by considering the service level and cost. Internet platforms with large flows choose the aggregation model, only require the minimal cost, and can realize traffic cash through information technologies to coordinate and match related services.

Bundle mode research makes a lot of sense for travelers, practitioners, enterprises, and society. Ride-hailing platforms choosing the aggregation model may greatly save costs to obtain new flow. Similarly, the aggregation platform needs only to coordinate, integrate, linkage of such external services, to attract consumers. By fully aggregating the existing capacity in the ride-hailing market, it can effectively reduce vehicle idleness, bringing about more improvement in urban travel. If the aggregation model is not well received, dozens of ride-hailing platforms are frantically developing their own apps and subsidies, and throwing the industry and society into chaos. The aggregation model, to a large extent, can improve the viscosity of users. However, for aggregation platforms, by providing high-frequency life services to consumers who are closely related to users, the user stickiness to large platforms may increase user usage and enhance the possibility that other platforms will be replaced. This increased user stickiness has an impact on user retention and activity of ride-hailing platforms.

This paper provides an analytical framework for ride-hailing and aggregation platforms through two Stackelberg games in the vertical, where the driver group serves both platforms on the service level and the platforms as leaders dictate the order prices for the driver group. We set up a Nash equilibrium in the horizontal between the ride-hailing platform and the aggregation platform to obtain optimal prices. We also analyze two pairs of parameters for the change in platform profits, namely, the cost coefficients of service level and costs.

There is little literature on bundle mode for ride-hailing and aggregation platforms, and even less research on models. This paper aims to fill this research gap in pricing and multi-channel layouts of ride-hailing and aggregation platforms. The main contributions of this paper are summarized as follows:

(1) We dictate that the bundle service on pricing is common in practice, but it has not yet received sufficient research attention. This paper focuses on the reactions in terms of prices and profits when the ride-hailing platform and the aggregation platform involve the bundle service.
(2) Observing that the ride-hailing platform is gaining increasing orders in the bundle mode, we consider a framework in which the driver group provides services to the ride-hailing platform and the aggregation platform respectively. Each platform serves as a leader in determining the price and influencing service level decisions for the driver group. We focus on the effect of introducing bundle services on direct selling. In addition, an equilibrium between the ride-hailing platform and the aggregation platform is explored to maximize their profits.
(3) For ride-hailing platforms, to adopt or not to adopt the bundle option is a key in introducing the bundle service. One main difference between unbundled and bundled formats is that there is an additional price, whereas in the bundle option it is decided by the ride-hailing platform, but needs to share a certain fraction of the revenue with the aggregation platform for providing access. We test two groups of parameters (two cost coefficients of service levels and two costs) and obtain boundary lines of profit competition between the ride-hailing and aggregation platforms.

The remainder of the paper is organized as follows. Section 2 reviews some recent studies on pricing and service level modes, slotting fees and revenue sharing, and game models. Section 3 introduces the bundle mode, basis notations and assumptions. Section 4 describes the decision-making process for ride-hailing and aggregation platforms, as well as the Nash equilibrium between these platforms. Section 5 gives some examples and numerical analysis. Finally, Section 6 gives some conclusions and future work.

2. Literature review

In this section, we describe the relationship between this research and some related streams of literature, which include pricing and service level modes, slotting fees and revenue-sharing, and game models.

2.1 Pricing and service level modes

This research belongs to a specific stream of pricing strategies. Interestingly, dynamic or surge pricing is controversial and has been questioned by riders, drivers, scholars, and policymakers. In contrast, the research by Banerjee et al. (2015) studies a pricing problem through a queueing-theoretic economic model. They show that dynamic pricing does not provide more payoff than static pricing with a large market limit. Research on this problem proceeds from the price differences between a conventional retailer channel and a direct online channel (Huang & Swaminathan, 2009; Matsui, 2017). A key distinction between no bundle and bundle formats is that there is an additional price, whereas in the bundle option they are decided by the ride-hailing platform, but that price is available on the aggregation platform. On the other hand, there is few research on non-discriminating pricing policy by manufacturers (Fruchter & Tapiero, 2005). Additionally, service level plays a strategic role in a dual-channel competitive market. Retail services have significant effects on customers' channel choice, demand, and loyalty (Littler & Melanthiou, 2006; Yan & Pei, 2011). Dumrongsiri et al. (2008) show that an increase in retailer's service quality may raise manufacturer's profit in dual-channel and consumer service sensitivity may benefit both parties in the dual-channel.

2.2 *Slotting fees and revenue-sharing*

Slotting fees and revenue-sharing contracts are two pricing instruments on aggregation platforms. Generally speaking, slotting fees are one-time charges that manufacturers pay to place their products on retail shelves. In this paper, the platform usage fee's analogy to slotting fee seems very appropriate. Bloom et al. (2000) summarize two earlier viewpoints regarding the role of slotting fees: product quality (Lariviere & Padmanabhan, 1997; Sullivan, 1997) and empty shelves (Marx & Shaffer, 2010). More recently, a new viewpoint argues that slotting fees arise from the operational costs or vertical margin differences (Dhar, 2013; Kuksov & Pazgal, 2007). In China's electronics retail market, slotting fees have long been criticized for creating unfair competition (Wang et al., 2012). Li (2009) analyzes various formats and origins of slotting fees in retail business. Moreover, the fixed-ratio revenue-sharing contract is the most common scheme studied so far to solve the profit assignment problem (Bart et al., 2021; Giannoccaro & Pontrandolfo, 2004). Wang et al. (2004) study the revenue-sharing contract between Amazon and its sellers on its platform, but they ignore slotting fees and the sellers can directly sell their products. Intuitively, slotting fees in our case are to cover the cost of a mini-store in the retail platform.

2.3 *Stackelberg game and Nash equilibrium*

Several studies indicate that the game schemes have a greater impact on competition outcomes and supply chain performance. In this paper, we consider two types of game schemes, namely, the Stackelberg game and Nash game. The Nash game allows us to deal with another supply-chain structure, in which the supplier and the retailer are equally powerful. Mixed equilibrium has been proposed as a consequence to study the equilibration behavior of multiple players in the ride-hailing system (Ban et al., 2019; Di & Ban, 2019). The Stackelberg game depicts a common supply chain system in reality, in which the platform is more powerful than the driver group. Many studies on pricing strategies have bi-level programs to assess the effects of transportation policies on traffic flows and system performance. Commonly, the decisions made by policy-makers or operators reside in the upper-level, and travelers respond through an equilibrate adjustment process in the lower-level (Yang & Bell, 2001). The Stackelberg game provides a good perspective to integrate the ride-hailing platform and users (both drivers and riders) in the transportation system. The diversity of objective functions varied in response to different decisions. The main reason for minimizing the total generalized travel costs rather than maximizing the overall occupancy ratio or minimizing the total number of solo drivers is that the latter two objectives may result in several optimal solutions, which does not help with decision-making (Di et al., 2018; Yang & Bell, 1997; Zhao et al., 2016).

3. Basic setting

In this section, we give a rough picture of the bundle mode. Notations and some assumptions as the basis of this paper are also introduced.

3.1. *Model description*

The order sales system consists of a ride-hailing platform, an aggregation platform, and a driver group. Price and service level are core factors interacting among those three stakeholders. There are two Stackelberg games where the driver group serves each platform respectively on the service levels and each platform as a leader dictates the order prices for the driver group. The two platforms aim at a Nash equilibrium to obtain optimal prices, as illustrated in Fig. 1.

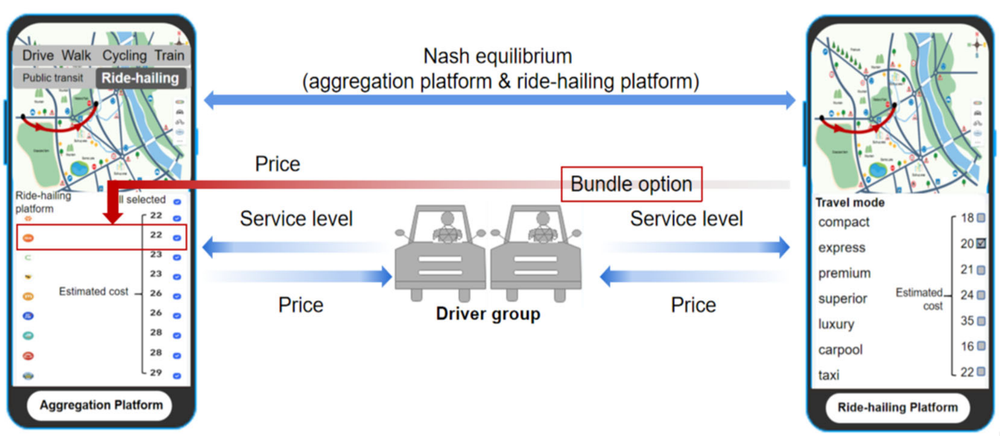

Fig. 1. Structure of the bundle mode

The ride-hailing platform bundles its partial business to the aggregation platform. On the basis that both platforms keep the original channel with the driver, there is an additional sales channel established by the aggregation platform to provide orders for the ride-hailing platform. A Stackelberg game is built to capture prices of the bundle channel and the direct channel jointly for the ride-hailing platform in the upper-level and the service levels by the driver group in the lower-level. Another Stackelberg game between the aggregation platform (leader) and the driver group (follower) determines the price in the upper-level and the service levels in the lower-level. The aggregation platform charges the ride-hailing platform commission and slotting fees. The competition between two platforms is formulated by a Nash game.

3.2. Assumptions

We make the following assumptions as the basis of this paper:

A1: The marginal cost of the order is zero.
A2: All orders from the ride-hailing platform are homogeneous.
A3: The drivers service both the aggregation platform and the ride-hailing platform.

The assumption **A1** literally describes a situation where an additional unit can be produced without increasing the total cost of production. Offering another unit of an order has zero marginal cost when the order is non-rivalrous, which means it is possible for a rider to get an order without impairing the ability of others to simultaneously consume it as well. **A2** indicates that the ride-hailing platform offers the same orders through the aggregation platform and its own channel. **A3** means that drivers are multi-homing for both the aggregation platform and the ride-hailing platform.

4. Mathematical model

Assume that demand functions are linear in prices and service level, which have been widely adopted. That is, the order demand decreases with the rise of price and increases with the rise of service level on its own channel. Meanwhile, this demand grows with the rise of price and falls with the rise of service level on rival channels (Dan et al., 2012; Gurnani et al., 2007; Wei et al., 2020). Let D_1 and D_2 be the base demands of the ride-hailing platform and the aggregation platform, respectively. The parameter α measures the price substitution of its own channel. The parameter β is the cross-price substitution of the rival channel. Besides, the parameter γ measures the demand sensitivity of its own service level. The parameter δ measures the service level sensitivity of another platform. Suppose that $0 \leq \beta \leq \alpha \leq 1$ and $0 \leq \delta \leq \gamma \leq 1$, where $\alpha \geq \beta$ means that the ownership price effect is prior to the cross-price effect, while $\gamma \geq \delta$ means that the ownership service level effect is prior to the cross-service level effect. In the bundle mode, the ride-hailing platform bundles onto the aggregation platform, which means that the ride-hailing platform is going to seize the market share from the aggregation platform. Let p_r and p_b be the prices of the direct and bundle channels of the ride-hailing platform, respectively. Let p_a be the price of the direct channel of the aggregation platform. Denote by s_r and s_a the driver group's service levels to the ride-hailing platform and the aggregation platform, respectively, with $s_r, s_a \in [s_l, s_h]$. Both p_b and p_r grow with the rise of s_r or the fall of s_a. Moreover, as s_a rises, the price p_a goes up, which results the decline of p_r to deal with this price competition. Thus, the demand function of the direct channel of the ride-hailing platform is given by

$$D_r = D_1 - \alpha p_r + \beta(p_b + p_a) + \gamma s_r - \delta s_a. \tag{1}$$

Let $\theta \in [0,1]$ be the potential proportion of orders that the ride-hailing platform acquires from the aggregation platform. The smaller θ is, the riders are more loyal to the aggregation platform. The base demand of the bundle channel of the ride-hailing platform is θD_2. Then, the demand function of the bundle channel of the ride-hailing platform is given by

$$D_b = \theta D_2 - \alpha p_b + \beta(p_r + p_a) + \gamma s_r - \delta s_a. \tag{2}$$

Thus, the total demand of the ride-hailing platform is $D_r + D_b$. Note that the base demand of the direct channel of the aggregation platform is $(1-\theta)D_2$. Hence, the demand function of the aggregation platform is

$$D_a = (1-\theta)D_2 - \alpha p_a + \beta(p_r + p_b) + \gamma s_a - \delta s_r. \tag{3}$$

Thus, the profit of the driver group from the ride-hailing platform is

$$w_r(p_r - c_r)D_r + w_r(p_b - c_r)D_b. \tag{4}$$

Correspondingly, the profit of the driver group from the aggregation platform is

$$w_a(p_a - c_a)D_a. \tag{5}$$

The driver group costs $\eta_r s_r^2/2$ and $\eta_a s_a^2/2$ to obtain orders from the ride-hailing platform and the aggregation platform, respectively. Therefore, the utility of the driver group is

$$\pi_d = w_r(p_r - c_r)D_r + w_r(p_b - c_r)D_b + w_a(p_a - c_a)D_a - \frac{1}{2}\eta_r s_r^2 - \frac{1}{2}\eta_a s_a^2. \quad (6)$$

For given prices $p_r \geq c_r$, $p_b \geq c_r$ and $p_a \geq c_a$, the driver group aims to obtain the optimal service levels by maximizing its utility. It is clear that π_d is jointly quadratic concave in s_r and s_a. Using the first-order optimality conditions, we obtain the optimal service level offered to the ride-hailing platform as

$$\bar{s}_r = \frac{\gamma}{\eta_r}\omega_r(p_r + p_b - 2c_r) - \frac{\delta}{\eta_r}\omega_a(p_a - c_a) \quad (7)$$

and the optimal service level offered to the aggregation platform as

$$\bar{s}_a = \frac{\gamma}{\eta_a}\omega_a(p_a - c_a) - \frac{\delta}{\eta_a}\omega_r(p_r + p_b - 2c_r). \quad (8)$$

We can further obtain

$$\partial\bar{s}_r/\partial p_r > 0,\ \partial\bar{s}_r/\partial p_b > 0,\ \partial\bar{s}_r/\partial p_a < 0, \quad (9)$$
$$\partial\bar{s}_a/\partial p_r < 0,\ \partial\bar{s}_a/\partial p_b < 0,\ \partial\bar{s}_a/\partial p_a > 0. \quad (10)$$

These results indicate that, the driver group's best response service level for the ride-hailing platform increases with the rise of p_r or p_b, and decreases with the rise of p_a. A rise in price prompts the platform to improve its service level for the lack of demand. Accordingly, it is necessary to enhance the service level covering a previous shortage of the profit. On the contrary, p_b, p_r increase with the little fall in $\bar{s}_a$ and p_a increases with the decline in $\bar{s}_r$. A rise in price of the rival platform brings about the demand of its platform growing accordingly, which also boosts the profit. For the service level set by the platform, it does not need to be as high as before to attract rider flows. Thus, we update the demand functions as

$$\overline{D}_r = D_1 - \alpha p_r + \beta(p_b + p_a) + \gamma\overline{s}_r - \delta\overline{s}_a, \quad (11)$$
$$\overline{D}_b = \theta D_2 - \alpha p_b + \beta(p_a + p_r) + \gamma\overline{s}_r - \delta\overline{s}_a, \quad (12)$$
$$\overline{D}_a = (1-\theta)D_2 - \alpha p_a + \beta(p_r + p_b) + \gamma\overline{s}_a - \delta\overline{s}_r. \quad (13)$$

When the ride-hailing platform bundles into the aggregation platform, they are simultaneously competitive and cooperative. The aggregation platform provides the channel for the ride-hailing platform to increase order volume and increases its revenue by charging the revenue commission and slotting fees. Let $\lambda \in (0,1)$ be the commission ratio. The revenue of the aggregation platform due to the transaction volume is $\lambda p_b \overline{D}_b$. Let $\sigma \geq 0$ be the slotting fee including a fixed technical service fee and a fixed deposit. Since $1 - w_r$ is the revenue sharing ratio for the ride-hailing platform, to determine the prices p_b and p_r, the ride-hailing platform's profit-maximization model is

$$\max_{p_r \geq c_r,\, p_b \geq c_r} \pi_r = (1 - w_r)\left((p_r - c_r)\overline{D}_r + (p_b - c_r)\overline{D}_b\right) - \lambda p_b \overline{D}_b - \sigma. \quad (14)$$

Since the revenue sharing ratio of the aggregation platform is $1 - w_a$, the aggregation platform's profit-maximization model is

$$\max_{p_a \geq c_a} \pi_a = (1 - w_a)(p_a - c_a)\overline{D}_a + \lambda p_b \overline{D}_b + \sigma. \quad (15)$$

In the competition between the ride-hailing platform and the aggregation platform, each platform selects its pricing policy in a non-cooperative manner, seeking to maximize its interests at a maximal profit until an equilibrium is achieved. Recall that a pricing policy (p_r^*, p_b^*, p_a^*) constitutes a Nash equilibrium if $\pi_r(p_r^*, p_b^*, p_a^*) \geq \pi_r(p_r, p_b, p_a^*)$, $\forall\, p_r, p_b \geq c_r$, and $\pi_a(p_r^*, p_b^*, p_a^*) \geq \pi_a(p_r^*, p_b^*, p_a)$, $\forall\, p_a \geq c_a$.

In what follows, for simplicity, we denote by

$$K_1 = \gamma^2/\eta_r + \delta^2/\eta_a, \quad K_2 = \gamma\delta/\eta_r + \gamma\delta/\eta_a, \quad K_3 = \gamma^2/\eta_a + \delta^2/\eta_r, \quad (16)$$

$$L_1 = \frac{(1-w_r)(\alpha c_a - \beta c_r - 2K_1 w_r c_r) - (1-w_r-\lambda)(\theta D_2 - 2K_1 w_r c_r + K_2 w_a c_a)}{(1-w_r-\lambda)(K_2 w_a - \beta)}, \tag{17}$$

$$L_2 = \frac{(\beta + K_1 w_r)(2-2w_r-\lambda)}{(1-w_r-\lambda)(K_2 w_a - \beta)}, \tag{18}$$

$$L_3 = \frac{(1-w_a)\big(\beta - K_2 w_r + 2L_2(K_3 w_a - \alpha)\big)}{(1-w_a)\big(K_2 w_r - \beta + 2L_4(\alpha - K_3 w_a)\big) + \lambda(K_2 w_a - \beta)}, \tag{19}$$

$$L_4 = \frac{2(K_1 w_r - \alpha)}{K_2 w_a - \beta}, \tag{20}$$

$$L_5 = \frac{(1-w_a)\big((1-\theta)D_2 + \alpha(c_a - 2L_1) + 2K_2 w_r c_r + 2(L_1 - c_a)K_3 w_a\big)}{(1-w_a)\big(K_2 w_r - \beta + 2L_4(\alpha - K_3 w_a)\big) + \lambda(K_2 w_a - \beta)}. \tag{21}$$

We further make the following assumption.

Assumption 1. $\lambda < 1 - w_r,\ \alpha > \max\left\{\frac{2-2w_r-3\lambda/2}{4(1-w_r-\lambda)} + K_1 w_r, 4(\beta + K_1 w_r)^2 + K_1 w_r, K_3 w_a\right\}$.

Proposition 1. Under Assumption 1, the optimal prices of the direct channel of the ride-hailing platform, the bundle channel, and the direct channel of the aggregation platform are respectively given by

$$\begin{aligned} p_r^* = \big(&(1-w_r)(D_1 + \alpha c_r - \beta c_r - 4K_1 w_r c_r + K_2 w_a c_a) + L_5(2-2w_r-\lambda)(\beta + K_1 w_r) \\ &+ (1-w_r)(\beta - K_2 w_a)(L_1 + L_2 L_5 + L_4 L_5 + L_3 L_4 L_5)\big) \\ &/\big(L_3(\beta + K_1 w_r)(2w_r - \lambda - 2) + 2(1-w_r)(\alpha - K_1 w_r) \\ &+ L_3(1-w_r)(L_2 + L_3 L_4)(K_2 w_a - \beta)\big), \end{aligned} \tag{22}$$

and

$$p_b^* = L_5 + L_3 p_r^*, \quad p_a^* = L_1 + L_4 L_5 + (L_2 + L_3 L_4) p_r^*. \tag{23}$$

Moreover, the service levels provided by the driver group to the ride-hailing platform and the aggregation platform are respectively given by

$$s_r^* = \frac{\gamma}{\eta_r} w_r (L_5 + (L_3 + 1)p_r^* - 2c_r) - \frac{\delta}{\eta_r} w_a (L_1 + L_4 L_5 + (L_2 + L_3 L_4)p_r^* - c_a), \tag{24}$$

$$s_r^* = \frac{\gamma}{\eta_a} w_a (L_1 + L_4 L_5 + (L_2 + L_3 L_4)p_r^* - c_a) - \frac{\delta}{\eta_a} w_r (L_5 + (L_3 + 1)p_r^* - 2c_r). \tag{25}$$

Proof. First of all, we can show that π_r is jointly quadratic concave in p_r and p_b, while π_a is quadratic concave in p_a. In fact, the Hessian matrix of π_r with respect to p_b and p_r is

$$\partial^2 \pi_r = \begin{bmatrix} 2(1-w_r)(K_1 w_r - \alpha) & (2-2w_r-\lambda)(\beta + K_1 w_r) \\ (2-2w_r-\lambda)(\beta + K_1 w_r) & 2(1-w_r-\lambda)(K_1 w_r - \alpha) \end{bmatrix}. \tag{26}$$

The first order principal minor of Hessian matrix $2(1-w_r)(K_1 w_r - \alpha) < 0$. By Assumption 1, we have $(4\alpha - 4K_1 w_r - 1)(1 - w_r - \lambda) > 1 - w_r - \frac{\lambda}{2} > 0$ and $1 - w_r > 1 - w_r - \frac{\lambda}{2} > 0$. Then, we have

$$(4\alpha - 4K_1 w_r - 1)(1-w_r-\lambda)(1-w_r) > \left(1 - w_r - \frac{\lambda}{2}\right)^2, \tag{27}$$

which implies $4(1-w_r)(\alpha - K_1 w_r)(1-w_r-\lambda) > (4\alpha - 4K_1 w_r - 1)(1-w_r-\lambda)(1-w_r) > \left(1 - w_r - \frac{\lambda}{2}\right)^2$. Since $\alpha - K_1 w_r > 4(\beta + K_1 w_r)^2$, we have

$$4(1-w_r)(\alpha - K_1 w_r)^2(1-w_r-\lambda) - (2-2w_r-\lambda)^2(\beta + K_1 w_r)^2 > 0. \tag{28}$$

Thus, the Hessian matrix of π_r with respect to p_b and p_r is a negative definite matrix, which means that π_r is concave in p_b, p_r. Furthermore, since

$$\nabla_{p_a}\pi_a = (1-w_a)((1-\theta)D_2 - 2\alpha p_a + \alpha c_a + \beta(p_r+p_b) - K_2 w_r(p_r+p_b-2c_r) + 2K_3 w_a(p_a-c_a)) + \lambda p_b(\beta - K_2 w_a). \quad (29)$$

The Hessian matrix of π_a with respect to the variable p_a is $\partial^2_{p_a}\pi_a = 2(1-w_a)(K_3 w_a - \alpha) < 0$. Hence, π_a is a concave function with respect to p_a.

The above result indicates that both platforms' models are convex optimization problems, which means that their stationary points are necessarily optimal solutions. By direct calculations, we can obtain the conclusion. ☐

Denote by

$$\overline{p}_r = ((1-w_r)(D_1 + \alpha c_r + \beta(p_a + 2p_b - c_r) + 2K_1 w_r(p_b - 2c_r) - K_2 w_a(p_a - c_a)) - \lambda(K_1 w_r + \beta))/(2(1 - w_r)(\alpha - K_1 w_r)), \quad (30)$$

$$\overline{p}_b = ((1-w_r)(\theta D_2 + \alpha c_r + \beta(p_a + 2p_r - c_r) + 2K_1 w_r(p_r - 2c_r) - K_2 w_a(p_a - c_a)) - \lambda(K_1 w_r - \alpha))/(-(1 - w_r)(3\alpha + 2K_1 w_r)), \quad (31)$$

$$\overline{p}_a = ((1-w_a)((1-\theta)D_2 - 2(\alpha - w_a K_3)p_a + (\alpha - 2w_a K_3)c_a + (\beta - K_2 w_r)(p_r + p_b) + 2K_2 w_r c_r)) + \lambda p_b(\beta - K_2 w_a))/(2(1-w_a)(\alpha - w_a K_3)). \quad (32)$$

Under the assumption that $\beta < \min\{K_2 w_a, K_2 w_r\}$, we have following results: If $c_r \le p_r < \overline{p}_r$, then $\partial\pi_r^*/\partial p_r > 0$; if $p_r > \overline{p}_r$, then $\partial\pi_r^*/\partial p_r < 0$. Furthermore, if $c_r \le p_b < \overline{p}_b$, then $\partial\pi_r^*/\partial p_b > 0$; if $p_b > \overline{p}_b$, then $\partial\pi_r^*/\partial p_b < 0$. Moreover, if $0 \le p_b + p_r - 2c_r \le \lambda/(1-w_r) < 1$, then $\partial\pi_r^*/\partial p_a > 0$; if $p_r + p_b - 2c_r \le \lambda/(1-w_r) < 1$, then $\partial\pi_r^*/\partial p_a < 0$. On the other hand, we have $\partial\pi_a^*/\partial p_r < 0$ and $\partial\pi_a^*/\partial p_r < 0$. If $c_a \le p_a < \overline{p}_a$, then $\partial\pi_a^*/\partial p_a > 0$; if $p_a > \overline{p}_a$, then $\partial\pi_a^*/\partial p_a < 0$.

The above results show that the ride-hailing platform's profit always decreases with increasing p_a and the aggregation platform's profit always decreases with the rise of rival channel prices p_r and p_b. With the rise of p_r and p_b, the profit of the ride-hailing platform grows and peaks at $\overline{p}_r$ and $\overline{p}_b$, followed by the declining profit instead. Similarly, with the increase of p_a, the profit of the aggregation platform grows and peaks at $\overline{p}_a$, followed by the decreasing profit instead.

5. Numerical results and analysis

In this section, we analyze the impacts of the following two pairs of parameters on the bundle mode for the ride-hailing platform and the aggregation platform through numerical experiments:

(i) η_r and η_a: cost coefficients of service level provided for two platforms;
(ii) c_r and c_a: cost prices of two platforms.

For clarity, in the figures given below, we use the blue legend color to represent the ride-hailing platform and the green legend color to represent the aggregation platform. We tested some combinations of parameters of the ride-hailing platform with the change of the demand scale θ. For figures with obvious rules, we summarize some results of critical points and boundaries under some specific parameters setting. All numerical tests were performed in MATLAB.

5.1 Cost coefficients of service levels

In our experiments, we set $\alpha = 0.8, \beta = 0.2, \gamma = 0.5, \delta = 0.15, w_r = 0.7, w_a = 0.7, c_r = 8, c_a = 8, \lambda = 0.1, \sigma = 50, D_1 = 200$, and $D_2 = 300$. The numerical results for the cost coefficients of service levels in ride-hailing and aggregation platforms respectively, the boundaries and critical points of the profit for both platforms are shown in Fig. 2.

A three-dimensional surface plot can be created in Fig. 2, where the blue grid surface fills the ride-hailing platform and the green face grid surface fills the aggregation platform. The function plots the values in platforms' profits (π_r and π_a) as heights above a grid in the $\eta_r - \eta_a$ plane, where η_r and η_a are both on the ranges of $[1, 50]$ with one unit step. Projecting grid surfaces, the color with the greater profit will cover the other color.

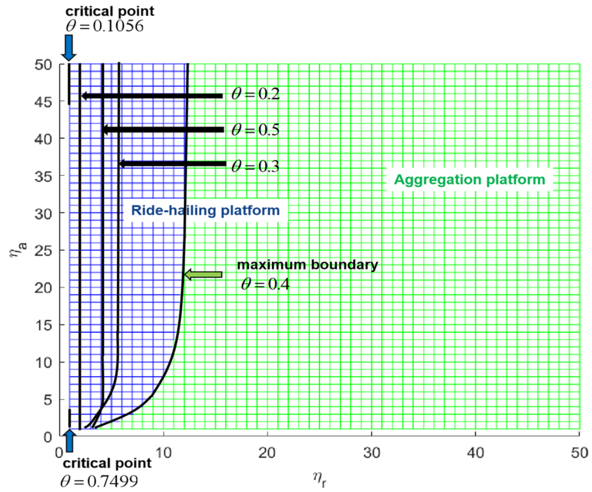

Fig. 2. Profits of both platforms with different combinations of η_r and η_a

We draw six boundaries between the green and the blue with the growth of θ. It can be observed that the blue line starts to appear on the $\eta_r - \eta_a$ plane (i.e., $\eta_r = 1, \eta_a = 50$) and the critical point is $\theta = 0.1056$. The blue area gradually expands as θ rises, which is the largest at $\theta = 0.4$ and disappears at $\theta = 0.7499$. Starting from the critical point $\theta = 0.2992$, a small change of the demand percentage θ will bring more profits to the ride-hailing platform. The more demand the ride-hailing platform obtains from the aggregation platform, the less profit it gets when bundled with the aggregation platform. This may be explained by the revenue sharing so that the ride-hailing platform pays more with the increasing demand.

5.2 Cost prices of two platforms

The other parameters were set as $\alpha = 0.8, \beta = 0.2, \gamma = 0.5, \delta = 0.15, w_r = 0.7, w_a = 0.7, \eta_r = 48, \eta_a = 40, \lambda = 0.1, \sigma = 50$, $D_1 = 200$, and $D_2 = 300$. The numerical results for the boundaries of the differences of profits for two platforms are shown in Fig. 3.

Projecting grid surfaces onto the $c_r - c_a$ plane in Fig. 3, the color with the greater profit will cover the other color. We draw boundaries between the green and the blue with the changes of θ. The locations where the blue starts and disappears on the $c_r - c_a$ plane are both on $c_r = 5, c_a = 20$, which correspond to the critical point $\theta = 0.234$ and $\theta = 0.573$, respectively. To be specific, as the rise of θ beginning at 0.234, the area of the blue gradually expands at the maximum region with $\theta = 0.405$, followed by the progressively smaller areas until the blue disappears at $\theta = 0.573$.

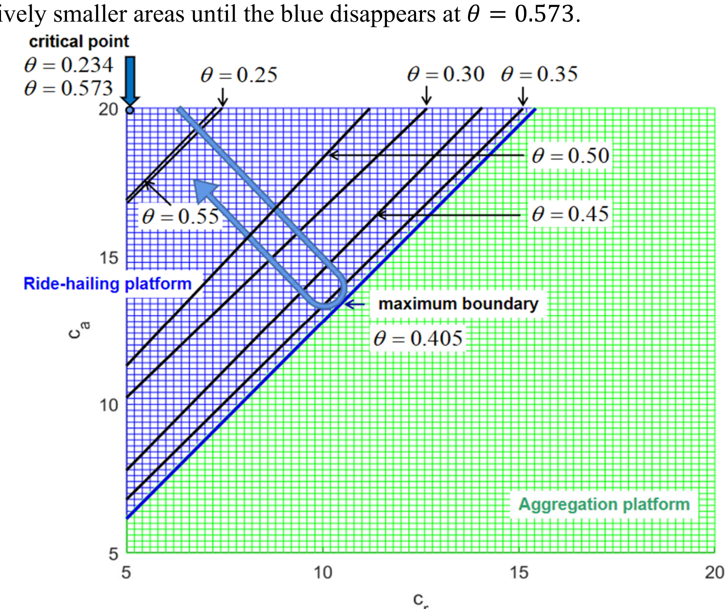

Fig. 3. Profits of both platforms with different combinations of c_r and c_a

The change rate of θ is inconsistent with the one of the intercept of boundary on the c_a axis. The ride-hailing platform reduces costs to gain more profits than the aggregation platform. If θ is within $[0, 0.234)$ or $(0.573, 1]$, the aggregation platform always has more profits than the ride-hailing platform. If θ is within $[0.234, 0.573]$, under some conditions, the ride-hailing platform has more profits in competition with the aggregation platform (for example, when $\theta = 0.405$, the ride-hailing platform chose cost c_r if $c_r < 0.7536c_a + 0.3275$).

6. Conclusions

We have presented an analytical framework for ride-hailing platforms under bundle mode, where the ride-hailing and aggregation platforms serve as leaders and the driver group serves as follower and, on the other hand, the two platforms play a Nash game. We have analyzed the impact of two pairs of parameters on profit, namely, the cost coefficients of service levels provided for the platforms and their cost prices. We have obtained some interesting managerial insights on pricing of ride-hailing and aggregation platforms by comprehensive numerical experiments and results analysis.

In the future, we will study the ride-hailing platforms with elastic travel demands. In the early study on aggregation platforms, accepting bundle services has always been a right choice for ride-hailing platforms. However, when many more platforms settle in, the demands allocated to ride-hailing platforms by aggregation platforms decrease generally, which will inevitably lead to competition formed by ride-hailing platforms within aggregation platforms. Moreover, as aggregation platforms increase, it is worth considering the number of bundled ride-hailing platforms introduced to aggregation platforms. Revenue-sharing contracts, commissions, and slotting fees rather than prices, are also worth studying.

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