On the Pricing Decision of Monopoly Online Car-Hailing Platform Considering Network Externality and Commission Rate

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Abstract. With the development of mobile internet, the online car-hailing (OCH) services have become one of the in urban transportation modes available. Accordingly, the OCH services pricing decision surfaces as a new transportation management problem that should be properly addressed. This paper analyzes the pricing and cooperation revenue sharing issues between the platform and the group of drivers by means of the dynamic game theory and the two-sided market theory. In order to reflect the characteristic of the practical situation of OCH industry, the network externality and the driver commission rate are considered in this model. The formula of the user payment, the driver commission rate, the user registration fee, the user and driver scale, and the platform profit at the equilibrium state as well as the relationship between them and network externality are analyzed. The simulation results validate the correctness of our analytical results.

Keywords: Online car-hailing platform · Pricing decision · Network externality · Commission rate · Two-sided market

1 Introduction

Over the last decades, with the rapid development and popularization of mobile internet, the OCH services have become one of the urban transportation modes available and the OCH companies such as Uber and Didi have obtained huge success and transformed the way we travel in cities. These companies connect users and drivers in real time by internet-based platforms to operate car-hailing services. Some achievements have been made in the research of OCH service mode selection behavior. Rayle et al. [1] find that the users of OCH display the characteristics of younger age and higher education level. At the same time, compared with taxi travel mode, the OCH services are more convenient and take a shorter waiting time. Dias et al. [2] study the choice behaviors of car-sharing and OCH services based on bivariate ordered probit model, and analyze the influence of basic characteristics of users such as whether they have children and the built environment on mobile travel choice. By observing the differences between users and non-users of OCH services, Dawes [3] finds that Uber and/or Lyft users are more likely

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to hold a positive attitude towards OCH service. Dawes also learns that participating in social and leisure activities and avoiding alcohol driving are the main reasons for travelers to choose Uber or Lyft. Contreras and Paz [4] estimate the effects of OCH platform on the taxicab industry by using multinomial linear regression analysis, and find that OCH services had a negative and significant effect on taxicab ridership. Nelson and Sadowsky [5] find that the emergence of the first OCH platform is an important supplement to the public transport system, but with the entry of the second OCH company, the utilization rate of public transport would decline.

The matching problem of OCH is also investigated by researchers. Thaithatkul et al. [6] obtain a matching model by considering user preference and study the relationship between user preference and OCH system's performance. Fahnenschreiber et al. [7] study the matching problem combining dynamic OCH and existing public transport systems. Masoud and Jayakrishnan [8] discuss the randomness of the flexible OCH system and propose an algorithm to solve this problem in real-time. Thaithatkul et al. [9] investigate the characteristics of dynamics of passenger matching problem in smart OCH systems by the simulation approach. Cheikh et al. [10] obtain a novel approach to solving the dynamic multihop ridematching problem. As for the pricing problem of OCH, Yang and Yang [11] analyze the equilibrium properties of three specific issues for taxi market by using general bilateral searching and meeting function. Wang et al. [12] obtain a game model of the taxi market with a single taxi hailing app by using an aggregate and static approach, and conduct the existence, stability and sensitivity analysis of pricing strategies at the equilibrium state. Zha et al. [13] analyze the economic output of OCH platform under different scenarios by using an aggregate model, and deduce the pricing structure from monopoly, the first-best and the second-best perspectives. Further, Zha et al. [14] propose the equilibrium models in OCH market under dynamic scenario and investigate the impact of surge pricing by using bi-level programming method. He et al. [15] propose an equilibrium framework to depict the operations of a regulated taxi market, formulate an optimal design problem of the taxi-hailing platform's pricing and penalty/compensation strategies and get the solving algorithm.

With the emergence of OCH platform enterprises, competition between different platform enterprises seems inevitable. Hall et al. [16] consider the emergence of Uber is a complement for public transit. Specifically, Uber is a complement for buses and rail transit. Alley [17] argues that Uber breaks the monopoly position of taxi industry in New York City, reduces the average price level of taxi industry and provides more economical and faster travel services. Chen [18] studies the behavior of taxi drivers in the case of widespread OCH services. This study finds that Didi's technical strength poses challenge to the survival and development of traditional taxi drivers, and thus taxi drivers are compelled to gradually adapt themselves to new technologies in order to obtain higher income, and Uber does not significantly worsen the traffic congestion in urban areas. In order to promote the healthy development of OCH industry, scholars have also carried out research on policy and regulation strategy of OCH Market. Dudley [19] considers that regulation should be carried out under the condition of ensuring the positive role of OCH. Schneider [20] thinks that the traditional taxi market regulation policy is not suitable for the online car-hailing platform. Edelman and Geradin [21] discuss the specific regulatory measures of OCH platform. Beer et al. [22] take a qualitative comparative analysis on the regulation policies of OCH in major American cities through the driver and platform perspectives. Lee [23] discusses the government's regulatory framework from the perspective of government regulation. The empirical study of OCH is also conducted by researchers. For instance, Bengtsson [24] reveals that sidestepping the regulations increases cost efficiency and informal bargaining leads to Pareto improvement through studying the Cape Town taxi market. Jiao [25] evaluates the characteristic of OCH platform Uber's surge pricing by using collected data in Austin, and reveals the obscurity of the price surge mechanisms. Shaheen and Cohen [26] review the shared ride service models and the impact studies for North American, and explore the convergence of shared mobility, electrification and automation, offering some advice to improve the management of the shared ride services. Yang and Yu [27] compare and analyze the traditional and present management modes and measures taken by the government with the Shanghai taxi management model as a case.

The OCH platforms are a meeting place for drivers and users. The drivers find users via the platforms and transport them to their designated destinations. When the driver scale is large, the platform can provide more potential driver candidates for users, and the average waiting time for users is relatively small and the utility increases accordingly. Similarly, the utility of drivers providing travel services through the platform is also related to the size of users. Therefore, the OCH market is a typical two-sided market. The two-sided market theory was first proposed by Rochet and Tirole [28] and Armstrong [29], and has become the basic framework of two-sided market research. Hagiu and Halaburda [30] investigate the effect of levels of information on two-sided platform profits. Roger [31] studies the duopoly problem of two-sided platforms competing in differentiated products at the two-sided market. Nourinejad and Ramezani [32] obtain a dynamic non-equilibrium ride-sourcing model by the two-sided market theory, and a controller based on the model predictive control approach. Kung and Zhong [33] study the profit maximization problem of two-sided platform under three pricing strategies by considering network externality in order to understand pricing in the sharing economy. Malavolti [34] considers that the airport is a platform for shops and passengers by using two-sided market theory, and obtains the influence factors of retailing activity and aeronautical tax. Djavadian and Chow [35] investigate the flexible transport services and day-to-day adjustment process by the two-sided market approach, and assume that a perfectly matched state is equivalent to a social optimum by using the Ramsey pricing criterion.

The network externality is a core feature of platform economy, and meanwhile the waiting time and the driver commission rate are important factors of OCH services. In this paper, the network externality means the inter-group network externality which consists of marginal utility and waiting time. We establish a two-stage price game model based on the game theory and two-sided theory, analyzing the cooperatition game between monopoly platform and drivers, and conduct an equilibrium analysis under the monopoly platform optimum. We prove that the marginal utility of the drivers to the platform users and the marginal utility of the platform users to the drivers together determine the user payment, the driver commission rate, the user registration fee, the user and driver scale, and the platform profit at the equilibrium state. We also test the conclusion of the model through simulation.

Next, the basic model for a hypothetical OCH market is presented in the second section. The third section explores the properties of the monopoly OCH service at the equilibrium state. In the fourth section, the simulation is given to test the results in the third section.

2 Basic Model

2.1 Problem Description

Researchers have investigated the influence factor of the two-sided platform profit. Hagiu and Halaburda [30] show that the monopoly platform has higher profits when users are more informed while the competition platform prefers facing less informed users. Nourinejad and Ramezani [32] indicate that the overall profit may be higher when the user demand increases and the driver demand decreases simultaneously. Kung and Zhong [33] study the two-sided platform profit maximization problem by considering network externality. It is well known that the OCH market is a typical two-sided market, and the core feature of OCH services are not only the network externality in the general platform economy, but also the waiting time of two-sided user and the driver commission rate. In this paper, we assume a hypothetical OCH market with a monopoly platform, a group of drivers and a group of users and the market is mature such that the platform will gain profit from providing the services. The OCH platform adopts unilateral charge, that is, the user registration fee and the driver commission fee, while the driver decides the user payment at transaction. Suppose there is a line city of length 1, and the users and drivers are evenly distributed in the linear city. This paper assumes that the waiting time of users is negatively related to the driver scale, that is, when the number of drivers increases, the waiting time of users traveling through the OCH platform decreases; similarly, the waiting time of drivers is negatively related to the user scale, that is, when the number of users increases, the waiting time for drivers to provide travel services through the OCH platform decreases.

2.2 Game Model of the Problem

Suppose the user registration fee is r. Since the users are evenly distributed in the interval [0, 1], then, the location of user i satisfying $x_i \in [0, 1]$, t is the unit cost of users joining the OCH platform, v is the basic utility of users, n is the number of drivers joining the platform, a is the marginal utility of the platform drivers to the users, i.e., the marginal utility brought by adding a driver to the monopoly platform for the users who join the platform, β_1 is the value of time of uses, $\gamma_1 n$ is the waiting time of users, $\gamma_1 < 0$ is the scale sensitive parameter of users, thus $a - \beta_1\gamma_1$ is the network externality of users. p is the user payment at transaction. For balanced calling pattern, the user payment is pn, then, the utility of user i is

$$u_i = v + an - \beta_1\gamma_1 n - r - tx_i - pn. \quad (1)$$

Similarly, for the location of driver j satisfying $y_j \in [0, 1]$, f is the unit cost of drivers joining the OCH platform, m is the number of users joining the platform, b is the marginal utility of the platform users to the drivers, that is, the marginal utility brought by adding a user to the monopoly platform for the drivers who join the platform, β_2 is the value of time of drivers, $\gamma_2 m$ is the waiting time of drivers, $\gamma_2 < 0$ is the scale sensitive parameter of drivers, thus $b - \beta_2\gamma_2$ is the network externality of drivers. λ is the commission rate of user's payment obtained by driver. For balanced calling pattern, the received of drivers is λpm, then, the profit of driver j is

$$L_j = bm - \beta_2\gamma_2 m + \lambda pm - fy_j. \tag{2}$$

From Eq. (1) and Eq. (2), we can obtain

$$x_i = (v - r + an - \beta_1\gamma_1 n - pn)/t, y_j = (bm - \beta_2\gamma_2 m + \lambda pm)/f. \tag{3}$$

Then, the user and driver scale at the equilibrium state is described as follows, respectively,

$$m_e = \left[f(v - r)\right]/\left[ft - (a - \beta_1\gamma_1 - p)(b - \beta_2\gamma_2 + \lambda p)\right]. \tag{4}$$

$$n_e = \left[(v - r)(b - \beta_2\gamma_2 + \lambda p)\right]/\left[ft - (a - \beta_1\gamma_1 - p)(b - \beta_2\gamma_2 + \lambda p)\right]. \tag{5}$$

Assuming the marginal cost of platform is c, thus, the profit function of monopoly OCH platform can be written as follows:

$$\begin{aligned} L_1(r, p, \lambda) &= rm_e + \left[(1 - \lambda)p - c\right]n_e m_e \\ &= \left\{f(v - r)^2\left[(1 - \lambda)p - c\right](b - \beta_2\gamma_2 + \lambda p)\right\}/\left[ft - (a - \beta_1\gamma_1 - p)(b - \beta_2\gamma_2 + \lambda p)\right]^2. \\ &+\left[fr(v - r)\right]/\left[ft - (a - \beta_1\gamma_1 - p)(b - \beta_2\gamma_2 + \lambda p)\right] \end{aligned} \tag{6}$$

The drivers profit is calculated in the manner as follows:

$$L_2(r, p, \lambda) = [f(v - r)^2(b - \beta_2\gamma_2 + \lambda p)^2]/2[ft - (a - \beta_1\gamma_1 - p)(b - \beta_2\gamma_2 + \lambda p)]^2. \tag{7}$$

The consumer surplus is determined as follows:

$$CS(r, p, \lambda) = [f^2 t(v - r)^2]/2[ft - (a - \beta_1\gamma_1 - p)(b - \beta_2\gamma_2 + \lambda p)]^2. \tag{8}$$

The total social benefit is shown as follows:

$$\begin{aligned} &TS(r, p, \lambda) = L_1(r, p, \lambda) + L_2(r, p, \lambda) + CS(r, p, \lambda) \\ &= \frac{f(v-r)[ft(v+r)+2(b-\beta_2\gamma_2+\lambda p)((a-\beta_1\gamma_1)r-rc+cv-pv)+(v-r)(\lambda^2p^2-(b-\beta_2\gamma)^2)]}{2[ft-(a-\beta_1\gamma_1-p)(b-\beta_2\gamma_2+\lambda p)]^2}. \end{aligned} \tag{9}$$

3 Equilibrium Analysis

Now, we have established a two-stage price game model for equilibrium analysis. In the first stage, the platform decides the driver commission fee to maximize the platform profit, and in the second stage, the platform decides the user registration fee to maximize the platform profit, and the driver decides the user payment to maximize the drivers profit. This is a typical perfect information dynamic game. The Nash equilibrium can be solved according to the backward induction approach.

According to the backward induction approach, in the second stage the platform decides the user registration fee to maximize the platform profit, and the driver decides the user payment to maximize the drivers profit. Let $\partial L_1/\partial r = 0$ and $\partial L_2/\partial p = 0$, we can obtain

$$\begin{aligned} p &= \frac{\sqrt{ft\lambda}-(b-\beta_2\gamma_2)}{\lambda}, \\ r &= \frac{\left[(b-\beta_2\gamma_2)-2(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)\lambda+(a-\beta_1\gamma_1+2\sqrt{ft\lambda})\lambda\right]v}{2\left[-(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)\lambda+\sqrt{ft\lambda}(1+\lambda)\right]}. \end{aligned} \tag{10}$$

In the first stage, the platform decides the driver commission fee to maximize the platform profit. In view of Eq. (10), we can show that Eq. (6) can be rewritten as follows:

$$L_1 = \sqrt{f}v^2/\left\{4\sqrt{t}[\sqrt{ft}(1+\lambda) - (a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)\sqrt{\lambda}]\right\}. \tag{11}$$

Then, let $\partial L_1/\partial\lambda = 0$. Thus, the driver commission rate is

$$\lambda^* = (a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2/4ft. \tag{12}$$

Substituting Eq. (12) into Eq. (10) yields

$$p^* = 2ft(a-\beta_1\gamma_1-b+\beta_2\gamma_2-c)/(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2. \tag{13}$$

$$r^* = v\frac{4ft(b-\beta_2\gamma_2)+(a-\beta_1\gamma_1)(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2-(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^3}{(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)[4ft-(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2]}. \tag{14}$$

Substituting Eq. (13) and Eq. (14) into Eq. (4)-Eq. (9) yields

$$\begin{aligned} m^* &= 2fv/[4ft-(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2], \\ n^* &= (a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)v/[4ft-(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2]. \end{aligned}$$

$$L_1^* = fv^2/[4ft-(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2].$$

$$L_2^* = (a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2fv^2/\{2[4ft-(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2]^2\}.$$

$$CS^* = 2f^2v^2t/[4ft-(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2]^2.$$

$$TS^* = fv^2[12ft-(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2]/\{2[4ft-(a-\beta_1\gamma_1+b-\beta_2\gamma_2-c)^2]^2\}.$$

Before equilibrium analysis, we first undertake the following assumption:

Assumption 1. $a-\beta_1\gamma_1 > b-\beta_2\gamma_2 \gg c$. This means the network externality of users is larger than the network externality of driver.

Assumption 2. $4ft - (a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)^2 \geq 0$. This means there are obvious differences between users and drivers in the market, and it can also ensure the driver commission rate $\lambda^* = (a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)^2/4ft \leq 1$.

Proposition 1. The driver commission rate at the equilibrium state is a strictly monotone increasing function of marginal utility $a,\ b$, a strictly increasing function of the value of time $\beta_1,\ \beta_2$, and a strictly decreasing function of the unit cost $t,\ f$.

Proof: from Eq. (12), it is easy to obtain

$$\partial\lambda^*/\partial a = \partial\lambda^*/\partial b = (a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)/2ft > 0,$$

$$\partial\lambda^*/\partial\beta_1 = -\gamma_1(a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)/2ft > 0,$$
$$\partial\lambda^*/\partial\beta_2 = -\gamma_2(a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)/2ft > 0,$$

$$\partial\lambda^*/\partial t = -(a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)^2/4ft^2 < 0,$$
$$\partial\lambda^*/\partial f = -(a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)^2/4f^2t < 0.$$

This proposition obtains the relationship among the driver commission rate and marginal utility, value of time and the unit cost of two-sided user joining the OCH platform. When the marginal utility and value of time of two-sided user is higher, the driver can get higher commission from each transaction. When the unit cost of two-sided user joining the OCH platform is higher, the driver can get lower commission from each transaction.

Proposition 2. The user payment at equilibrium state is a strictly decreasing function of marginal utility b, a strictly decreasing function of the value of time β_2, and a strictly increasing function of the unit cost $t,\ f$. The monotone of function p^* with of $a,\ \beta_1$ depends on the relationship between $a - \beta_1\gamma_1$ and $3(b - \beta_2\gamma_2)$.

Proof: from Eq. (13), it is easy to obtain.

$$\partial p^*/\partial a = 2ft[3(b - \beta_2\gamma_2) - (a - \beta_1\gamma_1) + c]/(a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)^3,$$

$$\partial p^*/\partial b = 2ft[(b - \beta_2\gamma_2) - 3(a - \beta_1\gamma_1) + 3c]/(a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)^3 < 0,$$

$$\partial p^*/\partial\beta_1 = -\gamma_1\partial p^*/\partial a,\ \ \partial p^*/\partial\beta_2 = -\gamma_2\partial p^*/\partial b < 0,$$

$$\partial p^*/\partial t = 2f(a - \beta_1\gamma_1 - b + \beta_2\gamma_2 - c)/(a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)^2 > 0,$$

$$\partial p^*/\partial f = 2t(a - \beta_1\gamma_1 - b + \beta_2\gamma_2 - c)/(a - \beta_1\gamma_1 + b - \beta_2\gamma_2 - c)^2 > 0.$$

This proposition obtains the relationship between the user payment and other parameters. When the marginal utility and value of time of drivers is higher, the user needs to pay litter for transaction. When the unit cost of two-sided user joining the OCH platform is higher, the user has to pay more for transaction.

The monotone of function r^*,m^*,n^*, L_1^*, L_2^*, TS^* of $a,\ b,\ \beta_1,\ \beta_2,\ t, f$ can be obtained in the manner as stated above.

4 Simulation Analysis

In this section, we only consider the relationship of functions λ^*, p^*, r^*, TS^*, m^*, n^*, L_1^*, L_2^* of marginal utility a, b, while the other parameters are constant. The condition of simulation diagram is listed in Table 1.

Table 1. The condition of simulation diagram

Figure Number	Function	a	b	c	f	t	v	β_1	β_2	γ_1	γ_2
Fig. 1	λ^*	[8, 14]	[3, 4]	0.001	10	10	–	3	1	−0.2	−0.1
Fig. 2	p^*	[8, 14]	[3, 4]	0.001	10	10	–	3	1	−0.2	−0.1
Fig. 3	r^*	[8, 14]	[3, 4]	0.001	10	10	0.01	3	1	−0.2	−0.1
Fig. 4	TS^*	[8, 14]	[3, 4]	0.001	10	10	0.01	3	1	−0.2	−0.1
Fig. 5	m^*	[8, 14]	[3, 4]	0.001	10	10	0.01	3	1	−0.2	−0.1
Fig. 6	n^*	[8, 14]	[3, 4]	0.001	10	10	0.01	3	1	−0.2	−0.1
Fig. 7	L_1^*	[8, 14]	[3, 4]	0.001	10	10	0.01	3	1	−0.2	−0.1
Fig. 8	L_2^*	[8, 14]	[3, 4]	0.001	10	10	0.01	3	1	−0.2	−0.1

The function in Table 1 is defined in Sect. 3. Then, the simulation diagram is indicated as follows:

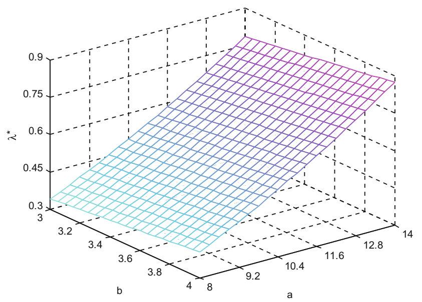

Fig. 1. The relationship among λ^* and a, b

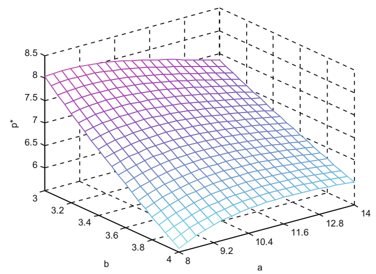

Fig. 2. The relationship among p^* and a, b

From Fig. 1, we can show that the driver commission rate at equilibrium state is a strictly monotone increasing function of the marginal utility a and b. This means that with the increase of marginal utility, drivers can get higher commission from each transaction. Figure 2 shows that the user payment at the equilibrium state is a strictly monotone decreasing function of marginal utility b and a strictly monotone increasing and then strictly monotone decreasing function of marginal utility a.

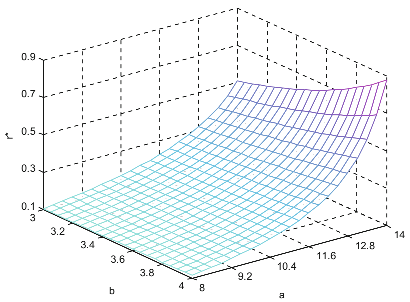

Fig. 3. The relationship among r^* and a, b

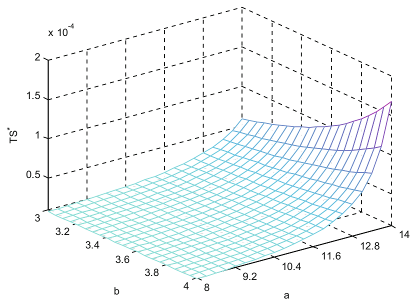

Fig. 4. The relationship among TS^* and a, b

From Fig. 3 and Fig. 4, we can find that the user registration fee and the total social benefit are a strictly monotone increasing function of the marginal utility a and b, respectively. If the marginal utility a (b) is fixed, the increment of the user registration fee (the total social benefit) changes more obviously with the increase of b (a).

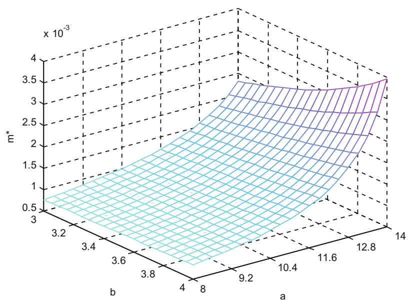

Fig. 5. The relationship among m^* and a, b

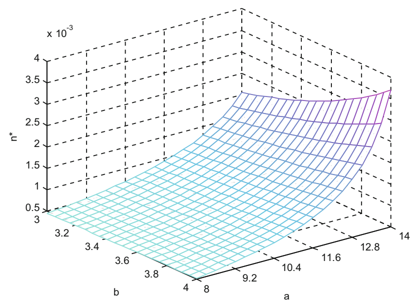

Fig. 6. The relationship among n^* and a, b

From Fig. 5 and Fig. 6, we can see that the user and driver scale is a strictly monotone increasing function of the marginal utility a and b, respectively. If the marginal utility a (b) is fixed, the increment of the user scale (the drive scale) changes more obviously with the increase of b (a). If the marginal utility a and b is fixed at the same time, we can find that the user scale is larger than the driver scale.

From Fig. 7 and Fig. 8, we can find that the platform profit and driver profit is a strictly monotone increasing function of the marginal utility a and b, respectively. If the marginal utility a (b) is fixed, the increment of the platform profit (the drive profit) changes more obviously with the increase of b (a). When the marginal utility a and b is relatively smaller, the platform profit is larger than the drive profit. Otherwise, the platform profit is less than the driver profit fixed at the same time. We can find that the user scale is larger than the driver scale.

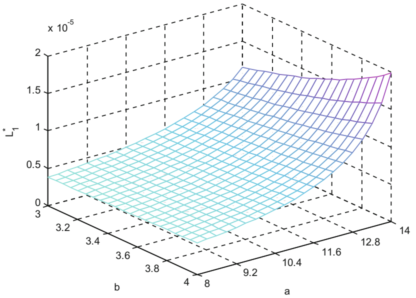

Fig. 7. The relationship among L_1^* and $a,\ b$

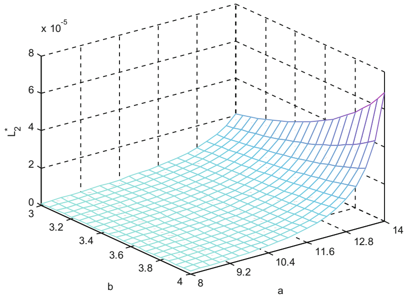

Fig. 8. The relationship among L_2^* and $a,\ b$

5 Conclusion

In this paper, we study the pricing decision of monopoly OCH platform considering network externality and commission rate. The network externality is inter-group externality which consists of marginal utility and the waiting time, and the dynamic game theory model of this pricing decision problem is obtained by two-sided market theory. The relationship among the user payment, the driver commission rate, the user registration fee, the user and driver scale, the platform profit at the equilibrium state and the marginal utility of the drivers to the platform users, and the marginal utility of the platform users to the drivers is obtained. The simulation results validate the correctness of our analytical results. Our ongoing work is to explore the pricing decision of duopoly platforms considering the inter-group network externality and inner-group network externality simultaneously.

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