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Pricing Decisions for Competitive Ride-Hailing Platforms with the Combination of Inner-Group and Inter-Group Network Externalities

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ABSTRACT

Based on two-sided market theory, this paper has studied the pricing problem of ride-hailing platforms with a combination of inter-group network externality and inner-group network externality. Two scenarios of user structure are considered. In scenario 1, both travellers and drivers are single-homing. In scenario 2, travellers are single-homing while drivers are multi-homing. Moreover, time sensitive factors and driver's commission rate are introduced to reflect the characteristics of transport industry. Finally, the impact of network externality, time sensitivity, driver's commission rate and entry cost on ride-hailing platform pricing, user scale and profits are analysed. The results show that inter-group network externality and inner-group network externality have a negative effect on platform prices charged to both travellers and drivers. However, when travellers are multi-homing, the price charged to travellers is positive with respect to the inter-group network externality from drivers. In the relationship between travellers' scale and inter-group network externality, inner-group network externality is positive. Further, in both scenarios, the network externalities from the two sides affect platform profits negatively.

KEYWORDS

ride-hailing platform; pricing decision; network externality; two-sided market.

1. INTRODUCTION

In transportation, various new travel modes are provided to make urban residents' travel more convenient [1–5]. In 2007, Uber was founded in the United States and has expanded rapidly around the world [6, 7]. In China, Didi started ride-hailing services in 2014. At an early stage, Didi put forward a price subsidy strategy to attract more users [8, 9]. The rise of ride-hailing services has stirred up various controversies in different countries [10]. In the United States, the Colorado State passed legislation on ride-hailing services as early as 2014. In 2016, the Chinese central government issued a document titled "The Interim Regulatory Measures for the Online Ride-Hailing Industry" to ensure the legal status of ride-hailing services since that year. However, ride-hailing services still face resistance in certain areas. For instance, in Japan, consumers can also use Uber, but mostly to hail taxis rather than on-demand peer-to-peer services due to government regulation policies. Moreover, such ride-hailing services have faced strict restrictions in some European countries. Although policies on ride-hailing services vary widely, it is beyond doubt that such services have become one of the most prominent travel modes. Furthermore, there are certain issues that are worth examining, and pricing decision is one of the topics that has been most widely studied.

In summary, the travel transactions of ride-hailing services are operated based on the development of mobile internet technology, and traditional businesses are facing the competition from online-based entrepreneurs [11]. Overall, the combination of mobile internet and transportation has been gradually changing travellers' behaviour [12]. On the one hand, ride-hailing platforms have provided new travel options for urban residents. On the other hand, the rapid growth of ride-hailing services has aroused various managerial issues for urban transportation [13, 14].

The pricing decision is one of the most vital managerial decisions for ride-hailing platforms. The importance of network externality on the decision behaviour of enterprises has been verified by some extant research [15–17]. With the effect of network externality on ride-hailing platforms, the pricing decision issue of ride-hailing platforms is more complicated than traditional transportation modes. In current research, this issue has been studied from different viewpoints.

Platform matching is the foundation of ride-hailing services, and the pricing issue can be studied from this aspect. Zha et al. (2016) studied the optimal and suboptimal strategies and social welfare under the scenarios of monopoly and competition from the standpoint of platform matching [18]. Based on this research, Zha et al. (2018) further extended the study on pricing decisions of ride-hailing platforms by considering a dynamic scenario, followed by constructing a time expanded network to analyse the pricing of ride-hailing platforms [19]. Besides, the factors of users' behaviour, spatial difference etc. should also be considered to address pricing decision problems. Sun et al. (2019) studied the optimal pricing of ride-hailing platforms by considering travellers' behaviour and drivers' positions [20]. Wu et al. (2020) investigated the pricing mechanism of ride-hailing platforms with the factors of network externality and spatial difference, suggesting that the optimal pricing depends on both travellers' heterogeneity and drivers' cost [21]. What is more, one of the typical features of ride-hailing services is surge pricing, which means the price of ride-hailing services is allowed to be adjusted according to time or positions, for example peak time or off-peak time. Yan et al. (2020) studied the dynamic pricing of ride-hailing services based on a combination of advanced matching and dynamic pricing algorithms [22]. As regards the efficiency of surge pricing, Hu et al. (2021) revealed that the efficiency of surge pricing with higher frequency is better than lower frequency [23].

In reality, ride-hailing platforms connect drivers and travellers to generate profits, but pricing strategies vary among major platforms. Based on the practical scenario, several features have been identified. Firstly, the strength of a subsidy strategy varies with the amount of capital held by such platforms. As a well-known ride-hailing platform, Didi provided 4.4 and 1.3 billion yuan as compensation to drivers and travellers respectively in 2022 [24]. Secondly, the commission rate for drivers differs across ride-hailing platforms [25, 26]. Currently, Uber and Didi, two of the most powerful platforms, charge drivers a commission rate of about 25% to 30% per order, while some minor platforms, such as CaoCao, charge a 20% platform commission fee. Thirdly, in certain scenarios, such as peak hours, bad weather or holidays, some platforms implement surge pricing strategy [23, 27]. Then the price may increase 3 to 5 times compared to the usual rate. A summary of the pricing strategies in current research and practical scenarios indicates that there are many complications involved in the pricing strategies of ride-hailing platforms, and that they need further examination.

As a type of theory focusing on pricing decision research, two-sided market theory was studied first by Rochet and Tirole (2003), Rochet and Tirole (2006), Armstrong (2006) et al. to form the fundamental framework of two-sided market studies [28–30]. Research on network externality and two-sided market was carried out from several aspects, i.e. the strength and direction of network externality and classifications of network externality [17, 31, 32]. Wu et al. (2020) studied the impact of spatial differentiation and network externality on a ride-hailing platform's pricing mechanism and indicated that network externality plays an important role in pricing strategy [21]. Unlike a conventional conclusion, Li and Zhang (2020) indicated that the group with a larger network externality may not be aggressive [33].

To sum up, some researchers have examined the pricing strategies and social welfare of ride-hailing platforms. The interactions from two sides have been considered vastly; however, only a small number of them focused on the interaction effect among groups of travellers or drivers. Travellers and drivers interact with each other through the ride-hailing platform, hence inter-group network externality exists. Among a group of travellers or drivers, individuals may imitate or learn the behaviour of others, which then generates inner-group network externality. Concerning the vital role of both inter-group and inner-group network externalities, it is necessary to study the pricing decisions of ride-hailing platforms with a combination of both factors. Moreover, few studies have considered the features of the specific industry.

This study has been carried out with the consideration of ride-hailing platforms' competitive scenarios. Based on two-sided market theory, this paper builds a model of the competition of ride-hailing platforms, in which both inter-group network externality and inner-group network externality are considered. Further, the effects of network externality on pricing, user scale and profits of ride-hailing platforms are analysed. Moreover, this research also introduces average waiting time and driver's commission rate to embody the features of transportation industry. To conduct this research, two scenarios have been established based on the user attribution structure. On the one hand, the pricing strategies of ride-hailing platforms are significantly influenced by the supply and demand from drivers and travellers. On the other hand, the supply and demand from both sides may not be consistent with different user attribution structures. Furthermore, in reality, travellers tend to join more than one platform, such as by installing two or more apps that provide ride-hailing services. However, due to policy regulations, drivers tend to be single-homing. Based on this observation, two scenarios are proposed. In scenario 1, both travellers and drivers are single-homing. In scenario 2, travellers are single-homing, while drivers are multi-homing.

Through the analysis of ride-hailing platforms competition, the purpose of this study is to answer the following questions: (1) What is the impact of inter-group and inner-group network externalities on the pricing and profits of ride-hailing platforms? (2) Does the pricing strategy differ among platforms with different user attribution structures? (3) To what extent will the driver's commission rate affect the pricing and profits of ride-hailing platforms?

This study aims to provide several theoretical insights on the market strategy of ride-hailing platforms. (1) From the perspective of a two-sided market, this paper investigates the pricing decisions of ride-hailing platforms. The ride-hailing services market is actually a two-sided market composed of travellers and drivers, and the application of two-sided market theory to model the pricing decision-making of ride-hailing platforms can better represent the key characteristics of such transportation platforms. (2) To examine the effect of network externality, factors of inner-group network externality are considered in addition to inter-group network externality, which may lead to a more comprehensive understanding of group behaviour among travellers or drivers. Compared with existing studies, the effect of inter-group network externality is extensively examined, but little research has focused on a combination of inner-group and inter-group network externalities. Therefore, this study may achieve some theoretical insights on platform competition theories. (3) This paper also constructs two types of user attribution structure scenarios. In the first scenario, both travellers and drivers are single-homing. In the second scenario, travellers can be multi-homing while drivers are single-homing. In addition, the study also considers the average waiting time of travellers and drivers, and drivers' commission rate to reflect the characteristics of ride-hailing services. It could be helpful to reveal the general pattern of consumer behaviour.

This study also provides several meaningful practical insights. Some ride-hailing platforms may face a balance between user scale and profit level, which may not always be consistent. For example, a higher profit level typically means a higher price level and higher commission rate, which may result in drivers or travellers quitting such platforms. However, operations and profits of such platforms rely on the scale of both sides simultaneously. Therefore, the balance problem arises, and this study may provide some practical insights by considering network externalities and user attribution structure.

The rest of this paper is organised as follows. In Section 2, the assumption and basic model are established. The pricing decisions in two scenarios are studied in Section 3. In Section 4, discussions and limitations are put forward. Finally, conclusions are presented in Section 5.

2. METHOD AND BASIC MODEL

2.1 Method description

In *Figure 1*, the method map is presented. Generally, the study has been carried out based on two-sided market theory. By considering both inter-group and inner-group network externalities, the basic model has been constructed. In addition, features of ride-hailing services have been considered in the basic model as well. Further, the pricing strategies of ride-hailing platforms in the two scenarios have been studied. The scenarios are divided by a classification of user structure. In scenario 1, both travellers and drivers are single-homing, whereas in scenario 2 travellers are multi-homing while drivers are single-homing. Finally, the pricing strategy of ride-hailing platforms is analysed.

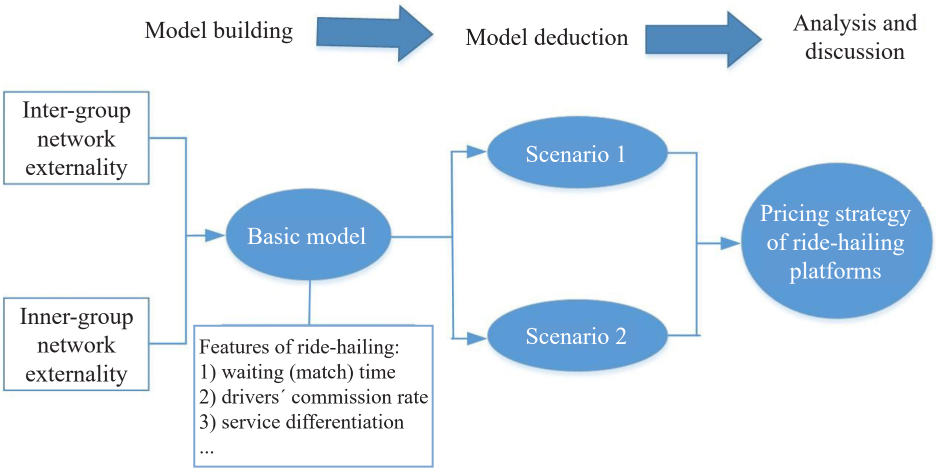

Figure 1 – Method description

2.2 Problem description and assumption

Assuming there is a linear city with a length of 1, two competitive ride-hailing platforms are located at two endpoints, i.e. 1 and 2. Travellers and drivers are distributed in positions x and y of this city. A platform charges a fee to the two sides for matching services, including a registration fee and a fraction of the transaction fee which relates to drivers' commission rate. In addition, travellers can join multiple platforms, while drivers can only join one platform. This is consistent with the real scenario, where travellers have more options, while drivers can join only one platform as a result of limitation policies from platforms or government.

One of the most vital effects of network externality is the utilising a specific product related to the user scale of the other side. In studying a traditional single-sided market, network externality is a result caused by users who use similar or same kind of products. However, there are not only interactions among users in the same group, but also interactions between travellers and drivers, which means inter-group network externality and inner-group network externality exist simultaneously in ride-hailing platforms.

The utility travellers achieve by using ride-hailing services is related to drivers' scale. When the drivers' scale is larger, a platform can provide more potential matches of drivers for travellers, leading to reduced average waiting times for travellers and increased utility. Similarly, the utility drivers achieve by providing travel services through ride-hailing platforms is related to users' scale as well. The average waiting time for travellers and drivers consists of three aspects, i.e. the match time of the platform, the time drivers arrive at the position of travellers and the on-road time from travellers' original position to destination. This paper mainly focusses on the match time waited by both sides. Zha et al. (2016) studied the average ride-hailing platform waiting time, and the average waiting time for users from one side is negatively related to the user scale of the other side, and positively related to the user scale of same side [18].

The model assumptions can be summarised in several bullet points as follows:

– A linear city is assumed to depict the competition of ride-hailing platforms.
– Ride-hailing platforms charge registration fees to both sides and commission fees to drivers.
– Drivers can only join one platform, while travellers can be multi-homing.
– The scale of users in the two sides is assumed to be related with inter-group and inner-group network externalities.
– Average waiting time of ride-hailing platforms is related to the scale of drivers and travellers.
– Travellers and drivers make their decisions according to the utility they achieve.

2.3 Utility function of travellers and drivers

Based on the assumption mentioned above and previous research [28–30], when both sides are single-homing, the utility function of travellers and drivers can be constructed as *Equations 1 and 2*. The utility function includes the effects of network externality, registration fee charged by platform, travellers' payment, drivers' commissions and time value. The parameters taken into account in this study are presented in *Table 1*. m denotes the platform, i.e. m=$\{1,2\}$, i=$\{c,d\}$, c denotes travellers, while d denotes drivers.

$$u_c^m = a_c n_d^m + e_c n_c^m - p_c^m h n_d^m - p_{sc}^m - \theta_c\left(\overline{\omega_c} - \beta_c n_d^m + r_c n_c^m\right) + v_c \quad (1)$$

$$u_d^m = a_d n_c^m + e_d n_d^m + \lambda_m p_c^m h n_c^m - p_{sd}^m - \theta_d\left(\overline{\omega_d} - \beta_d n_c^m + r_d n_d^m\right) + v_d \quad (2)$$

Table 1 – Notations

Parameter	Notation
x, y	Position of travellers or drivers in the linear city
u_i^m	Utility of travellers or drivers on platform *m*
$u_c^{1,2}$	Utility of travellers with multi-homing attribution
a_i	Unit benefit that travellers or drivers enjoy from inter-group network externality
e_i	Unit benefit that travellers or drivers enjoy from inner-group network externality
n_i^m	The scale of travellers or drivers that join ride-hailing platform *m*
p_c^m	Traveller's average payoff per transaction on platform *m*
λ_m	The commission rate of drivers on platform *m*
p_{si}^m	Platform *m*'s registration fee charge to travellers or drivers
θ_i	Unit time value of travellers or drivers
β_i	Coefficient of travellers' or drivers' average waiting time affected by drivers' or travellers' scale
r_i	Coefficient of travellers' or drivers' average waiting time affected by travellers' or drivers' scale
h	Constant
t	Unit cost of travellers for ride-hailing platform entry
f	Unit cost of drivers for ride-hailing platform entry
ω_i^m	Travellers' or drivers' average waiting time on platform *m*
$\omega_c^{1,2}$	Travellers' average waiting time when multi-homing
$\overline{\omega_i}$	The fixed waiting time of travellers or drivers
v_i	Fixed item of travellers' or drivers' utility
N^m	Transaction scale of travellers and drivers
π_m	Profit function of ride-hailing platforms *m*

When travellers are multi-homing, this means they can enjoy the services from two platforms and afford more costs as well. Users who are multi-homing will be jointly affected by network externalities from two platforms, and the average waiting time will decrease due to the increased scale of potential drivers. By referring to previous research [34], travellers' utility with a multi-homing scenario can be built as *Equation 3*.

$$u_c^{12} = a_c\left(n_d^1 + n_d^2\right) + e_c\left(n_c^1 + n_c^2\right) - p_c^1 h n_d^1 - p_c^2 h n_d^2 - p_{sc}^1 - p_{sc}^2 - \theta_c \omega_c^{12} \quad (3)$$

where $\omega_c^{12} = \overline{\omega_c} - \beta_c n_d^1 + r_c n_c^1 - \beta_c n_d^2 + r_c n_c^2$. u_c^{12} is travellers' utility in the multi-homing scenario. ω_c^{12} is travellers' average waiting time. In this paper, travellers who are multi-homing will choose to join two platforms. Since the scenario is that of a full market, travellers and drivers will choose to join at least one platform. Besides, as a typical two-sided market, travellers and drivers from the two sides of the ride-hailing platform tend to have a higher network externality, then we assume that $a_c + \theta_c\beta_c - p_c^m h > 0,\ a_d + \theta_d\beta_d + p_c^m h > 0$.

3. PRICING DECISION ANALYSIS OF COMPETITIVE RIDE-HAILING PLATFORMS

By introducing the combination of network externality and user attribution structure, this section constructs the model of the ride-hailing platform pricing decision issue with competitive scenarios. In this section, S1 denotes the scenario where both travellers and drivers are single-homing, whereas S2 denotes the scenario in which travellers are multi-homing, while drivers are single-homing. In this research, the Hotelling model is introduced to depict the competition of ride-hailing platforms. The Hotelling model is a mathematical model in economics used to describe the competition between sellers in a market, and it is widely used in transportation research [35, 36].

3.1 Pricing decision in scenario S1

In this scenario, users from the two sides can only join one ride-hailing platform. The scale of travellers is 1 and uniformly distributed in the linear city, which is same for drivers. The market structure of the ride-hailing platforms in this scenario is shown in *Figure 2*.

The indifference points of those travellers and drivers that join platforms 1 and 2 can be solved by *Equations 4 and 5*.

$$a_c n_d^1 + e_c n_c^1 - p_c^1 h n_d^1 - p_{sc}^1 - \theta_c\left(\overline{\omega_c} - \beta_c n_d^1 + r_c n_c^1\right) + v_c - tx = a_c n_d^2 + e_c n_c^2 - p_c^2 h n_d^2 - p_{sc}^2 - \theta_c\left(\overline{\omega_c} - \beta_c n_d^2 + r_c n_c^2\right) + v_c - t(1-x) \tag{4}$$

$$a_d n_c^1 + e_d n_d^1 + \lambda_1 p_c^1 h n_c^1 - p_{sd}^1 - \theta_d\left(\overline{\omega_d} - \beta_d n_c^1 + r_d n_d^1\right) + v_d - fy = a_d n_c^2 + e_d n_d^2 + \lambda_2 p_c^2 h n_c^2 - p_{sd}^2 - \theta_d\left(\overline{\omega_d} - \beta_d n_c^2 + r_d n_d^2\right) + v_d - f(1-y) \tag{5}$$

Then the scale of travellers and drivers from both ride-hailing platforms can be obtained, as it shown in *Equation 6*.

$$\begin{aligned} n_c^1 &= \frac{1}{2} + \frac{1}{2t}\left[\left(a_c + \theta_c\beta_c\right)\left(n_d^1 - n_d^2\right) + \left(e_c - \theta_c r_c\right)\left(n_c^1 - n_c^2\right) + \left(p_{sc}^2 - p_{sc}^1\right) - p_c^1 h n_d^1 + p_c^2 h n_d^2\right] \\ n_d^1 &= \frac{1}{2} + \frac{1}{2t}\left[\left(a_d + \theta_d\beta_d\right)\left(n_c^1 - n_c^2\right) + \left(e_d - \theta_d r_d\right)\left(n_d^1 - n_d^2\right) + \left(p_{sd}^2 - p_{sd}^1\right) + \lambda_1 p_c^1 h n_c^1 - \lambda_2 p_c^2 h n_c^2\right] \\ n_c^2 &= 1 - n_c^1 \\ n_d^2 &= 1 - n_d^1 \end{aligned} \tag{6}$$

Based on *Equation 6*, a more specific expression of users' scale can be calculated as *Equation 7*.

$$\begin{aligned} n_c^1 &= \frac{1}{2} + \frac{\left\{\begin{array}{c}\left[a_c + \theta_c\beta_c - \frac{1}{2}h\left(p_c^1 + p_c^2\right)\right]\left[\frac{1}{2}h\left(\lambda_1 p_c^1 - \lambda_2 p_c^2\right) + p_{sd}^2 - p_{sd}^1\right] \\ +\left(f - e_d + \theta_d r_d\right)\left[\frac{1}{2}h\left(p_c^2 - p_c^1\right) + p_{sc}^2 - p_{sc}^1\right]\end{array}\right\}}{2\left\{\left(t - e_c + \theta_c r_c\right)\left(f - e_d + \theta_d r_d\right) - \left[a_c + \theta_c\beta_c - \frac{1}{2}h\left(p_c^1 + p_c^2\right)\right]\left[a_d + \theta_d\beta_d + \frac{1}{2}h\left(\lambda_1 p_c^1 + \lambda_2 p_c^2\right)\right]\right\}} \\ n_d^1 &= \frac{1}{2} + \frac{\left\{\begin{array}{c}\left[a_d + \theta_d\beta_d + \frac{1}{2}h\left(\lambda_1 p_c^1 + \lambda_2 p_c^2\right)\right]\left[\frac{1}{2}h\left(p_c^2 - p_c^1\right) + p_{sc}^2 - p_{sc}^1\right] \\ +\left(t - e_c + \theta_c r_c\right)\left[\frac{1}{2}h\left(\lambda_1 p_c^1 - \lambda_2 p_c^2\right) + p_{sd}^2 - p_{sd}^1\right]\end{array}\right\}}{2\left\{\left(t - e_c + \theta_c r_c\right)\left(f - e_d + \theta_d r_d\right) - \left[a_c + \theta_c\beta_c - \frac{1}{2}h\left(p_c^1 + p_c^2\right)\right]\left[a_d + \theta_d\beta_d + \frac{1}{2}h\left(\lambda_1 p_c^1 + \lambda_2 p_c^2\right)\right]\right\}} \\ n_c^2 &= 1 - n_c^1 \\ n_d^2 &= 1 - n_d^1 \end{aligned} \tag{7}$$

The profits of ride-hailing platforms consists of two parts. The first part is the registration fees charged to both travellers and drivers. The second part is the fee charged to drivers from each transaction according to a commission rate, and this fee is related to the number of transactions. The Cobb-Douglas function is an economic function used to analyse and predict the output changes under different input combinations, as well as optimise the combination of input factors to achieve maximum output and profit. Based on previous research [34, 37], this paper assumes the transaction number as a Cobb-Douglas function form, and related to the scale of travellers and drivers, as shown in *Equation 8*.

$$\begin{aligned} N^1 &= h n_c^1 n_d^1 \\ N^2 &= h n_c^2 n_d^2 \end{aligned} \tag{8}$$

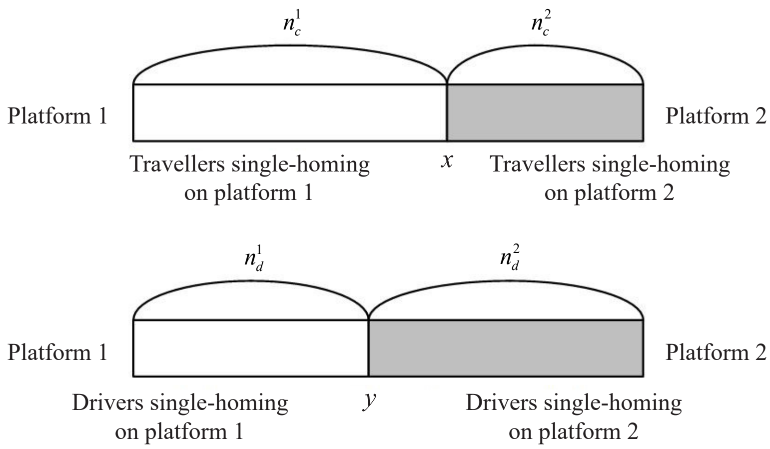

Figure 2 – Market structure in scenario S1

To simplify the calculation, the marginal cost of ride-hailing platforms is assumed as 0. With the advent of internet technology, the operation cost of platforms decreases to a large extent [38]. What is more, this assumption will not alter the main conclusions on the pricing strategy of ride-hailing platforms in this study and has also been verified by previous research [21]. Hence, the profit function of ride-hailing platforms is presented as *Equation 9*.

$$\begin{aligned}\pi_1 &= p_{sc}^1 n_c^1 + p_{sd}^1 n_d^1 + \left(1-\lambda_1\right) p_c^1 h n_c^1 n_d^1 \\ \pi_2 &= p_{sc}^2 n_c^2 + p_{sd}^2 n_d^2 + \left(1-\lambda_2\right) p_c^2 h n_c^2 n_d^2\end{aligned} \tag{9}$$

We further suppose that the target of ride-hailing platforms is profit maximisation, and the derivation of profit function can be obtained as in Appendix A.

Within the two-sided market model above, there may be several feasible solutions. However, this study mainly focuses on the equilibrium solution. Hence, considering extant literature and actual scenario, this paper supposes $\lambda_1 = \lambda_2 = \lambda,\ p_c^1 = p_c^2 = p_c$ According to the target of platform profit maximisation, on the condition of $4\left(t - e_c + \theta_c r_c\right)\left(f - e_d + \theta_d r_d\right) > [a_c + \theta_c \beta_c - p_c h + a_d + \theta_d \beta_d + \lambda p_c h]^2$, the equilibrium pricing structure with the scenario where both travellers and drivers are single-homing can be calculated, as presented in *Equation 10*.

$$\begin{aligned}p_{sc}^{S1} &= p_{sc}^1 = p_{sc}^2 = t - e_c + \theta_c r_c - a_d - \theta_d \beta_d - \frac{1}{2} h\left(1+\lambda\right) p_c \\ p_{sd}^{S1} &= p_{sd}^1 = p_{sd}^2 = f - e_d + \theta_d r_d - a_c - \theta_c \beta_c + \frac{1}{2} h\left(1+\lambda\right) p_c\end{aligned} \tag{10}$$

Further, the scale of travellers and drivers in the two sides of ride-hailing platforms can be obtained as *Equation 11*.

$$\begin{aligned}n_c^{S1} &= n_c^1 = n_c^2 = \frac{1}{2} \\ n_d^{S1} &= n_d^1 = n_d^2 = \frac{1}{2}\end{aligned} \tag{11}$$

Then, the ride-hailing platforms' equilibrium profit can further be calculated, as *Equation 12*.

$$\pi^{S1} = \pi_1 = \pi_2 = \frac{1}{2}\left(t - e_c + \theta_c r_c - a_d - \theta_d \beta_d + f - e_d + \theta_d r_d - a_c - \theta_c \beta_c\right) + \frac{1}{4}\left(1-\lambda\right) p_c h \tag{12}$$

The properties of ride-hailing platforms' pricing on both travellers and drivers can be analysed through *Equations 10 and 12*. It shows that the registration fee that the platform charges to one side is negatively related to the inter-group network externality this side has achieved. Besides, inner-group network externality negatively affects the registration fee of both sides. What is more, the equilibrium price of ride-hailing platforms is negatively related to inner-group network externality in this scenario. It also suggests that the profits of ride-hailing platforms are negatively related to the inter-group network externality of travellers and drivers, and the inner-group network externality from travellers and drivers will lead to a decrease of the platforms' profits.

The network effect will be internalised into the price structures of both sides, and this conclusion is similar to the results of Armstrong (2006) [30]. This result reflects the real scenario of the ride-hailing market and may draw some innovative points. If the inter-group network externality of one side is comparably higher than that of the other side, then the platform tends to charge a lower registration fee or even deploys a free strategy. This means the operations of ride-hailing services rely more on the side with a higher inter-group network externality and that they tend to reduce the fees to attract more users on this side. For example, in an early stage, ride-hailing platforms tend to offer subsidies or coupons to travellers, which can be explained by this result from the viewpoint of inter-group network externality.

Moreover, users in the same group may interact with each other and generate power in the same direction, which has been verified in previous research but rarely considered in the studies of ride-hailing markets. To some extent, the result may be innovative by considering the effect from the inner group. For example, drivers may unite to get a better work scenario or higher salary etc. In this scenario, ride-hailing platform should consider decreasing the driver registration fee as a result of inner-group network externality. On the contrary, if the scale of drivers is extremely high and they compete fiercely, then ride-hailing platforms may increase the fee level due to the negative effect of inner-group network externality.

Furthermore, both network externalities affect the profit negatively with the negative effect on registration fee. However, the platform with a higher network externality can also attract more travellers and drivers to join it and finally make more profit. This suggests that while network externality may hurt ride-hailing platforms, it could also be a strong profitable power with an appropriate strategy.

To summarise these results, Proposition 1 can be presented as followed: *In scenario S1, the registration fees of travellers or drivers charged by ride-hailing platforms are negatively related to inter-group network externality and inner-group network externality of both sides, and the profits of ride-hailing platforms are negatively related to inter-group and inner-group network externalities.*

This study has further examined the effect of entry cost, drivers' commission rate and time sensitive related to waiting time, which may address the specific pricing problem of ride-hailing services, and some interesting results have been obtained.

The entry cost also plays an important role on the pricing structure of ride-hailing platforms. If the entry cost of travellers and drivers is relatively higher, which means ride-hailing platforms can provide services with higher differentiation or individuation, ride-hailing platforms tend to charge a higher registration fee to travellers and drivers. Moreover, the entry cost of travellers and drivers has a positive effect on the profits of ride-hailing platforms. Entry cost can also be analysed as service differentiation, services with a higher differentiation will lead to a higher entry cost, resulting in increased pricing and profit.

As regards drivers' commission rate, if it is higher, platforms tend to decrease the registration fee charged to travellers and increase the registration fee charged to drivers, and the profit of ride-hailing platforms eventually shows a decreasing trend. What is more, the increase of average payoff per transaction has a negative effect on travellers' registration fees and a positive effect on drivers' registration fees, and the profit will be increased.

Further, the registration fee charged by ride-hailing platforms is determined by time sensitive factors of average waiting time as well, which verifies the results of Wei et al. (2020) [39]. To summarise these results, Proposition 2 is presented as followed: *In scenario S1, the registration fees of travellers or drivers charged by ride-hailing platforms are positively related to entry cost, and negatively related to drivers' commission rate and time sensitive factors of average waiting time.*

3.2 Pricing decision in scenario S2

In the ride-hailing market, travellers may have the opportunity to join more than one platform, which means a multi-homing scenario of travellers may exist. In this study, travellers have three options, i.e. join platform 1, join platform 2 or join both. However, drivers tend to join only one platform because of policy regulation from the platforms or government. The market structure of travellers and drivers is presented as *Figure 3*. The scale of travellers who only join platforms 1 or 2 is x_1 and 1-x_2, and x_2-x_1 is the scale of travellers who are multi-homing.

The scale of travellers who choose to be multi-homing is from x_1 to x_2. The indifference points can be solved through *Equations 13 and 14*.

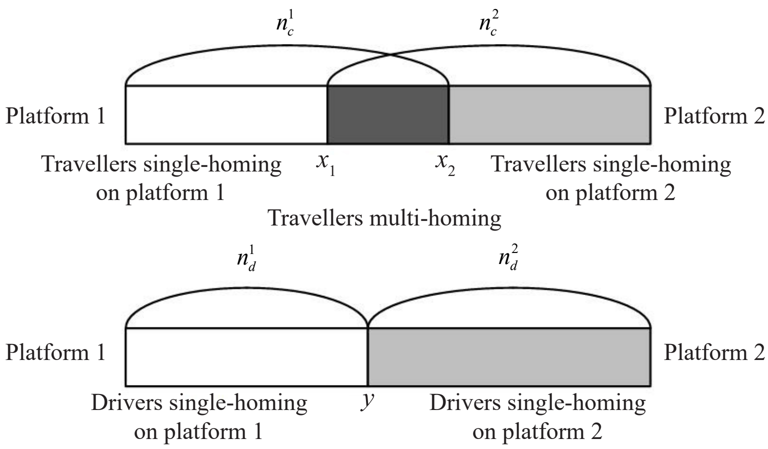

Figure 3 – Market structure in scenario S2

$$\begin{aligned} & a_c n_d^1 + e_c n_c^1 - p_c^1 h n_d^1 - p_{sc}^1 - \theta_c\left(\overline{\omega_c} - \beta_c n_d^1 + r_c n_c^1\right) + v_c - t x_1 = a_c\left(n_d^1 + n_d^2\right) + e_c\left(n_c^1 + n_c^2\right) - p_c^1 h n_d^1 - p_c^2 h n_d^2 \\ & - p_{sc}^1 - p_{sc}^2 - \theta_c \omega_c^{12} + v_c - t \end{aligned} \tag{13}$$

$$\begin{aligned} & a_c n_d^2 + e_c n_c^2 - p_c^2 h n_d^2 - p_{sc}^2 - \theta_c\left(\overline{\omega_c} - \beta_c n_d^2 + r_c n_c^2\right) + v_c - t\left(1 - x_2\right) = a_c\left(n_d^1 + n_d^2\right) + e_c\left(n_c^1 + n_c^2\right) - p_c^1 h n_d^1 - p_c^2 h n_d^2 \\ & - p_{sc}^1 - p_{sc}^2 - \theta_c \omega_c^{12} + v_c - t \end{aligned} \tag{14}$$

The travellers' scale on platforms 1 and 2 can be calculated, as shown in *Equation 15*.

$$\begin{aligned} & n_c^1 = x_2 = \frac{\left[a_c + \theta_c \beta_c - \frac{1}{2} h\left(p_c^1 + p_c^2\right)\right] n_d^1 - p_{sc}^1}{t - e_c + \theta_c r_c} \\ & n_c^2 = 1 - x_1 = \frac{\left[a_c + \theta_c \beta_c - \frac{1}{2} h\left(p_c^1 + p_c^2\right)\right] n_d^2 - p_{sc}^2}{t - e_c + \theta_c r} \end{aligned} \tag{15}$$

Since drivers are single homing, the calculation method of drivers' scale is similar to *Equation 7*, then drivers' scale can be obtained as *Equation 16* by combination of *Equations 7 and 15*.

$$n_d^1 = \frac{1}{2} + \frac{\begin{array}{c} \frac{1}{2}\left[\left(a_d + \theta_d \beta_d + \lambda_1 p_c^1 h\right)\left(a_c + \theta_c \beta_c - p_c^1 h\right) - \left(a_d + \theta_d \beta_d + \lambda_2 p_c^2 h\right)\left(a_c + \theta_c \beta_c - p_c^2 h\right)\right] \\ + \left(a_d + \theta_d \beta_d + \lambda_2 p_c^2 h\right) p_{sc}^2 - \left(a_d + \theta_d \beta_d + \lambda_1 p_c^1 h\right) p_{sc}^1 + \left(t - e_c + \theta_c r_c\right)\left(p_{sd}^2 - p_{sd}^1\right) \end{array}}{2\left(t - e_c + \theta_c r_c\right)\left(f - e_d + \theta_d r_d\right) - \left(a_d + \theta_d \beta_d + \lambda_1 p_c^1 h\right)\left(a_c + \theta_c \beta_c - p_c^1 h\right) - \left(a_d + \theta_d \beta_d + \lambda_2 p_c^2 h\right)\left(a_c + \theta_c \beta_c - p_c^2 h\right)} \tag{16}$$

$$n_d^2 = 1 - n_d^1$$

The profit function of ride-hailing platforms is shown in *Equation 17*, and the target of the ride-hailing platforms is to maximise profit.

$$\begin{aligned} & \pi_1 = p_{sc}^1 n_c^1 + p_{sd}^1 n_d^1 + \left(1 - \lambda_1\right) p_c^1 h n_c^1 n_d^1 \\ & \pi_2 = p_{sc}^2 n_c^2 + p_{sd}^2 n_d^2 + \left(1 - \lambda_1\right) p_c^2 h n_c^2 n_d^2 \end{aligned} \tag{17}$$

From *Equation 14*, we can further obtain the expressions in Appendix B.

Like in scenario S1, we assume $\lambda_1 = \lambda_2 = \lambda$, $p_c^1 = p_c^2 = p_c$. Based on the profit maximisation of the ride-hailing platforms and equilibrium conditions of the Hotelling model, the pricing structure of scenario S2 can be achieved as *Equation 18*.

$$p_{sc}^{S2} = p_{sc}^1 = p_{sc}^2 = \frac{1}{4}\left(a_c + \theta_c\beta_c - a_d - \theta_d\beta_d - 2hp_c\right)$$

$$p_{sd}^{S2} = p_{sd}^1 = p_{sd}^2 = \frac{1}{4\left(t - e_c + \theta_c r_c\right)}\left\{\begin{array}{c} 4\left[\begin{array}{c}\left(t - e_c + \theta_c r_c\right)\left(f - e_d + \theta_d r_d\right) \\ -\left(a_c + \theta_c\beta_c - hp_c\right)\left(a_d + \theta_d\beta_d + hp_c\right)\end{array}\right] \\ +\left(a_c + \theta_c\beta_c - a_d - \theta_d\beta_d - 2hp_c\right)\left[-a_c - \theta_c\beta_c + \left(2 - \lambda\right)hp_c\right]\end{array}\right\} \tag{18}$$

The scale of travellers and drivers in an equilibrium scenario can further be calculated, as presented in *Equation 19*.

$$n_c^{S2} = n_c^1 = n_c^2 = \frac{a_c + \theta_c\beta_c + a_d + \theta_d\beta_d}{4\left(t - e_c + \theta_c r_c\right)}$$

$$n_d^{S2} = n_d^1 = n_d^2 = \frac{1}{2} \tag{19}$$

Finally, the equilibrium profit of the ride-hailing platforms can be obtained, as shown in *Equation 20*.

$$\pi^{S2} = \pi_1 = \pi_2 = \frac{1}{16\left(t - e_c + \theta_c r_c\right)}\left\{\begin{array}{c}\left(a_c + \theta_c\beta_c + a_d + \theta_d\beta_d\right)\left(a_c + \theta_c\beta_c - a_d - \theta_d\beta_d - 2\lambda hp_c\right) \\ +8\left[\left(t - e_c + \theta_c r_c\right)\left(f - e_d + \theta_d r_d\right)\right. \\ \left.-\left(a_c + \theta_c\beta_c - hp_c\right)\left(a_d + \theta_d\beta_d + hp_c\right)\right] \\ +2\left(a_c + \theta_c\beta_c - a_d - \theta_d\beta_d - 2hp_c\right)\left[-a_c - \theta_c\beta_c + \left(2 - \lambda\right)hp_c\right]\end{array}\right\} \tag{20}$$

In this scenario, the registration fee charged by the ride-hailing platforms will be affected by the inter-group network externality of both sides. To simplify the analysis process, we formulate that $A_c = a_c + \theta_c\beta_c$, $A_d = a_d + \theta_d\beta_d$, $T = t - e_c + \theta_c r_c$, $F = f - e_d + \theta_d r_d$. Then the properties can be analysed through Appendix C.

Appendix C indicates that the travellers' registration fee charged by the ride-hailing platforms is positively related to the inter-group network externality generated by the drivers' side, and negatively related to the inter-group network externality generated by the travellers' side. What is more, the drivers' registration fee charged by the ride-hailing platforms is jointly affected by the inter-group network externality and inner-group network externality. Both network externalities of the two sides have a negative effect on drivers' registration fee. This result may be different from previous studies, and it demonstrates the necessity of introducing network externality factors, especially inner-group network externality.

Further, the increase of entry costs of the two sides will lead to a drivers' registration fee increase. The analysis results are similar to the conclusions drawn based on network externality. In scenario S2, if the average waiting time of one side is highly affected by scale of the other side, then the platform tends to reduce the registration fee. Moreover, if the average waiting time of one side is affected more by this side, the platform will increase the registration fee.

The properties have been summarised, and Proposition 3 is presented as follows: *In scenario S2, the registration fees of travellers charged by ride-hailing platforms are positively related to the inter-group network externality generated by the drivers' side, and negatively related to the inter-group network externality generated by the travellers' side. The registration fees of travellers charged by ride-hailing platforms are negatively related to the inter-group and inner-group network externalities of both sides, and negatively related to the entry cost of the two sides.*

By analysing the scale of travellers in an equilibrium scenario, Appendix D can be obtained. It indicates that the travellers' scale in scenario S2 is positively affected by the inter-group network externality from both sides and the inner-group network externality of travellers' side. Further, travellers' entry cost has a negative effect on travellers' scale. Then Proposition 4 can be deduced as follows: *In scenario S2, travellers' scale is positively* *related to the inter-group network externality from both sides and the inner-group network externality of the travellers' side, and negatively related to the entry cost of travellers.*

Furthermore, based on the analysis of ride-hailing platforms' profits in scenario S2, we have obtained the expressions in Appendix E.

Appendix E suggests that the profits of ride-hailing platforms will be decreased with the increase of network externalities. Specifically, both inter-group network externality and inner-group network externality have a negative effect on profit, and this result agrees with the conclusions in scenario S1. In addition, the profits of ride-hailing platforms can also be positively affected by the entry cost of travellers and drivers.

To summarise this result, Proposition 5 is presented: *In scenario S2, the profits of ride-hailing platforms are negatively related to the inter-group network externality and inner-group network externality from both sides, and positively related to the entry cost of both sides.*

Based on further analysis of drivers' commission rate, Appendix F can be deduced. The increase of drivers' commission rate will lead to a decrease of profit. However, the relationship between drivers' commission rate and drivers' registration fee charged by the ride-hailing platforms also relies on the relative strength of the inter-group network externalities of the two sides. This result reveals the potential pattern of ride-hailing drivers, which may be meaningful and contribute to current research.

If the inter-group network externality of drivers is relatively higher, then there exists $\partial p_{sd}^{S2} / \partial \lambda < 0$. If the inter-group network externality of travellers is relatively higher, then there exists $\partial p_{sd}^{S2} / \partial \lambda > 0$. It shows that when inter-group network externality generated by drivers is higher, drivers' registration fee is negatively related to drivers' commission rate. Further, when inter-group network externality generated by travellers is higher, then the increase of drivers' commission rate will lead to an increase in driver registration fee.

The effects of average cost per transaction can be analysed through Appendix G. Unlike scenario S1, in the relationship between average cost per transaction and pricing, the profit relies on the relative strength of the inter-group network externality generated by travellers and drivers. If the inter-group network externality generated by travellers is relatively higher, there exists $\partial p_{sd}^{S2} / \partial p_c > 0,\ \partial \pi^{S2} / \partial p_c > 0$, which means the increase of average cost per transaction will lead to a higher registration fee for drivers and a higher profit for ride-hailing platforms. Moreover, if the inter-group network externality generated by drivers is relatively higher, there exists $\partial p_{sd}^{S2} / \partial p_c < 0,\ \partial \pi^{S2} / \partial p_c < 0$, which suggests that average cost per transaction has a negative effect on both drivers' registration fee and ride-hailing platforms' profit.

4. DISCUSSION

The results obtained in the two scenarios indicate that the factors of network externalities play an important role in the pricing strategies of ride-hailing platforms. Generally, the effect of inter-group network externality examined in this paper verifies the conclusions drawn from previous research [28–30]. However, the results obtained by consideration of inner-group network externality shows a different trend, which could be meaningful and enrich current research. By comparisons with previous studies, we believe that the factors of inner-group network externality also have a significant influence on the pricing of ride-hailing platforms, which may have been less considered by previous research. What is more, the conclusions are also related to specific scenarios, for example, user structure in this study.

In general, an increase of inter-group network externality will lead to a reduction of registration fees for travellers and drivers. However, in the case of multi-homing, the registration fee charged by the platform for multi-homing travellers is positively related to the inter-group network externality of drivers. As an important part of network externalities, the research proves that inner-group network externalities also play an important role in platform operations. Among them, an increase in inner-group network externality will reduce the registration fee for travellers and drivers. However, in the case of multi-homing, the platform's pricing structure for travellers is not affected by the inner-network network externality, which may be an insightful result.

As for the factor of entry cost, it can also be illustrated as service differentiation. One of the significant features of ride-hailing platforms is customised service. There is no doubt that customised services will generate higher costs than normal travel services, which may result in higher registration fees and better travel experience. Platforms will make more profit by providing several differentiated services. For example, Uber provides UberX, Uber Black and Uber Van [40]. In China, Didi provides several services [13], like fast ride, tailored ride etc.

Additionally, the effect of drivers' commission rate has been less explored in previous research [41]. The conclusions drawn from this study provide an insight to strategies of ride-hailing platforms. They indicate that when the inter-group network externality generated by drivers is relatively large, as the drivers' commission rate increases, the platform will reduce the registration fee for drivers. According to several interviews of Didi drivers, the platform takes almost 15% to 20% of income per transaction. Based on the results of this research, there is a balance between the effects of drivers' commission rate and network externality.

Nowadays, the effect of network externality arouses attention from ride-hailing platforms. At an early stage, ride-hailing platforms tend to put forward more attractive policies for travellers and drivers, for example lower prices [1, 2, 18]. In China, Didi has provided discount coupons for travel transactions, and travellers can apply for rewards after successful invitation from their friends or families. Through such policies, the user scale of Didi has increased rapidly. With respect to the conclusions in this research, although network externality may affect platform profit negatively, it is still essential for ride-hailing platforms to use network externality rationally to attract users and improve their stickiness, and finally make profit in the long term.

Overall, this research has examined the pattern of ride-hailing services operations and studied the role of inter-group and inner-group network externalities, which may contribute to the understanding of group behaviour and sharing economy. Moreover, the factors of entry cost, drivers' commission rate and average waiting time are introduced into the model, which may provide a better understanding of operation mode of ride-hailing platforms and reveal the rules behind the superficial phenomenon of sharing economy.

5. CONCLUSION

The purpose of this research is to examine the general pattern of the pricing strategies of ride-hailing platforms. In this paper, the pricing problem of ride-hailing platforms is investigated by considering inter-group network externality and inner-group network externality. Additionally, the structures of travellers and drivers are introduced into model construction. Further, this study has considered time sensitive factors and drivers' commission rate to reflect the characteristics of transportation industry. Based on model construction and analysis process, the effect of network externality, time sensitive factors, drivers' commission rate and entry cost on pricing, user scale and profits of ride-hailing platforms are examined.

Some implications and suggestions can be derived from researching the pricing strategies of ride-hailing platforms.

Theoretical implications. From a theoretical perspective, the questions proposed in the introduction have been answered, and the gap in research on the pricing strategy of ride-hailing platforms with network externalities has been closed to some extent. As one of the key issues of ride-hailing platforms, it is necessary to investigate the pricing strategy from the perspective of network externalities and user attribution structures. Based on two-sided market theory, this paper investigates the general pattern of platform competition behaviour in the ride-hailing area. The results suggest that the combination of inter-group network externalities and inner-group network externalities is useful for understanding pricing strategies. In addition, the results drawn from two user attribution structures show a distinct feature, for example, the price charged to travellers is positively related to the inter-group network externality from drivers when travellers are multi-homing. Overall, from the perspective of consumer behaviour and platform competition, it is theoretically meaningful.

Practical implications. From a practical perspective, this paper provides several practical implications. On the one hand, it is necessary for ride-hailing platforms to understand the regular patterns in the operation of the market and the group behaviour of both sides of users. This study examines the effect of inter-group network externalities and inner-group network externalities under different user attribution structures, which may be helpful for ride-hailing platforms to formulate practical pricing strategies. On the other hand, from the aspect of government, this study may provide a reference for more thoughtful and scientific regulation policies on ride-hailing platforms. Therefore, it may offer practical implications for both ride-hailing platforms and government or transportation management departments.

Policy suggestions. Based on the research results of this paper, several policy suggestions can be presented, both for governments and ride-hailing platforms. On the government side, it is important to promote a thriving transportation market and maintain fairness for both drivers and travellers. Then the multi-homing behaviour of travellers should be protected and the commission rate for drivers should be limited to a reasonable interval. Further, such market environment should be guaranteed as to avoid platform monopoly. On the side of ride-hailing platforms, it is essential to balance the relationship between user scale and total profit. According to the results, the platforms should make a relative equilibrium between the scales of drivers and travellers to balance bilateral network externalities. Also, an appropriate commission rate for drivers should be put forward to promote the development of the platform.

This study may contribute to strategy and policy decision making for ride-hailing platforms, but there are still several limitations which should be noted. Firstly, ride-hailing platform operations include various complicated factors and agents from multiple aspects, hence it is essential to further investigate ride-hailing platform issues by considering more related factors. Secondly, massive amounts of data have been generated with the promotion of ride-hailing services, so it is necessary to study the general patterns of ride-hailing platforms and travellers' behaviour based on methods of big data analysis. Thirdly, this research has been carried out mainly from a macroscopic viewpoint, hence the behaviour of travellers and drivers at a more detailed level may be overlooked, which needs to be further considered in the next stage.

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考虑组间和组内网络外部性的网约车平台定价决策研究

摘要：
基于双边市场理论构建模型研究了组间网络外部性和组内网络外部性作用下的网约车平台定价决策问题。考虑了两种用户归属结构，出行者和司机均单归属、出行者多归属司机单归属。此外，在研究中引入了时间敏感参数和司机提成比例等体现交通出行行业特征。最终分析了网络外部性、时间敏感参数、司机提成比例和平台单位进入成本对网约车平台定价、用户群体规模和平台收益的影响。研究表明：组间网络外部性、组内网络外部性的提高会导致平台对出行者和司机注册费定价的降低，但在出行者多归属的情况下，平台对多归属方出行者收取的注册费还与单归属方司机所产生的组间网络外部性正相关。在出行者规模方面，组间网络外部性、组内网络外部性与用户规模正相关。此外，在两种用户归属结构下，网约车平台的收益都会与双边出行者和司机产生的组间网络外部性和组内网络外部性负相关。

关键词：
网约车平台，定价决策，网络外部性，双边市场

APPENDIX

To simplify the expressions in the Appendix, this paper set $A_c = a_c + \theta_c\beta_c, A_d = a_d + \theta_d\beta_d$, $T = t - e_c + \theta_c r_c, F = f - e_d + \theta_d r_d$.

A. The derivation of profit function with respect to pricing in scenario S1.

$$\frac{\partial \pi_1}{\partial p_{sc}^1} = n_c^1 + \left[p_{sc}^1 + (1-\lambda_1)p_c^1 h n_d^1\right]\frac{\partial n_c^1}{\partial p_{sc}^1} + \left[p_{sd}^1 + (1-\lambda_1)p_c^1 h n_c^1\right]\frac{\partial n_d^1}{\partial p_{sc}^1}$$

$$\frac{\partial \pi_1}{\partial p_{sd}^1} = \left[p_{sc}^1 + (1-\lambda_1)p_c^1 h n_d^1\right]\frac{\partial n_c^1}{\partial p_{sd}^1} + n_d^1 + \left[p_{sd}^1 + (1-\lambda_1)p_c^1 h n_c^1\right]\frac{\partial n_d^1}{\partial p_{sd}^1}$$

$$\frac{\partial \pi_2}{\partial p_{sc}^2} = n_c^2 + \left[p_{sc}^2 + (1-\lambda_2)p_c^2 h n_d^2\right]\frac{\partial n_c^2}{\partial p_{sc}^2} + \left[p_{sd}^2 + (1-\lambda_2)p_c^2 h n_c^2\right]\frac{\partial n_d^2}{\partial p_{sc}^2}$$

$$\frac{\partial \pi_2}{\partial p_{sd}^2} = \left[p_{sc}^2 + (1-\lambda_2)p_c^2 h n_d^2\right]\frac{\partial n_c^2}{\partial p_{sd}^2} + n_d^2 + \left[p_{sd}^2 + (1-\lambda_2)p_c^2 h n_c^2\right]\frac{\partial n_d^2}{\partial p_{sd}^2}$$

B. The derivation of profit function with respect to pricing in scenario S2.

$$\frac{\partial n_c^1}{\partial p_{sc}^1} = \frac{\left[a_c + \theta_c\beta_c - \frac{1}{2}h\left(p_c^1 + p_c^2\right)\right]\frac{\partial n_d^1}{\partial p_{sc}^1} - 1}{t - e_c + \theta_c r_c}$$

$$\frac{\partial n_c^1}{\partial p_{sd}^1} = \frac{\left[a_c + \theta_c\beta_c - \frac{1}{2}h\left(p_c^1 + p_c^2\right)\right]\frac{\partial n_d^1}{\partial p_{sd}^1}}{t - e_c + \theta_c r_c}$$

$$\frac{\partial n_c^2}{\partial p_{sc}^2} = \frac{\left[a_c + \theta_c\beta_c - \frac{1}{2}h\left(p_c^1 + p_c^2\right)\right]\frac{\partial n_d^2}{\partial p_{sc}^2} - 1}{t - e_c + \theta_c r_c}$$

$$\frac{\partial n_c^2}{\partial p_{sd}^2} = \frac{\left[a_c + \theta_c\beta_c - \frac{1}{2}h\left(p_c^1 + p_c^2\right)\right]\frac{\partial n_d^2}{\partial p_{sd}^2}}{t - e_c + \theta_c r_c}$$

C. The derivation of pricing with respect to network externalities and entry costs in scenario S2.

$$\frac{\partial p_{sc}^{S2}}{\partial A_c} = \frac{1}{4} > 0$$

$$\frac{\partial p_{sc}^{S2}}{\partial A_d} = -\frac{1}{4} < 0$$

$$\frac{\partial p_{sd}^{S2}}{\partial A_c} = \frac{1}{4T}\left(-3A_d - 2A_c - \lambda p_c h\right) < 0$$

$$\frac{\partial p_{sd}^{S2}}{\partial A_d} = \frac{1}{4T}\left(-3A_c + 2p_c h + \lambda p_c h\right) < 0$$

$$\frac{\partial p_{sd}^{S2}}{\partial F} = 1 > 0$$

$$\frac{\partial p_{sd}^{S2}}{\partial T} = \frac{1}{16T^2}\begin{bmatrix} 8\left(A_c - p_c h\right)\left(A_d + p_c h\right) + 4\left(A_d + p_c h\right)\left(1-\lambda\right)p_c h \\ +4\left(A_c - p_c h\right)\left(A_c - p_c h\right) + 4\left(A_c - p_c h\right)\left(A_d + \lambda p_c h\right) \end{bmatrix} > 0$$

D. The derivation of traveller's scale with respect to network externalities and entry costs in scenario S2.

$$\frac{\partial n_c^{S2}}{\partial A_c} = \frac{1}{4T} > 0$$

$$\frac{\partial n_c^{S2}}{\partial A_d} = \frac{1}{4T} > 0$$

$$\frac{\partial n_c{}^2}{\partial T} = \frac{-\left(A_c + A_d\right)}{4T^2} < 0$$

E. The derivation of platform profit with respect to network externalities and entry costs in scenario S2.

$$\frac{\partial \pi^{S2}}{\partial F} = \frac{1}{2} > 0$$

$$\frac{\partial \pi^{S2}}{\partial T} = \frac{1}{\left[16T\right]^2}\begin{bmatrix} 16\left(A_c - p_c h\right)^2 + 16\left(A_d + p_c h\right)^2 + 64\left(A_c - p_c h\right)\left(A_d + \lambda p_c h\right) \\ +32\left(A_c - p_c h\right)\left(A_d + p_c h\right) \end{bmatrix} > 0$$

$$\frac{\partial \pi^{S2}}{\partial A_c} = \frac{1}{16T}\left(-2A_c - 6A_d - 4\lambda p_c h\right) < 0$$

$$\frac{\partial \pi^{S2}}{\partial A_d} = \frac{1}{16T}\left[-2A_d - 2A_c - 4\left(A_c - p_c h\right)\right] < 0$$

F. The derivation of platform profit and pricing with respect to driver's commission rate in scenario S2.

$$\frac{\partial p_{sd}^{S2}}{\partial \lambda} = \frac{1}{4T}\left[-p_c h\left(A_c - A_d - 2p_c h\right)\right]$$

$$\frac{\partial \pi^{S2}}{\partial \lambda} = \frac{1}{16T}\left[-4p_c h\left(A_c - p_c h\right)\right] < 0$$

G. The derivation of platform profit and pricing with respect to average cost per transaction in scenario S2.

$$\frac{\partial p_{sc}^{S2}}{\partial p_c} = -\frac{1}{2}h < 0$$

$$\frac{\partial p_{sd}^{S2}}{\partial p_c} = \frac{h}{4T}\left[\left(2+\lambda\right)A_d + 4\lambda p_c h - \lambda A_c\right]$$

$$\frac{\partial \pi^{S2}}{\partial p_c} = \frac{h}{16T}\left(-4\lambda A_c + 8\lambda p_c h + 4A_d\right)$$