Regulation for ride-sourcing market considering congestion

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Abstract: Ride-sourcing refers to a transportation service where private car owners make their own car available for public hire for passengers. In recent years, ride-sourcing market has been growing rapidly and became a huge market. Nevertheless, unlike the traditional taxi market, ride-sourcing market is lack of regulation, which means that there could be some conflicts between the platform who wants to maximize the profit and the city planner who wants to maximize the social welfare. Therefore, regulation is necessary to achieve the balance between profit and social welfare. One of the big issues that may caused by ride-sourcing is traffic congestion, since the most vehicles are private cars. Therefore, it is necessary to take congestion into consideration when establishing the optimal regulation. In this paper, the regulation for ride-sourcing platform in terms of trip fare and commission is investigated in both situation where congestion is considered and not considered. By comparing the two results, it can be conclude that when considering congestion, the optimal regulation policy could be different.

Key words: *Ride-sourcing; Transportation; Congestion*

1. Introduction

As the development of smart mobile device and internet technology, location tracking service becomes more reliable and convenient for individuals to use. This brings a new kind of transportation service, ride-souring. Matching between traditional taxi and passengers usually based on the possibility that customers meet an empty-crusing taxis on the streets. Such traditional way makes the matching effeciency relatively poor and lacks of comfort since the waiting time is unpredictable. However, the appearence of ride-sourcing allows customers and drivers to track the location of each other so that if a customer sends a demand from their smartphone, the platform which run by the ride-sourcing company will find a relatively close crusing driver to pick up the passenger as soon as possible, which significantly raises the matching rate and efficiency. After reaching the destination, customers will pay trip fare to drivers and the platform will charge a small percent of commission. Thanks to the convenience and competitive price, ride-sourcing service attracts many drivers and customers.

Although ride-sourcing enjoys great success in the last few years, some controversies caused by ride-sourcing cannot be ignored. Unlike the traditional taxi market, ride-sourcing has comparatively fewer regulatory requirements (1986) [1]. For the ride-sourcing company, the goal is always to maximize the profit, which may bring some issues. On the other hand, for city planner, total social welware will be considered in the first place, which may cause a conflict against the ride-sourcing platform. Previous study done by Zha, Yin and Yang (2016) [2] indicated that without regulation, price could be very expensive in a monoply ride-sourcing market and they explored the effective regulation policies in terms of trip fare in a hypothetical situation subject to the constraint that ride-sourcing companies are self-sustainable.

Nevertheless, the model in the study didn't consider the effect of congestion which is a rather important thing to be considered because the source of ride-sharing vehicles is mostly private cars and taxis which are the main cause of congestion in urban road networks. When ride-sourcing becomes popular in a city, it is possible that too many drivers are trying to make money by crusing around in the downtown area and offer the ride-sourcing service, which increases the congestion. Actually, New York City has already established some regulations for ride-sharing companies like Uber and Lyft to reduce congestion caused by too many empty crusing vehicles. The regulation emphasized that these companies should mandate their drivers to carry a passenger at least 69 percent of the time while operating in Manhattan below 96th St (2019)[3]. Such kind of regulation indicates the importance of considering congestion in the regulation making. However, it might not be always true that reducing the user of ride-sourcing is preferable in terms of the social welfare. Since the popularization of ride-sourcing can also reduce the users of private cars, thus, subsequently reduce the congestion. In conclusion, it is difficult to decide the optimal regulation policy considering congestion.

In this study, the effective regulation for ride-sourcing considering congestion in a hypothetical city is investigated. In one situation, public transportation is a substitutional option. In the other situation, public transportation is not a substitutional option. In these two situations, the optimal regulation on the trip fare and commission fee of ride sourcing is analyzed considering congestion. After that, the optimal regulation without considering congestion is also analyzed and compared with those cnosidering congestion. Then, based on the result of the comparison, implications are derived as to how the optimal regulation policy is affected as congestion is considered.

The organization of this paper is as follows. Chapter 2 discusses the previous studies and their relation with this study. Chapter 3 formulates the model composed of two main parts, matching function part and customer demands part. Chapter 4 shows the result of numarical analysis and discusses the properties of the optimal regulation for different situations. The paper then concludes with a summary of this study and the policy implications as well as the discussion of future work in Chapter 5.

2. Privious studies

Previous researches about the regulations for ride-sourcing will be reviewed in the following two sections. In the first section, studies about the regulation for ride-sourcing market will be reviewed. In the second section, studies about the matching model will be reviewed.

(1) Studies related to regulation for ride-sourcing

Compared with the relatively new ride-sourcing market, taxi industry has a comprehensive regulation policies in many aspects, such as fares, entry level and service according to the report done by Frankena and Pautler (1986) [1]. Researches also proved that these regulations does not only protect the drivers income but also reduce the externality like pollution and congestion [4]. However, when ride-sourcing company such as Uber and Lyft appeared, the lack of regulation caused unfair competition between cab drivers and ride-sourcing drivers, which brought troubles for goverment officials and legislators. Some countries simply reject these kind of companies and treat them as illegal [2]. The others accept the service after they regulate the ride-sourcing market. Study by Shasheen (2014) [5] found that although there are various laws and regualtions, they all essentially codify the insurance coverage, drviers background check and inspection protocols that ride-sourcing companies already have in place. Based on this situation, Zha, Yin and Yang conducted their study (2016) [2] of investigating the regulation for ride-sourcing in new aspects, service fare and fleet size. Their study indicates that in the monoply market, ride-sourcing company maximizes the joint profit with the drivers. By regulating trip fare and commision, the social welfare could be improved. Nevertheless, the study is based on the assumption that congestion is not caused by the vehicles of ride-sourcing.

On the other hand, some studies of the regulation in the taxi market already took congestion externality into consideration. For the work of Yang et al. (2005) [6], they use Hong Kong as an example to show the high density of taxi and then investigate the monopoly scenario, the social optimum of cruising taxi services in the presence of congestion externality by adopting a realistic distance-based and delay-based fare structure. As a conclusion, they find the optimal solution is different according to whether congestion is considered or not, which shows the importance of considering congestion also in ride-sourcing regulation.

(2) Matching model

The studies of taxi market were initiated by Douglas (1972) [7] who developed the aggregated model for the taxi sector. His work had been adopted by many subsequent studies. For example, De vany (1975) [8] proposed equilibrium solutions for different types of markets, such as monoply market and competitive market. Most studies about taxi markets used aggregated models with some basic assumptions [9]. Specifically, demand is a decreasing function of the expected fare and waiting time; the expected customer waiting time decreases with the total vacant taxi-hours; and the cost of operating a taxi per unit time is a constant. The expected waiting time plays an important role because it is the measure of service quality and affects the custmoers' desicions whether to take taxi or not, which ultimately affects the market equilibrium. Thus, the waiting time is considered to be a crucial variables in many studies.

However, some later studies, for example, study by Yang and Yang (2011) [9], claimed that it is not precise to express the customer waiting time as a function of only vacant taxi-hours. They argued that it is necessary to pay more attention to the bilateral customer-taxi searching and meeting relationship that characterizes the real-world taxi market where the customer waiting time is affected by both the number of vacant taxi vehicles and the number of waiting customers. Bilateral searching and matching are modeled by a matching function to account for time and efforts required to look for each other, also known as the market friction. Bilateral searching and mathicng between agents is a topic first appeared in economics. In economics, mathicng function is widely used to describe the time and effort under the presence of market frictions [10]. Mathcing function was firstly introduced to the analysis of taxi market by Schroeter (1983) [11]. He analyzed the services in a regulated market where radio dispatching and an airport taxi stand are the primary modes of operation. By applying a Cobb-Douglas type function as matching function, Yang and Yang (2011) [9] investigated an aggregate taxi market with search frictions.

As the development of matching model in taxi market, study of He and Shen (2015) [12], Wang et al. (2016) [13] find that the matching techonology used for radio dispatch taxi companies is quite similar to the one offered by ride-sourcing platform although that of ride-sourcing is more effecient with a larger matching area and more complete information. Thus, Zha, Yin and Yang (2016)[2] assume that aggregate mathcing function is also valid for ride-sourcing and analyze the solution properties and general economic outcomes of a hypothetical monopoly ride-sourcing market.

(3) Relationship between privious study and this study

Although the study of Yang et al. (2005) [6] explored the regulation for taxi service in the presence of congestion externality, the market friction between customers and drivers were not considered. On the other hand, work of Zha, Yin and Yang (2016) [2]explored the regulation policy for ride-sourcing market without considering congestion. Therefore, the purpose of this study is to develop the regulation policy for ride-sourcing market considering congestion with the application of matching process modeling.

In the study of Zha, Yin and Yang (2016) [2], since congestion is not considered, the choice model consists of only two options, ride-sourcing and other alternative modes. To bring congestion into considerarion, it is necessary to formulate the traffic volume as a function of both ride-sourcing vehicles and private vehicles. Then, by applying a BPR function, travel time can be expressed as a funtion of the traffic volume, which is different from the previous study where travel time is treated as a constant. Since travel time is one of the elements that affect decision making of users, the degree of congestion will ultimately affect the market equilibrium.

To discuss the effect of congestion on the regulation policy, a hypothetical city with only two areas is considered as figure 1. Living area and business area are connected by two one-way road. People will use road 1 to go to work in the morning and road 2 to come home in the evening. Therefore, to make the matching as soon as possible, drivers will be crusing around in the living area in the morning and business area in the evening, which also indicates that vacant cruising vehicles are not considered as a source of congestion. Then, two situation is considered in this city. The first is that ride-sourcing and private car are the only two options for transportation. The second is that public transportations like trains which are not affected by the road condion is also added to the options. The optimal regulation policies in these two situations are analyzed. Then, based on the result of the analysis, implications are derived as to how the optimal regulation polict is affected as congestion is considered.

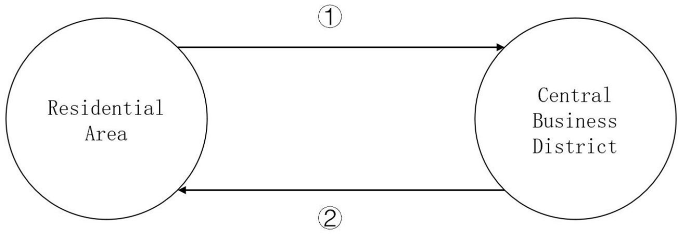

Figure 1: Hypothetical City

3. Model derivation

The model derivation will be divided into three parts, matching model, decision making of the households and optimization problems to analyze the optimal regulation policy as well as the monopoly market.

(1) General frame

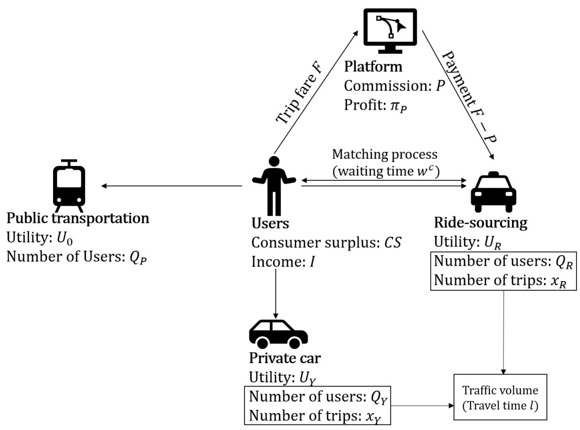

Figure 2: General Frame

Figure 2 shows the general frame of this model. Users of transportation modes are decision makers in this model and they will have three options, public transportation, private car and ride-sourcing. Each option has a utility U based on the cost. By applying logit model, number of users can be estimated from the utility. And for each user, number of trips x will be made based on the budget and cost. After that, the number of users and their number of trips will determine the total traffic volume which related to the travel time l. If users choose ride-sourcing, the platform will match the user and the driver through a matching algorithm. This matching process will determine the waiting time w^c. After reaching destination, user will pay trip fare F to the platform and platform will keep P as the commission. Finally, drivers receive $F-P$ as their payment. When considering monopoly market, platform will always maximize their profit π_P. The regulation will be determined in terms F and P to achieve the first-best scenario where sum of consumer surplus CS and producer surplus π_P is maximized. Details of matching process, decision making and optimization problems will be introduced subsequently.

Let N^c denote the number of waiting customers and N^{vt} denote the number of vacant ride-sourcing vehicles. I assume a stationary state where N^c and N^{vt} are time invariant. Then, N^c can be expressed as:

$$N^c = w^c Q \tag{1}$$

where w^c is the average customer waiting time and Q is the customer demand per hour. N^{vt} can be expressed as:

$$N^{vt} = w^t T^{vt} \tag{2}$$

where w^{vt} is the is the average searching time for a driver before the meeting and T^{vt} is the arrival rate of vacant vehicles per hour. The purpose of matching function is to capture the market friction between users and drivers, hence, the matching rate or the meeting rate m^{c-t} will be a function of both N^{vt} and N^c. More specifically, a Cobb-Douglas function is constructed to express the meeting rate m^{c-t}:

$$m^{c-t} = M(N^{vt}, N^c) = A(N^{vt})^{\alpha_1}(N^c)^{\alpha_2} \tag{3}$$

Here, α_1 and α_2 are the elasticities which reflect the matching technology of the ride-sourcing platform. The sum of α_1 and α_2 determines the mathcing function exhibits increasing returns to scale when the sum is larger than one, constant returns to scale when the sum is one, and decreasing returns to scale when the sum is less than one according to the previous study by Yang and Yang (2011) [9]. Based on the previous study of Schroeter (1983)[11], in radio-dispatching taxi markets and other transportation systems, increasing-returns-to-scale property is commonly discovered. The reason is that higher density of both deivers and users increases the matching probability. In this study, the focus will be also on the increasing returns to scale matching function. A is a scaling parameter, which describes the other factors in the metching technology that are not fully captured by α_1 and α_2. By considering the stationary state, which implies $m^{c-t} = Q = T^{vt}$, the following equation can be derived from equations (2.1) (2.2) and (2.3):

$$w^c = (Q)^{\frac{1-\alpha_1-\alpha_2}{\alpha_2}}(A)^{-\frac{1}{\alpha_2}}(w^t)^{-\frac{\alpha_1}{\alpha_2}} \tag{4}$$

In this study, since the congestion is considered, it is necessary to focus on not only the number of users Q but also the numbers of trips per user made in a certain period x so that the total traffic volume can be calculated as number which affects the travel time l. Therefore, equation (3.4) is be rewritten as:

$$w^c = (Q_R x_R)^{\frac{1-\alpha_1-\alpha_2}{\alpha_2}}(A)^{-\frac{1}{\alpha_2}}(w^t)^{-\frac{\alpha_1}{\alpha_2}} \tag{5}$$

where Q_R is the number of ride-sourcing users and x_R is the number of trips per user.

N is the sum of the number of vacant vehicles N^{vt} and the occupied vehicles N^o, thus, the following equation is derived:

$$N = N^{vt} + N^o = w^t T^{vt} + lQ_R x_R = Q_R x_R(w^t + l) \tag{6}$$

(2) Decision making of households

There are three choices for households: private cars, ride-sourcing services and public transportation which does not share roads with other vehicles, such as metros. Each household first determines the option of transportation according to a logit model. This logit model determines also the number of the households who choose each option denoted by Q.Then, each household determines the number of trips x to maximize a quasi-linear utility function.

Because the law of diminishing marginal utility, the utility of traveling is not linearly related to the number of trips. As the number of trips increases, the marginal utility decreases. In order to express this property, the following quasi-linear utility function with the budget constraint is adopted:

$$u_1 = z + \alpha \ln x \tag{7}$$

$$I = z + \mu x \tag{8}$$

where u_1 is the total utility, z is the total expenses other than travelling, α is a parameter related to the size of utility derived from making trips and x is the number of trips. For the constraint, I is the constant income and μ is the generalized cost per trip. From the maximization problem of the utility u subject to the budget constraint of equation (3.8), the indirect utility function can be derived:

$$u_2 = I - \alpha\left(1 + \ln\frac{\mu}{\alpha}\right) \tag{9}$$

With this indirect utility function, the utility for each transportation mode is formulated:

$$U_0 = I - \alpha\left(1 + \ln\frac{\hat{C}}{\alpha}\right) \tag{10}$$

$$U_R = I - \alpha\left(1 + \ln\frac{\mu}{\alpha}\right) \tag{11}$$

$$U_Y = I - k - \alpha\left(1 + \ln\frac{\beta l}{\alpha}\right) \tag{12}$$

U_0 denotes the utility of public transportation. The generalized cost per trip of this mode is denoted by a constant $\hat{C}$. U_R denotes the utility of ride-sourcing. The generalized cost for ride sourcing is expressed by three elements:

$$\mu = F + \beta l + \beta w^c \tag{13}$$

where F is the trip fare, βl is the travel time cost, βw^c is the waiting time cost and β is the value of time of the households. U_Y denotes the utility of private car, k is the fixed cost for purchasing a car and βl is the travel time cost.

Based on the formulation of the utilities, the households of each transporation mode is determined by applying a logit model as follows:

$$Q_R = \frac{\exp(\theta U_R)}{\exp(\theta U_R) + \exp(\theta U_Y) + \exp(\theta U_0)} \bar{Q} \quad (14)$$

$$Q_Y = \frac{\exp(\theta U_Y)}{\exp(\theta U_R) + \exp(\theta U_Y) + \exp(\theta U_0)} \bar{Q} \quad (15)$$

where Q_R is the number of ride-sourcing users and Q_Y is the number of private car users. $\bar{Q}$ is the number of households. θ is a positive dispersion parameter of the logit model.

The other variable needed to calculate the traffic volume is the number of trips x. From equation (3.16) and (3.17), x can be calculated by total travelling expenses devided by cost per trip:

$$x_R = \frac{\alpha}{\mu} = \frac{\alpha}{F + \beta l + \beta w^c} \quad (16)$$

$$x_Y = \frac{\alpha}{\beta l} \quad (17)$$

Finally, travel time l can be determined by using the BPR function:

$$l = l_0 \left(1 + 0.15 \left(\frac{Q_Y x_Y + Q_R x_R}{K}\right)^4\right) \quad (18)$$

where l_0 is the free flow time and K is the capacity of the road. Since the public transportation does not share the road, the total traffic volume will only depend on ride-sourcing vehicles and private cars.

(3) Optimization problems

In the business model of ride-sourcing market, trip fare F will be charged from the customer, commission P will be charged by the platform and $F - P$ will be the profit of drivers. In the monoply scenario, ride-sourcing company always tries to maximize the profit π_p expressed as follows:

$$\max \pi_p = P Q_R x_R - C_P Q_R x_R \quad (19)$$

where C_P is the constant operation cost per trip.

On the other hand, the purpose of city planner is to maximize the total social welfare S, which is the sum of the consumer surplus CS and the producer surplus π_P, by regulating the trip fare F and commisson P. The social welfare S is formulated as follows:

$$\max S = CS + \pi_p \quad (20)$$

$$CS = \frac{\bar{Q}}{\theta} \ln(\exp(\theta U_R) + \exp(\theta U_Y) + \exp(\theta U_0)) \quad (21)$$

After formulating the objective functions, the next step is to set the constraints. In this system, there are 15 variables including two decision variables, namely trip fare F and commission P. The degree of freedom is two and the number of constraints is 13. The constraints are as follows.

The first constraint is the entry-exit equilibrium condition of the drivers of the ride-sourcing platform. The condition implies that the total revenue of the drivers $(F - P) Q_R x_R$ is equal to the total cost of the drivers $(k + c)N$ where c is the opportunity cost of a driver.

$$(F - P) Q_R x_R - (k + c) N = 0 \quad (22)$$

The other constraints are transformations of the previous equations that describe the equillibrium of this system.

Equation of waiting time:

$$(Q_R x_R)^{\frac{1-\alpha_1-\alpha_2}{\alpha_2}} (A)^{-\frac{1}{\alpha_2}} (w^t)^{-\frac{\alpha_1}{\alpha_2}} - w^c = 0 \quad (23)$$

Equation of number of total vehicles:

$$Q_R x_R (w^t + l) - N = 0 \quad (24)$$

Equations of utilities:

$$I - \alpha \left(1 + \ln \frac{\mu}{\alpha}\right) - U_R = 0 \quad (25)$$

$$I - k - \alpha \left(1 + \ln \frac{\beta l}{\alpha}\right) - U_Y = 0 \quad (26)$$

Equations of number of users:

$$\frac{\exp(\theta U_R)}{\exp(\theta U_R) + \exp(\theta U_Y) + \exp(\theta U_0)} \bar{Q} - Q_R = 0 \quad (27)$$

$$\frac{\exp(\theta U_Y)}{\exp(\theta U_R) + \exp(\theta U_Y) + \exp(\theta U_0)} \bar{Q} - Q_Y = 0 \quad (28)$$

Equations of number of trips:

$$\frac{\alpha}{\mu} = \frac{\alpha}{F + \beta l + \beta w^c} - x_R = 0 \quad (29)$$

$$\frac{\alpha}{\beta l} - x_Y = 0 \quad (30)$$

Equation of travel time:

$$l_0 \left(1 + 0.15 \left(\frac{Q_Y x_Y + Q_R x_R}{K}\right)^4\right) - l = 0 \quad (31)$$

Equation of total profit:

$$P Q_R x_R - C_P Q_R x_R - \pi_p = 0 \quad (32)$$

Equation of total social welfare:

$$CS + \pi_p - S = 0 \quad (33)$$

Equation of consumer surplus:

$$\frac{\bar{Q}}{\theta} \ln(\exp(\theta U_R) + \exp(\theta U_Y) + \exp(\theta U_0)) - CS = 0 \quad (34)$$

4. Analysis and Discussion

(1) Analysis method

In this study, two situations are discussed to demonstrate the regulation strategy. In the first situation, the public transportation is assumed to be unavailable, which means that customers are only allowed to choose between private car and ride–sourcing service and the substitutability between public transportation and other modes does not exist. In the second situation, all three choices are available, which means that the public transportation and the road transportation are substitutable.

In each situation, the analysis procedure is the same. First of all, the monoply scenario where the platform maximizes its profit is investigated. Then, the optimal first-best regulation in terms of trip fare F and P is investigated when congestion is not considered. In other words, the travel time l is assumed to be constant. Finally, the first-best regulation is investigated considering congestion and compared with the optimal regulation without considering the congestion. The following table shows the parameter values used in the analysis.

$A = 10$	$\bar{Q} = 500$	$I = 100$	$l_0 = 1$
$\alpha_1 = 0.6$	$\beta = 6$	$c = 10$	$\hat{C} = 8$
$\alpha_2 = 0.6$	$C_P = 2$	$\alpha = 10$	
$\theta = 0.1$	$k = 10$	$K = 500$	

Figure 3: Parameter values

(2) Results and discussion

a) Situation without the public transportation

Table 1 shows the results of the first situation that public transportation is unavailable and the households can only choose ride-sourcing and private car as the transportation mode. In the monoply scenario, it is obvious that trip fare F and commission P are both very high because the platform tries to maximize their profit and only limited customers and drivers are using the platform. The social welfare is comparatively low compared with the regulated case. It is obvious that under the optimal regulation of F and P, lower trip fare encourages the households to use more ride-sourcing service. However, the regulation policy is slightly different depending on whether the congestion is considered or not.

When congestion is considered, F and P are regulated to a even lower level compared with the case where congestion is not considered. As a result, the number of ride-sourcing users Q_R increases. Since the number of total households is constant, larger Q_R means smaller Q_Y. In other words, part of the private car users switch to ride-sourcing.

The reason of this result is that when people has their private car, they tend to make trips by the vehicles more often compared to the households using ride-sourcing due to the lower marginal cost to make a trip. This is shown in the table by the fact that x_R is much higher than x_Y. Therefore, as more people choose ride-sourcing abandoning the use of the private car, the traffic volume as well as the travel time l are reduced, which is also demonstrated in the table.

To sum up, when congestion is considered, F and P should be regulated to a lower level so that more people use the ride-sourcing service and the travel time becomes shorter because of less congestion.

Table 1: Results of situation without the public transportation

Scenario	Monopoly	First-best (No congestion)	First-best (Congestion)
Trip Fare F	72.1753	27.6684	23.3360
Commission P	46.5450	2.0002	-0.6649
Scocial welfare S	43,184.8981	43,730.5108	44,027.1555
Consumer Surplus CS	42,634.7334	43,730.5016	44,189.1341
Platform profit π_P	550.1647	0.0092	-161.9786
Number of ride-sourcing vehicles N	15.8277	63.3477	72.9407
Waiting time w^c	0.1763	0.1826	0.1351
Searching time w^t	0.0529	0.0548	0.0405
Utility of ride-sourcing U_R	69.1303	77.1531	78.6525
Users of ride-sourcing Q_R	99.5530	178.3616	189.0544
Trips of ride-sourcing per user x_R	0.1241	0.2767	0.3215
Utility of private car U_Y	83.0492	83.0492	83.6284
Users of private car Q_Y	400.4470	321.6384	310.9456
Trips of private car per user x_Y	1.3565	1.3565	1.4374
Travel time l	1.2286	1.2286	1.1595

b) Situation with the public transportation

Table 2 shows the results of the second situation where all three transportation modes are available. Just as the previous situation, F and P are very high in the monopoly situation. On the other hand, the optimal regulation policy changes compared with the previous situation.

When congestion is considered, F and P become slightly higher than the case where congestion is not considered. In this situation, higher trip fare actually realizes shorter travel time. The reason is that ride-sourcing service is highly substitutional with public transportation. If the price of ride-sourcing is regulated to be cheap, people will switch from public transportation to ride-sourcing, which invites more ride-sourcing vehicles operating on the road. The increment of vehicles worsens congestions.

To sum up, when congestion is considered and public transportation is a substitutable choice of ride-sourcing, the F and P should not be set too low because some of the users of public transportion will shift to ride-sourcing service, which increases the number of ride-sourcing vehicles N. Ultimately, the congestion becomes worse and the travel time becomes longer.

Table 2: Results of situation with the public transportation

Scenario	Monopoly	First-best (No congestion)	First-best (Congestion)
Trip Fare F	55.7928	22.8277	22.9050
Commission P	34.4059	1.6894	1.7679
Scocial welfare S	48,706.9634	48,916.7825	48,916.9760
Consumer Surplus CS	48,504.6745	48,924.7461	48,922.8997
Platform profit π_P	202.2890	-7.9636	-5.9236
Number of ride-sourcing vehicles N	6.6752	27.0994	26.9677
Waiting time w^c	0.1975	0.1561	0.1562
Searching time w^t	0.0592	0.0468	0.0469
Utility of ride-sourcing U_R	71.5884	79.0725	79.0466
Users of ride-sourcing Q_R	39.3508	76.4707	76.3009
Trips of ride-sourcing per user x_R	0.1586	0.3353	0.3344
Utility of private car U_Y	85.0078	85.0078	85.0087
Users of private car Q_Y	150.5735	138.4400	138.5045
Trips of private car per user x_Y	1.6500	1.6500	1.6502
Travel time l	1.0101	1.0101	1.0100
Users of public transportation Q_P	310.0758	285.0893	285.1946

5. Conclusion and Future work

In this study, the optimal regulation policy for ride-sourcing is investigated considering congestion in a hypothetical city with a single operator of ride-sourcing. First of all, it is obvious that in the monoply scenario, ride-sourcing platform tries to maximize their own profit by setting a reletively high fare, which reduces the social welfare. Therefore, regulation is necessary. However, the regulation policy varys whether congestion is considered or not. To investigate the optimal regulation policy considering congestion, travel time l is formulated as a function of traffic volume. The effects of considering congestion was investigated by comparing the optimal regulatiuon policy considering congestion with the one without considering congestion

When the substitutability between public transportation and ride-sourcing is low, regulating the fare to a lower price than the situation without considering regulation will be more socially benificial. Because the lower trip fare encourages the private car users to shift their transportation mode to the ride-sourcing, which finally reduces the congestion and travel time.

When the substitutability between public transportation and ride-sourcing is high, it is not approriate to set the price too low because part of the public transportation users will switch to ride-sourcing, which increases the ride-sourcing vehicles and ultimately leads to more congerstion.

There are some directions for future work of this study. Model used in this study didn't consider the effect of vacant ride-sourcing vehicles. Vacant vehicles is also a source of congestion, therefore it is better to also include these vehicles in the future study. Moreover, in this study public transportation was assumed not to share the roads with other vehicles, which means that public transportation like bus was not considered. It is important to also consider such options.

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