05 Writing Sample: A Study of Government Subsidy Strategies on Public Transportation – with additional Online Taxi-Hailing as Background

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ABSTRACT

Under the "Internet Plus" environment in China, business models supported by network technologies are constantly innovating and new burgeoning industries continue to emerge. As a new business model underpinned by big data, the development of online taxi-hailing service requires proper guidance as well as appropriate industrial standards in urban policies. Based on the random utility theory, this paper builds an ideal discrete choice model for three travel modes, including online taxi-hailing service, private cars and public transport. Three scenarios are set up to explore the reasonable tendency of government subsidies under different conditions to develop public transport. Policy suggestions and taxation strategies are provided as further guidance and standards for taxi-hailing vehicles and will also serve as an improvement to the urban transport environment.

Keywords: Online taxi-hailing, public transport, discrete choice model, government subsidy

1. INTRODUCTION

Along with the development of wireless mobile communication technology, many internet-based car-rental networking platforms have sprung up around the world to provide online taxi-hailing services, Didi, Uber, Shenzhou Cars, Lyft to name but a few. Compared to the traditional cruising taxi, online taxi-hailing platforms achieve efficient request-matching by integrating real-time information of supply and demand networks, and improve the long existed problems of information asymmetry in traditional taxi market; at the same time, these platforms, who introduced sharing-economic concept, make a rapid expansion on their fleet of cars through access to private car owners as part-time drivers, as a result, filling in the travel demand gap where public transport and taxi services failed to cover. Online taxi-hailing have been regarded as a tool to solve the problem of urban residents' travelling difficulties.

As a pioneer in the sharing-economy industry, taxi-hailing has initiated the "Internet Plus" reform of the transportation industry. It reduces the use of private cars and makes it convenient for urban residents to travel, but on the other hand, it increases the traffic congestion and other negative effects. It is currently a global hot issue and one that continues to ferment about how taxi-hailing services should be developed.

2. LITERATURE REVIEW

At present, there have been a lot of researches on the online taxi-hailing, and all the existing researches are mainly divided into two directions. The first focused on discussing specifically the impact of online taxi-hailing on urban transportation modes and put forward suggestions on the supervision of online taxi-hailing, because the online taxi-hailing services have exerted a huge impact on the taxi market. Feng and Jing (2016) divided online taxi-hailing services into tailored taxi services and carpooling services, to study the relationship between information exchange strategies and earnings in tailored taxi services, carpooling services and traditional taxi services respectively, and then proposed two suggestions for operation and management of online taxi-hailing platforms from the perspective of the government and platforms operators. Rayle, Dai, Chan et al. (2016) explored the users' characteristics and the reasons of using the online taxi-hailing in San Francisco, and the impact on the market of the traditional taxi, public transportation, and private cars. According to their study, there are overlaps between the online taxi-hailing market and the taxi market. It has both positive and negative effects on urban traffic conditions, which is difficult to judge based on the limited existing data and therefore needs further researches. Zhou and Liu (2016) put "the phenomenon of online taxi-hailing" into multiple logical analysis frameworks, digging out the root cause of the dilemma of online taxi-hailing management. Their research showed that "sharing-economy" improved the efficiency of provision of cars and cracked the controls of the "government failure", but without the supervision of the government, online taxi-hailing blindly chasing efficiency could lead to "market failure". This research provided a mechanistic explanation for the dilemma of urban governance after the intervention of technology and it also expanded the analytical pathway for urban research. Zhang, Gao et al. (2016) extracted factors such as the degree of convenience, safety, travel time and cost, to establish Logit models to analyze the behaviors of urban residents in selecting taxis or taxi-hailing vehicles, which provides some theoretical basis for the supervision of car-hailing services.

The second focused on studying the technical support of the online taxi-hailing platform independently, mostly about how to formulate the pricing strategy. Wang, He, Yang et al. (2016) studied the influence of online taxi-hailing platforms' pricing strategy on the traditional taxi market based on the bilateral market theory and the equilibrium model, and proposed a pricing strategy model that can guarantee the stable balance between the traditional taxi market and the online taxi-hailing platform under certain conditions. On this basis, they constructed a pricing strategy model, which should be overseen by the government, in order to control and guide the price and operation process of online and offline service of online taxi-hailing platform companies and achieve the purpose of supervision. Xing, Wang, Zheng et al. (2016) used the efficacy coefficient method to quantify the effect of different subsidy strategies on the taxi-hailing platform and put forward the optimal subsidy scheme under different time and space conditions. In the view of time value difference 0between users, Li, Lu, Zhang et al. (2017) established a user equalization model based on the user's waiting time and the hourly takings of a driver, and they analyzed the positive and negative impact of the taxi-hailing platform.

Most of the relevant studies have been qualitative, focusing more on the supervision of the online taxi-hailing market from the legal perspective but only a few on impacts of the online taxi-hailing system had on the entire urban traffic system from the perspective of residents and their travelling habits. In addition, there is still a lack of quantitative research about the relationship between the government's control policy on online taxi-hailing services and the changes in residents' travelling behavior due to the introduction of such services.

In this study, we conduct a quantitative analysis to study the impact on urban traffic system and discuss further the relationship between different subsidy policies and travel choice for residents. Section 3 makes, first, an induction of the operation mode, characteristics and potential disputes in online taxi-hailing services and then, a prediction for its tendency in the future. Section 4 describes the general model formulation and the transport system under certain hypotheses. Section 5 lists the numerical examples and 3 scenarios aimed at finding the interactions between different stakeholders and calculating utility of the whole system to achieve a balance between subsidizing the public transportation, charging extra fee on the online taxi-hailing service or private cars, then to realize the maximum value for social welfare. Section 6 gives some conclusions and proposes ongoing studies.

3. ONLINE TAXI-HAILING SYSTEM

3.1 Object of Study

With the advancement of big data collecting and processing technologies, online taxi-hailing is mainly based on the Internet and cellphone APPs to build a travel-service platform to contact drivers and passengers, integrating online and offline travel services.

This paper takes Didi Travel (referred to as Didi thereafter) one of the most popular Chinese online taxi-hailing platforms, as the research object. It will define Didi’s development path and characteristic patterns by studying and analyzing its operation mode, positive impacts and potential disputes over its services. Finally, it will discuss the interaction between traditional car-bus system and burgeoning online taxi-hailing under certain management strategies.

3.2 Operation Mode

There are 6 steps in Didi’s operations:

Step 1: Passengers first publish travel demand information via convenient mobile APPs.

Step 2: After receiving the demand, Didi immediately makes big data processing and distributes the demand information to the mobile APPs of the service providers - the Didi drivers.

Step 3: Drivers then accept orders according to passengers’ destinations.

Step 4: The platform will send the driver name and vehicle information back to the passenger. Then the driver and passenger will contact each other via telephone or through online media to determine a designated location for pick up.

Step 5: After the service, the passenger pays the fair through an APP such as WeChat or AliPay, or an online taxi-hailing account, to the Didi and conducts a short online service evaluation to offer feedback.

Step 6: After deducting a pre-agreed percentage for relevant expenses, the platform will transfer the remaining money to the driver. And the driver can withdraw cash within a limited date, or transfer it to his/her own Alipay, WeChat or UnionPay cards.

3.3 Characteristics

3.3.1 Strong technical support:

Use big data cloud computing, processing, and feedback technology to provide comprehensive and real-time information and to disseminate information through the Internet.

3.3.2 Personalized service model:

Provide passengers with diversified travel options such as hiring special cars, express cars, meeting the needs of different groups. Also help passengers to solve problems such as ‘where and how long’ to find a ride as with the traditional cruising taxi services, or ‘how to get to the final destination’ as with the bus services.

3.3.3 Diversified choices:

The two-way selection mode between drivers and passengers can provide more flexible and user-friendly adjustment space for the service hence improve the satisfaction ratings on both sides.

3.4 Positive Impacts

①Reducing taxi vacancy rate:

Compared with traditional taxis, it saves resources for both drivers and passengers, reduces the pressure on urban roads, and reduces the hidden dangers of traffic accidents.

②Enhance information symmetry:

The platform can provide effective and real-time travel information for drivers and passengers alike hence save on costs of communication and improve travel efficiency through diversified choices by both sides.

③Speed up the operation cycle:

Using Internet technology, it can solve customers’ problems, such as not able to find a taxi, waiting too long, etc. in less than 2 minutes. And drivers can also promptly and accurately find customers and increase their earnings.

3.5 Disputes

①Many security issues:

The platform lacks effective control of hidden dangers faced by the Didi drivers and customers. Abusing and/or even beating up of passengers by Didi drivers occurs frequently. Furthermore, in order to grab orders, the drivers tend to focus on the mobile phone interfaces whiling driving, distracted from road conditions, leaving the passengers and other road users in great personal danger. Thirdly, the passengers and drivers may face the danger of information leakage. Some drivers, after having arguments with passengers, arbitrarily disseminate passengers’ personal information on the Internet, causing serious troubles to passengers.

②Incomplete complaint feedback mechanism:

Complaints and feedback mechanisms are not well established. Passengers cannot provide feedback or raise a complaint through normal channels. Sometimes, passengers’ complaints are unfounded, resulting in the drivers’ reputation being damaged and their rights not upheld. The complaint mechanism has no public supervision and no clear rules and regulations, causing low efficiency and low credibility, which is of no help in solving any problems arisen from the transaction.

③Low service efficiency:

After the ending of the platform subsidy, the decline in driver's earnings reduce their enthusiasm, leading to the decreased provision of platform vehicles. In addition, bad behaviors of some drivers disrupt the market order which leads to reduced service efficiency and increased bad user experience.

④Insufficient state supervision:

The subject of legal liability in the industry is not clear. As a result, unfair behaviors, such as malicious competition, nonpayment, abusing of customers, cannot be restrained and regulated, which will affect the normal operation of the market.

⑤Huge competitive pressure:

The competition is fierce in this industry. In addition, some customer groups prefer the traditional way of travel and do not want to try online taxi-hailing services.

3.6 Trends and Tendency

- Increasing service costs as a result of decreasing platform price subsidy
- Mature operation mode follows the establishment of the industry norms
- Attractive to both private car drivers and bus users

4. RESEARCH ON THE THEORETICAL MODEL

4.1 Basic Hypotheses

First of all, this paper put forwards a few basic hypotheses as follows, in order to present the main points of the research more clearly and to make sure the model possess strong applicability and generality.

H1: Suppose there is only a fixed trip route OD in the city, and the number of passengers (the users) remains the same. Each user makes independent selection choice between the private cars, the bus (using the special road) and the taxi-hailing.

H2: Suppose that the pick-up points and their route choices are the same and fixed, which implies that except for those independent variables specific to the model, the remaining influencing factors are always the same and constant for different decision makers. The final result of the total cost is only influenced by the independent variables.

H3: Suppose that all the residents are homogeneous with the same utility function. Each decision maker adopts Discrete Choice Model to make decision, which means always choosing the most valuable alternative.

H 4: Suppose the total number of taxi-hailing cars is positively related to the users who send online travel orders under the market-oriented mechanism. Define the number of online taxi-hailing cars as N in the area where the path OD is located.

H 5: Suppose that the government has imposed congestion charges on private cars and taxi-hailing vehicles to subsidize public transportation and reduce bus fares, affecting individual travel choices in order to relieve traffic congestion and reduce carbon emissions.

4.2 Explanation On the Main Theoretical Models

4.2.1 Road Impedance Function

Road impedance is caused by the increasing number of vehicles in the urban transportation system. The road impedance function describes this effect by quantitatively measuring the value of travel time. The most widely used road impedance function is the BPR function which is obtained by the U.S. Bureau of Public Roads (BPR) in 1966. In this paper, road impedance function refers to the BRP function and the formula expresses as:

$$\mathrm{t} = t_0\left[1+\alpha\left(\frac{q}{C}\right)^{\beta}\right] \tag{1}$$

In Formula 1, t is the vehicle's travel time (min) pass the road section; t_0 is the free-flow time (min) of the road section; q is the actual traffic volume of the road section (veh/min); C is the designed traffic capacity of the road section (veh/min); α, β are the parameters to be calibrated. In this paper, we take the conventional values α = 0.15 and β = 4.0.

4.2.2 Discrete Choice Model of Travel Mode

Discrete Choice Model is a model based on the theory of random utility maximization. That is, the utility of the choice (U_{in}) is divided into two parts: the utility determinants dominated by observable variables (V_{in}) and the unobserved utility random items (ε_{in}), expressed as:

$$U_{in} = V_{in} + \varepsilon_{in} \tag{2}$$

Discrete Choice Models takes the macro decision makers group with a certain ability of behavior explanation as the object. Multinomial Logit Model (MNL) has been widely used for a long time in such case.

$$Pr_{in} = \frac{\exp\left(\beta \cdot V_{in}\right)}{\sum_j^J \exp\left(\beta \cdot V_{jn}\right)} \tag{3}$$

Here, β is the scale parameter.

In this paper, the hypothesis is that there are only 3 means of transport, and all the citizens have to choose one from the private cars, buses and the online-taxi hailing. Their probability Pr_i can be expressed as following:

$$Pr_i = \frac{\exp\left(\beta \cdot V_i\right)}{\exp\left(\beta \cdot V_{bus}\right) + \exp\left(\beta \cdot V_{car}\right) + \exp \beta \cdot \left(V_{\text{online-}car}\right)} \tag{4}$$

4.3 Model Building Under the Hypotheses

4.3.1 Passenger Choices

When making a choice on travel mode, passengers mainly take two aspects of the travel utility into consideration, time cost and money cost – people tend to choose the option which minimizes their total utility of time and money (based on different valuation of individuals).

People choose private cars because of their convenience. They do not need to spend time waiting, but they do need to bear higher fuel cost and have higher possibility of traffic congestion which adds to their time cost.

People choose taxi-hailing to increase travel efficiency, which allows passengers to make quick bookings and to save waiting time compared with bus travel. In addition, compared with the fuel costs of private cars, the fare of taxi-hailing is relatively low.

People choose buses because bus fares are cheap, and the low carbon emission is consistent with the concept of low-carbon travel.

4.3.2 The utility analysis

Part 1—Individual Passenger Choice and Passenger Utility

The separate utility of the three choice Vbus, Vcar, Vonline-car and the total utility of all passengers can be expressed respectively as:

$$V_{\text{bus}} = -\left(\mathrm{t}_{\text{walk|bus}} + \mathrm{t}_{\text{wait|bus}} + \mathrm{t}_{\text{in-veh|bus}}\right) \cdot \mathrm{vot} - \left(C_{fare|bus}\right) \tag{5}$$

$$V_{\text{car}} = -\left(t_{walk|car} + t_{in-veh|car}\right) \cdot vot - \left(C_{fule|car} + C_{fare|car} + C_{fee|car}\right) \tag{6}$$

$$V_{\text{online-car}} = -\left(t_{walk|online-car} + t_{wait|online-car} + t_{in-veh|online-car}\right) \cdot vot - \left(C_{fule|online-car} + C_{fee|online-car}\right) \quad (7)$$

$$TC = q_{bus} \cdot V_{bus} + q_{car} \cdot V_{car} + q_{online-car} \cdot V_{online-car} \quad (8)$$

Part 2—Total Utility of Urban Traffic System

In this model, the total utility of social travel consists of three parts, total time cost, total travel expenditure (money cost during the trip), total emission. They are mainly affected by the individual choices.

The emerging of online taxi-hailing cars offer new options to travelers in bus – car choice, changing their choice and utility, thus affecting the whole urban traffic system. The impact can be classified into three aspects: traffic congestion, travel structure, and carbon emissions, which means changing of in-veh time, changing of bus choice and changing of sum-carbon emissions.

The traffic congestion situation is reflected by the time spent in vehicle, expressed as $t_{in-veh|car}$ or $t_{in-veh|online-car}$.

The total carbon emission is equal to the sum of the carbon emissions of all the road users with three travel modes, expressed as:

$$TE = q_{bus} \cdot e_{bus} + q_{car} \cdot e_{car} + q_{online-car} \cdot e_{online-car} \quad (9)$$

The travel structure is reflected in the probability of choosing each travel mode.
The probability of travel modes can be predicted through the discrete choice model, expressed as：

$$\Pr_{car} = \frac{\exp(\beta \cdot V_{car})}{\left(\exp(\beta \cdot V_{car}) + \exp(\beta \cdot V_{bus}) + \exp(\beta \cdot V_{online-car})\right)} \quad (10)$$

$$\Pr_{bus} = \frac{\exp(\beta \cdot V_{bus})}{\left(\exp(\beta \cdot V_{car}) + \exp(\beta \cdot V_{bus}) + \exp(\beta \cdot V_{online-car})\right)} \quad (11)$$

$$\Pr_{\text{online-car}} = \frac{\exp(\beta \cdot V_{\text{online-car}})}{\left(\exp(\beta \cdot V_{car}) + \exp(\beta \cdot V_{bus}) + \exp(\beta \cdot V_{online-car})\right)} \quad (12)$$

Assumed that the total travel demand is Q, the number of travelers choosing one of the three modes in this idealized model can be expressed as follow:

$$Q_{\text{car}} = Q \cdot \Pr_{car} \quad (13)$$

$$Q_{\text{bus}} = Q \cdot \Pr_{bus} \quad (14)$$

$$Q_{\text{online-car}} = Q \cdot \Pr_{\text{online-}car} \quad (15)$$

The total utility of urban traffic system U is expressed as:

$$U = -(TC + TE) \quad (16)$$

5. NUMERICAL EXAMPLE AND SCENARIO ANALYSIS

5.1 Index Setting

According to data searches and adequate experiments, the relevant parameters in the model above are set as follows:

$$\beta = 0.1$$

Value of time vot=1.5

Total demand $Q = 1000$

capacity=800

5.2 Scenario 1: Traditional BUS & CAR System

Starting with the simplest system only with private cars and buses, subsidize public transportation with fees charged on parking of private cars. In China, taxes on private cars are collected through parking fees, so fees paid by private cars are sometimes referred to as taxes.

According to the research of road impedance function, the road congestion condition expressed as time on the road (noted as $t_{in-veh|car}$) is measured by the formula related to the number of private cars, expressed as:

$$t_{in-veh|car} = t_{0in-veh|car} \cdot \left(1 + \alpha_1 \cdot (q_{car} / capacity)^{\alpha_2}\right) \quad (17)$$

$$\alpha_1 = 0.15$$

$$\alpha_2 = 4$$

Substituting values for the above parameters into the original model, it can then be denoted by Table 1 below.

Table 1: List of elements in the model

	walking	waiting	in-veh	fuel cost	fee
Car	3	0	15	20	0
Bus	3	5	25	0	4

Change the parking fee of a car from 0 to 4 and set the step value as 0.1. Calculate the total social utility through the Macro Command on the model iterative calculation, and produce charts for total cost, travel time and emissions, respectively. We come to the following conclusions.

When the parking fee (the tax) for private cars is less than 3.5, the total cost of passengers is continuously decreasing. Therefore, as car charges increase, the total cost reaches a minimum when the tax amount reaches 3.5; when the tax amount is larger than 3.5, passengers choose to take the bus.

The trend of travel cost change is shown in Figure 1

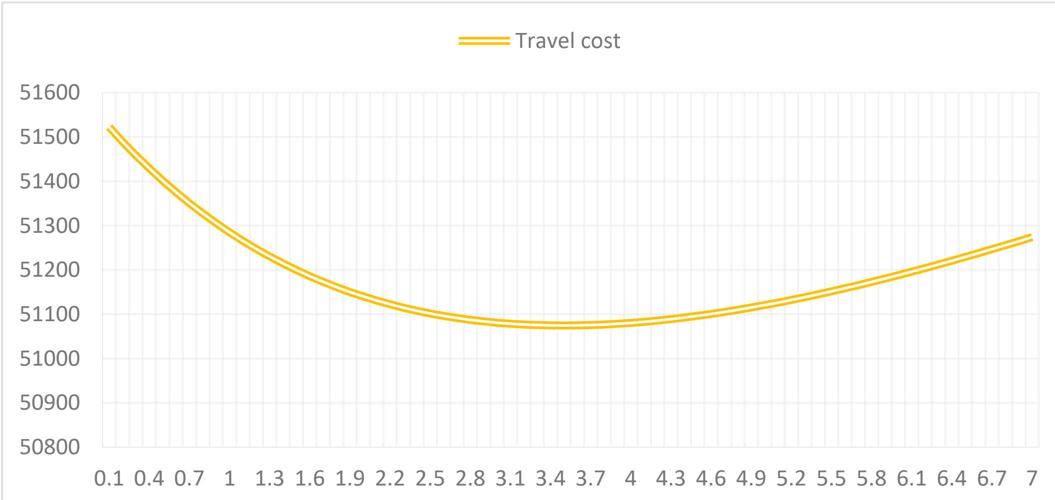


Figure 1: Relationship between total cost and car fee

With taxes levied on private cars, some owners will choose the cheaper option of public transport, which in turn leading to a decreased number of private cars on urban roads, hence traffic condition is improved and the time spent in transit is reduced, so the total utility is reduced; when the fee increased to a level that most people find it unaffordable, the number of people who opted for public buses increased significantly, with more time spent on waiting for a bus, the total time spent increased. Although the number of cars on the way decreased and traffic congestion eased, the negative effect of bus travel was greater than the positive effect of reduced car travel time, and thus the total cost was on the rise.

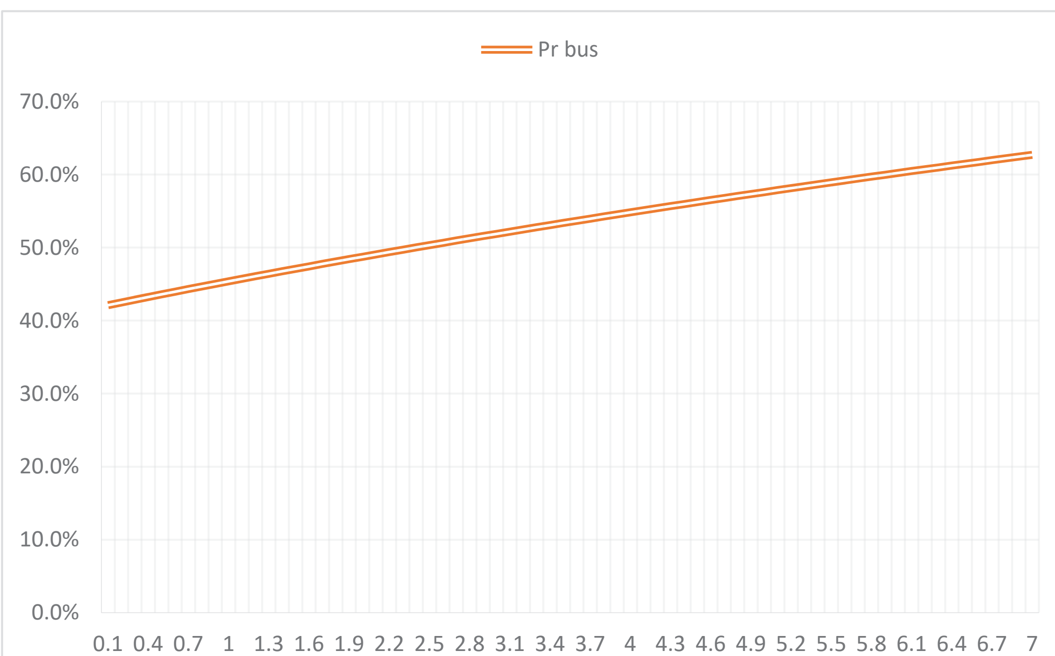


Figure 2: Relationship between $\Pr_{bus}$ and car fee

5.3 Scenario 2: Take Online-car into Consideration

Take online-car into consideration, but without taxing it.

(1) Definition: taxi vacancy rate η of online-car

As far as road congestion is concerned, private cars and taxi-hailing are equally affected by road congestion and all the on-line cars on the road will add to the road congestion whether it is fare-carrying or not. As a result, we take both N and q_{car} into consideration in the process of calculating the in-vehicle time, which can be expressed as:

$$\mathrm{t}_{in-veh|online-car} = t_{in-veh|car} = t_{0in-veh|car} \cdot \left(1+\alpha_1 \cdot \left(\frac{q_{car}+N}{capacity}\right)^{\alpha_2}\right) \tag{18}$$

According to expert scoring and adequate experiments, the relevant parameters of the model above are set as follows:

$$t_{0in-veh|car} = 15 \quad ,\alpha_1 = 0.15 \quad ,\alpha_2 = 4$$

It's worth noting that the number of taxi-hailing N differs from $q_{online-car}$, which refers to the passenger who actually chose the taxi-hailing. To build relationship between them, we introduce the concept of taxi vacancy rate, expressed as η.

$$\eta = \frac{N - q_{online-car}}{N} \tag{19}$$

$$\eta = 0.1$$

$$N = \frac{1}{1-\eta} \cdot q_{online-car} \tag{20}$$

$$N = 1.11 q_{online-car}$$

(2) Effect of the number of the taxi-hailing cars on waiting time

Online-car waiting time is affected by the total number of taxi-hailing vehicles, we choose the road impedance function as the formula here, after many digital calibrations and debugging, the final selected formula and parameters are as following.

$$t_{waiting|online-car} = t_{0waiting|car} \cdot \left(1+\gamma_1 \cdot \frac{q_{online-car}}{capacity}\right)^{\gamma_2} \tag{21}$$

$$\gamma_1 = 0.8, \gamma_2 = 2$$

(3) Charge private cars to subsidize bus fare.

$$\Delta c_{fare|bus} = \tau \cdot \frac{q_{car}}{q_{bus}} \tag{22}$$

Substituting the above parameters into the original model, it can be expressed by Table 2 below.

Table 2: List of elements in the model

Mode	Time (minutes)			Money (CNY)		
	walking	waiting	In-veh	Fuel cost	Fare/Fee	unit emissione
Car	3	0	15.5	20	4	10
Bus	3	5	25	0	4	4
Online-car	0	3.24	15.5	0	15	10

Change the fee of a car from 0 to 4 and set the step value as 0.1. Through the Macro Command on the model iterative calculation, we find following conclusions.

After the inclusion of Internet-based vehicles into the overall system, the overall cost was reduced, but compared with scenario 1, the travel time significantly increased as well, as shown in Figure 3 and Figure 4 below.

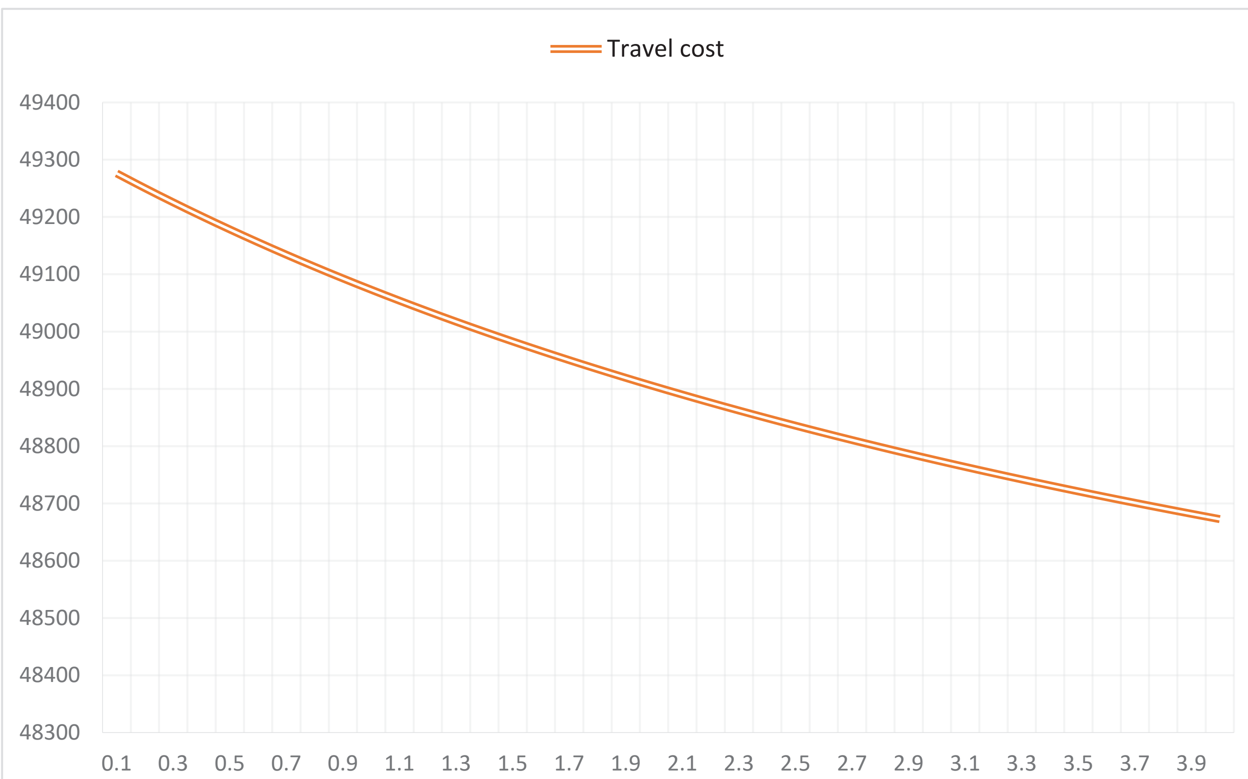


Figure 3: Relationship between total cost and car fee (with online-car)

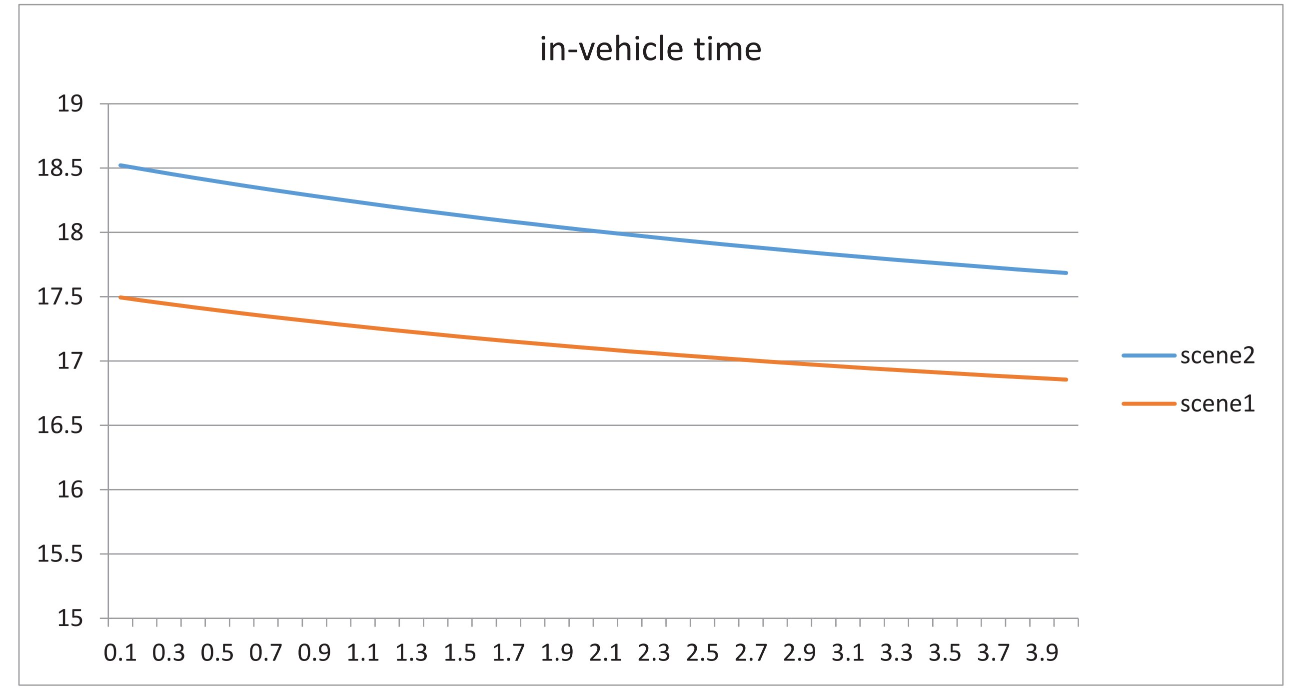


Figure 4: Comparison of in-vehicle time between Scenario 1 & Scenario 2

When fees charged on cars started rising gradually, we can see that Pr_{car} is falling while Pr_{bus} increases slightly, but on the other hand, $Pr_{online\text{-}car}$ rises significantly. Without charging fees on online cars, people tend to choose more online cars than buses, as shown in Figure 5, Figure 6, and Figure 7, respectively.

Figure 5: Relationship between Prcar and car fee

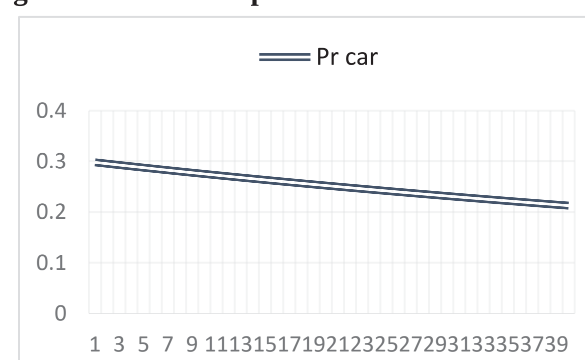


Figure 6: Relationship between Prbus and car fee

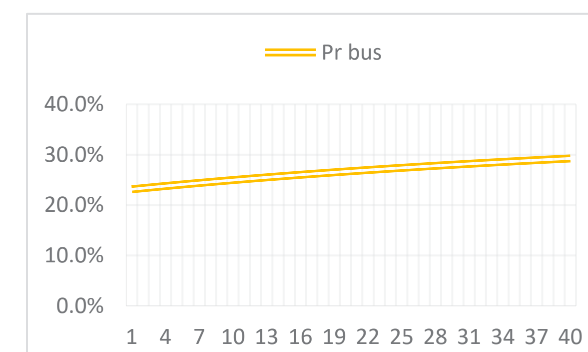
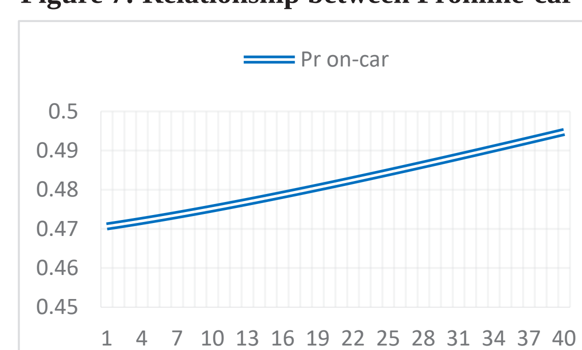


Figure 7: Relationship between Pronline-car and car fee



When fees are charged on cars, the total cost decreases, and it will continue to decrease with the rising fees. This will carry on without an extreme point. The charging policy still has the potential to continue to reduce the total cost.

Compared with Scenario 1, the transit time is significantly increased, which indicates that the traffic on the taxi-hailing has exacerbated traffic congestion to some extent, which also matches the trend in Figure 7.

5.4 Scenario 3 Charging Online-cars

Take the taxi-hailing into consideration, and collect taxes on both the taxi-hailing and private cars to subsidize the public transportation at the same time. Taxes on taxi-hailing cars are sometimes referred to as policy fees.

Data calculation：

Parking fee of Subsidy to bus fare = τ_1

Policy fee of on online car to bus fare = τ_2

$$\tau_1 \in [0.1, 4] \ , \tau_2 \in [0.1, 4]$$

In this scenario, the number of variables has increased from one to two, leading to the number of subsidies for public transport been changed from the unilateral subsidy from private cars to the joint subsidy from both fees.

$$\Delta c_{fare|bus} = \frac{\tau_1 \cdot q_{car} + \tau_2 \cdot q_{online-car}}{q_{bus}} \tag{23}$$

Substituting above parameters into the original model, it can be expressed as Table 3 below.

Table 3: List of elements in the model

Mode	Time (minutes)			Money (CNY)			
	walking	waiting	In-veh	Fuel cost	Fee	Fare	unit emission e
Car	3	0	20	20	4	0	10
Bus	3	5	25	0	0	4	4
Online-car	0	3	20	0	4	15	10

Take 0.1 yuan as the step value to make one of the charges invariant, to consider the influence of the change of another item on the overall total cost. The code for this calculation is written in Excel with its built-in solver.

By selecting the conditional format (shown with the color scale in Excel), and preparing the gradient color, the cells can be heat-mapped directly. It can be seen from the figure below varying τ_1 from 0.1 to 4, and τ_2 also from 0.1 to 4, the minimum value of total cost is obtained at $\tau_1 = 4$ and $\tau_2 = 1.6$, as shown in Figure 8.

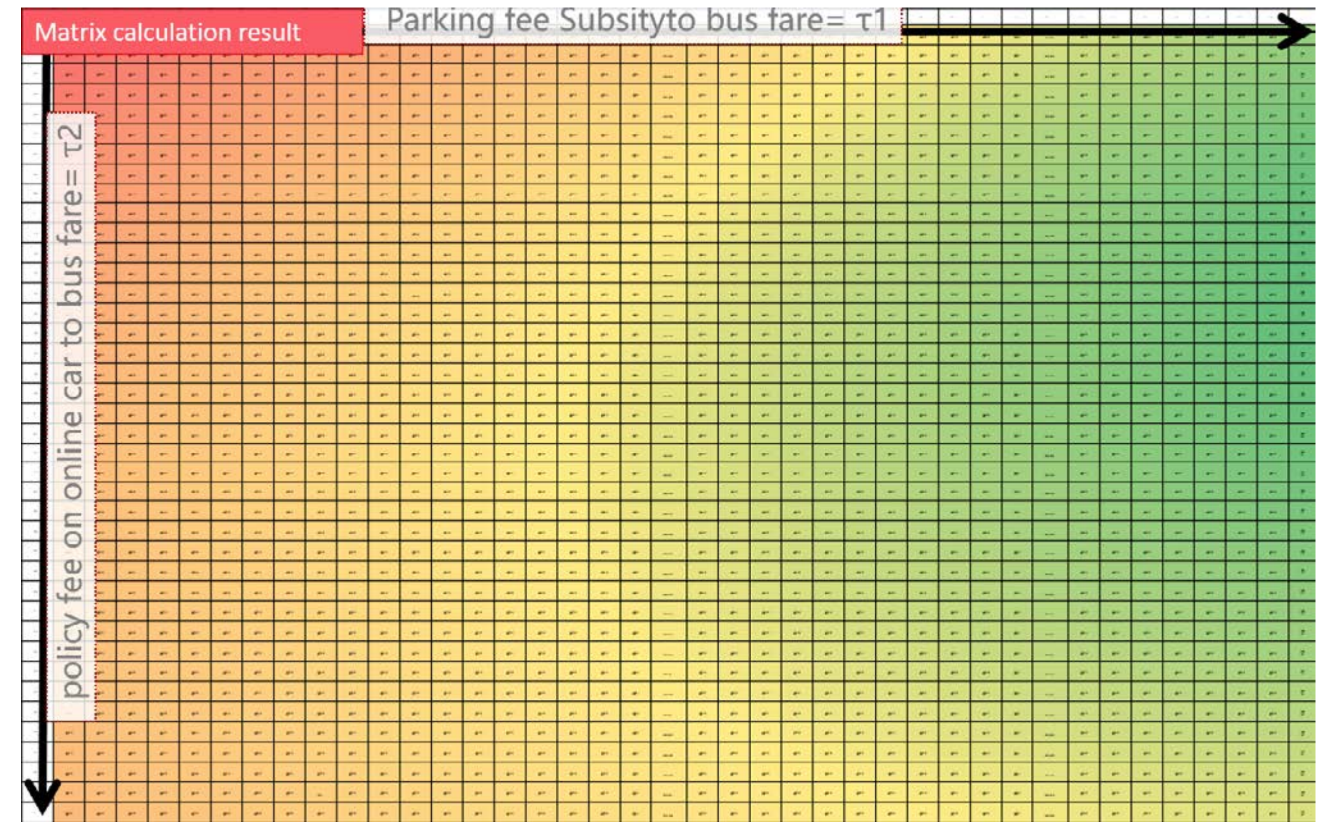


Figure 8: billing matrix of private car and online car

Keeping the online car fee $\tau_2 = 1.6$ unchanged and increasing the private car charges, the total cost is decreasing continuously, as shown in Figure 9 below.

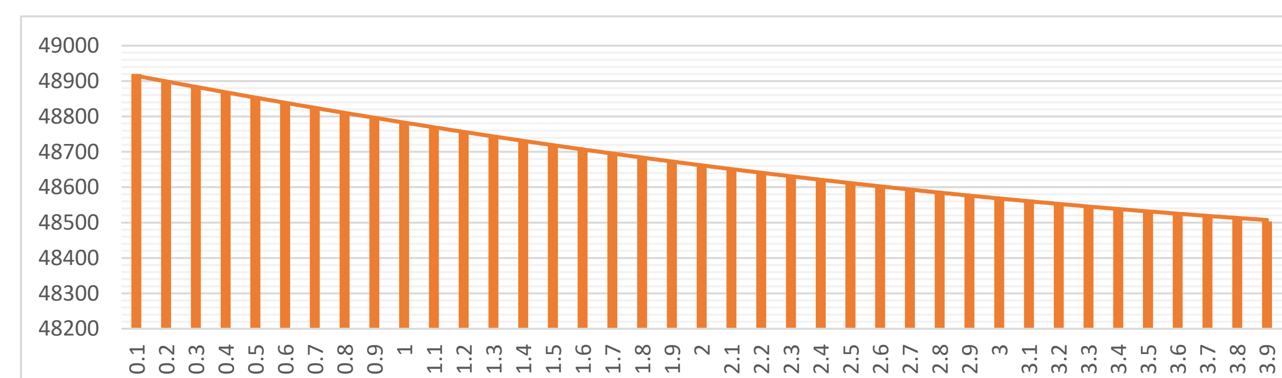


Figure 9: With τ_2 unchanged, relationship between τ_1 and total cost

Retaining the tax of the private cars $\tau_1 = 4$ as the same and increasing tax for the taxi-hailing, there is a minimum value for the total cost. At this point, the total cost of the whole system is the smallest, as shown in Figure 10.

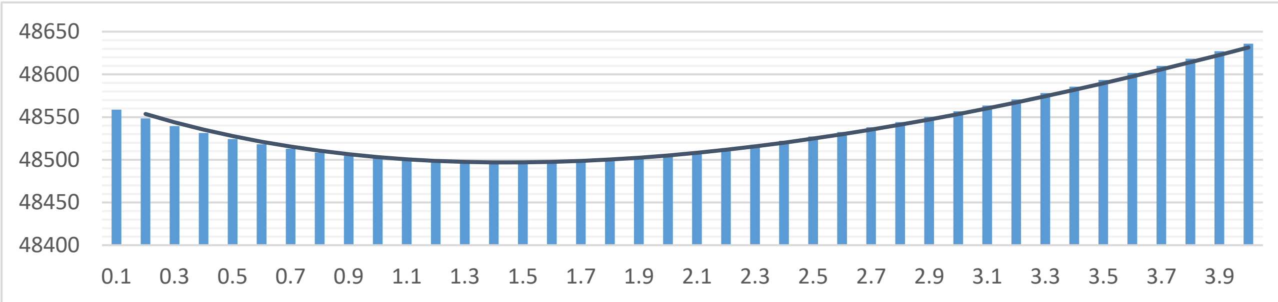


Figure 10: With τ_1 unchanged, relationship between τ_2 and total cost

After charging for cars, total social cost fell because people chose buses and taxi-hailing cars that cost less. After charging for online cars, the total cost comes down at first, but then goes up again. It comes down because people choose public transport and reduce congestion. It rises after a while because when there is no congestion on the road, the cost of people taking bus gradually becomes higher than those of driving cars and taking online cars.

5.5 Advice

① The government should adjust tax strategy flexibly according to market changes, and promote a reasonable pricing of the taxi-hailing service. In order to seize the market share, the current Didi and other taxi-hailing operators are using "burn money subsidy" with lax self-supervision. In this regard, the government should exert policy control to prevent its vicious competition and reduce the negative externality of the network traffic. The government should not directly control the number of taxi-hailing cars or command an increased travel price by the traditional means of planned economy, but instead, should adjust the taxation, tighten the supervision, or improve entry standard, so that the company increases the price on its own accord.

② Although the tax on the net is helpful to reduce the urban traffic congestion and carbon emission, the excessive tax will lead to the decrease of social utility and the aggravation of the urban static parking problem. Therefore, appropriate taxes should be selected to guide the healthy development of the taxi-hailing service and to maximize the social utility.

③ In addition, the government can also establish a mechanism of incentive system and tax subsidies to urge the taxi-hailing operators to use its existing technology and market basis to actively explore new traffic tools such as new energy vehicles, driverless cars, personal / customized minibuses, based on Internet platform and large data; and take the lead in putting new means of transportation into the market. Through the operator's innovation and technology optimization, the negative externality of taxi-hailing service can be fundamentally reduced, and total social utility can be increased.

6. CONCLUSION

In this model, this paper selected a certain travel route, set a limit on the market and a size on the number of consumers. Under this assumption, this paper researched on what the impact of the taxi-hailing has on the urban traffic network, and furthermore, calculated the total social utility of traditional travel mode (cars and buses) and taxi-hailing mode (cars, taxi-hailing cars and buses). This research shows that, the arrival of taxi-hailing cars harms the original "private cars + buses" mode of transportation, because online taxi-hailing has higher compatibility between supply and demand and lower travel cost. And as a result, it has changed travelling patterns of urban residents.

If the taxi-hailing mode is added to the transportation system without subjecting it to a policy control (paying taxes), and at the same time, charging a fee for private cars to subsidize public transportation, it is expected that passengers will transfer from private cars to taxi-hailing cars, and the proportion of bus travel is actually reduced rather than increased. Although the total utility of passenger trips has increased, the addition of the taxi-hailing service has led to the increase of urban traffic congestion and carbon emissions. Meanwhile, with the increase of the number of taxi-hailing trips, the traffic congestion has become more serious and the carbon emissions continuously increase. In fact, the expansion of the taxi-hailing fleet will greatly stimulate the demand for travel, resulting in the amplification of negative utility above.

Therefore, in order to control the excessive expansion of the taxi-hailing cars and reduce its negative utility, the government needs to impose tax policies on the taxi-hailing cars to increase its price. According to the research, under the policy conditions of taxing on the taxi-hailing cars and private cars to subsidize the bus service, the proportion of passengers who choose to travel by bus are significantly increased, the traffic congestion and the carbon emission is reduced. Therefore, appropriate government supervision and policy guidance can reduce the negative effects on urban transportation network and improve the social utility, and finally realize the Pareto improvement.

There are some deficiencies in the above studies. Due to the lack of abundant data, the mathematical model we constructed is relatively idealized, and many parameters and adjustments require more empirical support. For example, the preferences of different income groups and different travel destinations are not reflected in this model. In addition, in terms of urban equity and healthiness, online taxi-hailing may also have potential side effects, which are not measured and discussed in this model. All the above requires further theoretical support, and these questions will be considered in ongoing postgraduate studies.

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