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Model Construction and Quantitative Analysis of Taxi-Hailing Subsidy Scheme

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Abstract: The convenient taxi-hailing is a big issue for nearly all cities in China. Striving to ease the taxi-hailing difficulty" as the objective function, the "economic expenditure of the subsidies" as the budget constraints, a more ideal taxi subsidy program and its budget is obtained by solving the conditional extreme value function based on the Lagrange method. The subsidy schemes according to the per mileage subsidy to the taxi driver will be optimal choice in the peak hours/urban center and in the off-peak hours/ urban fringes. Whereas, the subsidy schemes will be the most effective in the off-peak hours/ urban center and in peak hours/urban fringes in the light of the fuel consumption subsidy to the taxi driver. A sensitivity analysis is made for the parameters of model to evaluate its key influencing factors on stability.

Keywords: Budget, Taxi-Hailing Subsidy Scheme, Sensitivity Analysis

1. Introduction

With the improvement of people's living standards, an increasingly amount of people are preferable to take a taxi. However, it is still inconvenient to hail a taxi in many cities, especially in the rush hour or bad weather in China. "Taxi-hailing difficulty" may lower people's happiness index, which has attracted the attention of the entire community [1-2].

There are two determinants of "taxi-hailing difficulty". First is whether the number of taxi and passengers are balanced; second is whether the information of taxi drivers and passengers are symmetrical, that is, whether the taxi resources are reasonably dispatched or not in certain area.

Taxi-hailing apps accurately solve the informational asymmetry between the taxi and passengers, integrate the taxi resources with great intelligence and high efficiency and play a role of optimizing the allocation of taxi resources, easing the taxi-hailing difficulty and reducing the taxi no-load rate, which are generally welcomed by both the taxi drivers and passengers [3-8]. The taxi-hailing subsidies offered by the software companies motivate taxi drivers and passengers and effectively ease the taxi-hailing difficulty. Discussions on the taxi-hailing subsidy scheme are currently focused on a rough qualitative description [9-10]. Given the current four major taxi-hailing subsidy schemes of the software companies, the previous paper [11], taking Beijing as an instance, quantitatively studied the effectiveness of subsidy schemes to ease the taxi-hailing difficulty. On this basis, this paper, still taking Beijing as an example, sets "striving to ease the taxi-hailing difficulty" as the objective function, and obtains some reasonable and specific subsidy schemes by quantitative analysis in theory.

2. Optimization of the Taxi-Hailing Subsidy Scheme

It is a matter of observation that the balance of supply and demand in the taxi market is mainly related to the social economy, transportation facilities, urban transportation system service quality, traffic policy, market competition, market instruments, vehicle comfort level, industry management means, freight rate. In order to establish a reasonable index system, in this paper, we take the following six indicators as a "taxi difficult" specific standards:

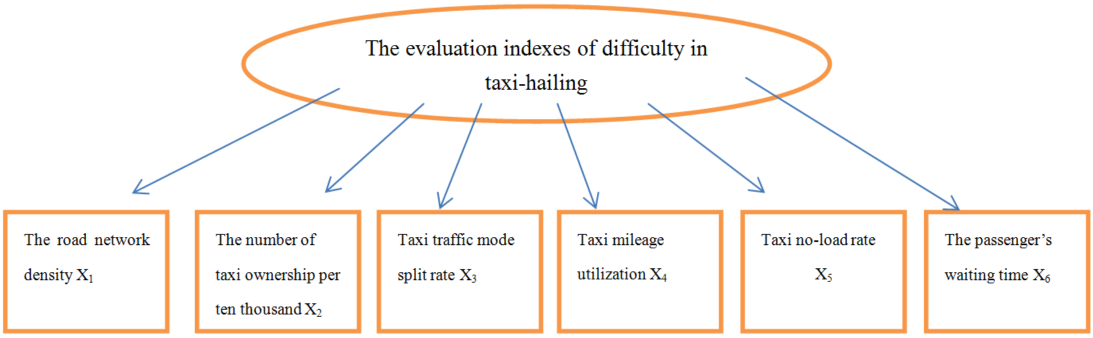

Figure 1. *The evaluation indexes of difficulty in taxi-hailing.*

Based on the above evaluation index system, an evaluation model of "taxi-hailing difficulty" can be drawn as:

$$W = \sum_{i=1}^{6} A_i X_i^0 \quad (1)$$

In this formula, A_i (i =1,2,3,4,5,6) is the weight of each index, and X_i^0 is the efficiency coefficient of the evaluation index corresponding to the evaluation object, $0 < X_i^0 < 1$. W is a comprehensive evaluation index. Through the principal component analysis method, the correlation matrix and communality can be calculated as shown in Table 1 [11].

Table 1. *Correlation Matrix and Communality.*

	Mileage Utilization	Load Factor	Waiting Time	Initial	Extraction
Mileage Utilization	1.000	-0.788	0.909	1.000	0.927
Load Factor	-0.788	1.000	-0.740	1.000	0.804
Waiting Time	0.909	-0.740	1.000	1.000	0.895

Let $\Sigma_{i=1}^{6} A_i = 1$, A_i is shown in Table 2.

Table 2. *Weighted Values of Evaluation Indexes.*

A_1	A_2	A_3	A_4	A_5	A_6
0.08	0.11	0.10	0.10	0.23	0.28

If this is plug into the above formula, it can be drawn that

$$W = 0.08 * X_1^0 + 0.11 * X_2^0 + 0.10 * X_3^0 + 0.10 * X_4^0 + 0.23 * X_5^0 + 0.28 * X_6^0 \quad (2)$$

According to the efficiency coefficient method, when W is less than 0.6, it will be evaluated as "poor"; when W range is from 0.6 to 0.8, it will be evaluated as "medium"; and when W is higher than 0.8, it will be evaluated as "good". The subsidy scheme of each taxi-hailing app company is mainly one of the following four forms or an integrated form.

(A) The taxi drivers who receive orders from the taxi-hailing app will get a certain amount of subsidies for each order, which is denoted as p^1;

(B) The taxi drivers who receive orders from the taxi-hailing app will get subsidies directly proportional to the amount of fuel consumption, which is denoted as p^2;

(C) The taxi drivers who receive orders from the taxi-hailing app will get subsidies directly proportional to the mileage within the order, which is denoted as p^3;

(D) The passengers who take a taxi by using the taxi-hailing app will get a certain amount of subsidies for each order, which is denoted as p^4;

X_i is the actual value of the evaluation index corresponding to the evaluation object. So research will be focused on the influence of the four forms of subsidies on X_i Taking the relationship between the taxi load rate X_5 and its efficiency coefficient X_5^0 as an example. Usually, the taxi no-load rate should be controlled between 30% and 40%. Relationship between no-load rate and its efficiency coefficient is:

$$X_5^0 = 1 - |X_5 - 35\%| \quad (3)$$

The efficiency coefficient of taxi no-load rate in different spatial and temporal contexts of Beijing can be shown in Table 3[11].

Table 3. *The efficiency coefficient of taxi no-load rate in different spatial and temporal contexts of Beijing.*

	Peak	Off-peak
Urban Centers	0.53	0.64
Urban Fringes	0.65	0.72

Thus we can see the relationship between the various subsidy schemes and the efficiency coefficient of taxi no-load rate in different spatial and temporal contexts of Beijingin Table 4.

Table 4. *The relationship between the various subsidy schemes and the efficiency coefficient of taxi no-load rate in different spatial and temporal contexts of Beijing*

Subsidy Policies	The Efficiency Coefficient X_5^0 of the Taxi No-load Rate
No Subsidy	0.635
Subsidy in the Urban Centers and in the Peak Hours	$0.53-0.002*p^1-0.01*p^2$
Subsidy in the Urban Centers and in the Off-peak Hours	$0.64-0.05*p^1-0.03*p^2$
Subsidy in the Urban Fringes and in the Peak Hours	$0.65-0.014*p^1-0.1*p^2$
Subsidy in the Urban Fringes and in the Off-peak Hours	$0.72-0.02*p^1-0.05*p^2$

The relationship between them can be displayed in 3D coordinates.

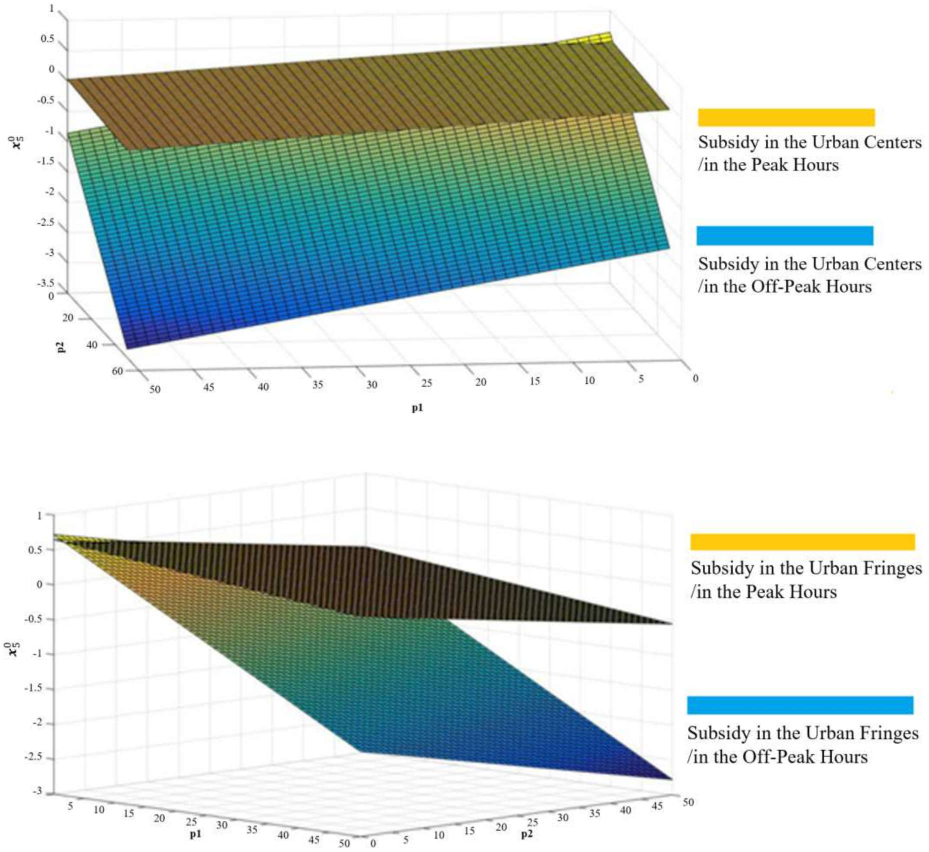

Figure 2. *The relationship between the various subsidy schemes and the efficiency coefficient of taxi no-load rate in different spatial and temporal contexts of Beijing.*

These formulas have been derived from our previous articles [11]:

(A) Travel in peak hours in urban centers (within the fifth ring road):

$$W = 0.08 * X_1^0 + 0.11 * X_2^0 + 0.10 * X_3^0 + 0.10 * X_4^0 + 0.23 * X_5^0 + 0.28 * X_6^0$$

$$= 0.647 + 0.0056 * p^1 + 0.0027 * p^2 + 0.018 * p^3 - 0.00045 * p^4 \quad (4)$$

(B) Travel in peak hours in urban fringes (outside the fifth ring road):

$$W = 0.08 * X_1^0 + 0.11 * X_2^0 + 0.10 * X_3^0 + 0.10 * X_4^0 + 0.23 * X_5^0 + 0.28 * X_6^0$$

$$= 0.625 + 0.0008 * p^1 - 0.012 * p^2 + 0.09 * p^3 - 0.00045 * p^4 \quad (5)$$

(C) Travel in off-peak hours in urban centers (within the fifth ring road):

$$W = 0.08 * X_1^0 + 0.11 * X_2^0 + 0.10 * X_3^0 + 0.10 * X_4^0 + 0.23 * X_5^0 + 0.28 * X_6^0$$

$$= 0.71 + 0.0008 * p^1 - 0.0009 * p^2 + 0.006 * p^3 - 0.00074 * p^4 \quad (6)$$

(D) Travel in off-peak hours in urban fringes (outside the fifth ring road):

$$W = 0.08 * X_1^0 + 0.11 * X_2^0 + 0.10 * X_3^0 + 0.10 * X_4^0 + 0.23 * X_5^0 + 0.28 * X_6^0$$

$$= 0.699 - 0.002 * p^1 + 0.0035 * p^2 - 0.11 * p^3 - 0.00074 * p^4 \quad (7)$$

In order to optimize the tail-hailing subsidy scheme, let Wat any time or place is higher than 0.75, and the budget restraints of the software company of the taxi-hailing apps are as loose as possible.

According to the average statistics of Beijing taxi, one taxi driver can receive 30 orders, with the average mileage of 6km per order and the average fuel consumption of 10L per 100km. One taxi consumes 30L fuel per working day, then the Lagrange equations with the maximization of the efficiency coefficient under the budget restraints are respectively are:

(i) Peak hours in urban centers:

$$0.647 + 0.0056 * p^1 + 0.0027 * p^2 + 0.018 * p^3 - 0.00045 * p^4 > 0.75 \quad (8)$$

$$\min\{30 * p^1 + 6 * p^2 + 30 * p^3\} \quad (9)$$

Finally obtains: $p^1 = p^3 = p^4 = 0, p^2 = 0.38$.

That is, in peak hours in urban centers, the subsidy of the taxi-hailing apps shall preferably go to the per mileage subsidy to the taxi driver, which is 0.38 yuan.

(ii) Peak hours in urban fringes:

$$0.625 + 0.0008 * p^1 - 0.012 * p^2 + 0.09 * p^3 - 0.00045 * p^4 > 0.75 \quad (10)$$

$$\min\{30 * p^1 + 6 * p^2 + 30 * p^3\} \quad (11)$$

Finally obtains: $p^1 = p^2 = p^4 = 0, p^3 = 1.38$

That is, in peak hours in urban fringes, the subsidy of the taxi-hailing apps shall preferably go to the fuel consumption subsidy to the taxi driver, which is 1.38 yuan.

(iii) Off-peak hours in urban centers:

$$0.71+0.0008*p^1-0.0009*p^2+0.006*p^3-0.00074*p^4>0.75 \quad (12)$$

$$\min\{30*p^1+6*p^2+30*p^3\} \quad (13)$$

Finally obtains: $p^1=p^2=p^4=0, p^3=2.38$

That is, in off-peak hours in urban centers, the subsidy of the taxi-hailing apps shall preferably go to the fuel consumption subsidy to the taxi driver, which is 2.38 yuan.

(iv) Off-peak hours in urban fringes:

$$0.699-0.002*p^1+0.0035*p^2-0.11*p^3-0.00074*p^4>0.75 \quad (14)$$

$$\min\{30*p^1+6*p^2+30*p^3\} \quad (15)$$

Finally obtains: $p^1=p^2=p^4=0, p^3=0.28$

That is, in off-peak hours in urban fringes, the subsidy of the taxi-hailing apps shall preferably go to the per mileage subsidy to the taxi driver, which is 0.28 yuan.

Based on the above schemes, the annual subsidy expenditure of a software company of the taxi-hailing apps can be calculated as shown in Table 5.

Table 5. *Optimized subsidy scheme and budget report.*

Time and Place	Optimized Subsidy Scheme	Total Amount of the Budget
Peak Hours/Urban Centers	The per mileage subsidy to the taxi driver: 0.38 yuan	36.8 million yuan
Peak Hours/Urban Fringes	The fuel consumption subsidy to the taxi driver: 1.38 yuan	82.8 million yuan
Off-peak Hours/Urban Centers	The fuel consumption subsidy to the taxi driver: 1.28 yuan	76.8 million yuan
Off-peak Hours/Urban Fringes	The per mileage subsidy to the taxi driver: 0.28 yuan	100.8 million yuan

3. Sensitivity Analysis

Based on the model conclusion, the following sensitivity analysis is conducted: exploring how the deviations of the above four subsidy policies affect the overall "taxi-hailing difficulty" index system W under different spacial and temporal contexts, namely different spacial and temporal scales, which are calculated separately:

$$\frac{\partial W}{\partial p^i}, i=1,2,3,4 \quad (16)$$

Result is shown in Table 6.

Table 6. *Influence of subsidy deviation on "taxi-hailing difficulty" index.*

Different Spacial and Temporal Contexts of Hailing a Taxi	$\frac{\partial W}{\partial p^1}$	$\frac{\partial W}{\partial p^2}$	$\frac{\partial W}{\partial p^3}$	$\frac{\partial W}{\partial p^4}$
Peak Hours/Urban Centers	0.0056	0.0027	0.018	-0.00045
Peak Hours/Urban Fringes	0.0008	-0.012	0.09	-0.00045
Off-peak Hours/Urban Centers	0.0008	-0.0009	0.006	-0.00074
Off-peak Hours/Urban Fringes	-0.002	0.0035	-0.11	-0.00074

As we can see from the table, during the peak hours in Beijing within the fifth ring road, if the driver subsidy deviation of 1% occurs, the "taxi-hailing difficulty "index deviation will be 0.0056%; if the per mileage subsidy deviation of 1% occurs, the "taxi-hailing difficulty "index deviation will be 0.0027%; if the fuel consumption subsidy deviation of 1% per litre occurs, the "taxi-hailing difficulty "index deviation will be 0.018%; if the passenger subsidy deviation of 1% occurs, the "taxi-hailing difficulty "index deviation will be 0.00045% (negative correlation).

4. Conclusion and Recommendation

Determination of subsidy scheme should be based on different time and region in order to work optimally. Sensitivity analysis is used to apportion the variation of model output to different source of variation. It shows that the most significant factor is p^3 and the evaluation model of "taxi-hailing difficulty" is stableand suitable. However, due to the continuous changes and basic hypothesis of data, a preliminary analysis of the model predictions is given in the paper. The formulae for the design introduced in more detail and model results verified through the independence test, cointegration test, Grangercausality and so on will be more persuasive.

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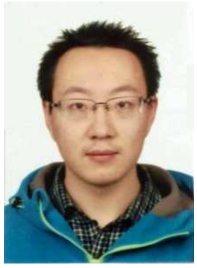
Biography



Xing Jiarui was born in 1993. He is an undergraduate in Beijing Normal University, specializing in electronic science and technology now.