Research on Pricing of Parent-Child Shared Bicycles Based on Biogeme

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Abstract. This study conducts a quantitative study on the reasonable pricing of parent-child shared bicycles. First of all, this study carried out a field SP (stated preference) survey in Beijing; secondly, on the basis of considering individual heterogeneity, this paper constructs the RPL (random parameters logit) model containing attitude latent variables, characterizes the latent variables with an ordered probit model, and uses PandasBiogeme software to compile a quasi-Newton algorithm and calibrate parameters; thirdly, this paper establishes a pricing model to maximize the revenue of parent-child bike sharing operator; finally, this paper uses the survey data as a representative, and uses Monte Carlo integration method to solve the model on Matlab software through sample expansion. The research results show that when the price of parent-child shared bicycle in Beijing is 1.97 yuan, the operator's revenue is the largest. At this time, 29.09% of children's parents adopt parent-child shared bicycle. The results also provide a reference for the bicycles' delivery at different pick-up distances.

Keywords: Traffic engineering; Pricing; Behavior analysis; Shared bicycles; Biogeme; Monte-Carlo integral.

1 Introduction

At present, parent-child bike sharing, as a new mode of transportation, has been launched in Wenzhou, China, reflecting the concept of caring for children. The parent-child shared bicycle is mainly used for children under 22kg, that is, it is suitable for picking up preschool children. For the operators, the pricing of shared bicycles is also an important part in addition to the delivery, so it is necessary to conduct in-depth quantitative research on the pricing of parent-child shared bicycles.

At present, the discrete choice model is mainly used to study travelers' choice behavior. Discrete choice models mainly include MNL (multinomial logit) model [1], etc. Because the MNL model has the IIA (independence of irrelevant alternatives) feature [2], researchers mainly use NL (nested logit) [3], CNL (crossed nested logit) [4], RPL (random parameters logit) [5] models for research. Among them, the RPL model is considered as one of the most promising discrete choice models [6].

In addition to the choice behavior, the current research will use attitude factors to describe the latent variables and integrate them into the choice model. At present, the structural equation method [7] and ordered probit model [8] are mainly used to characterize latent variables. The ordered probit model method can avoid the problem that the linear regression method ignores the internal ordering of data.

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At present, scholars have researched the pricing of shared bicycles, but there is relatively scarce research and literature on parent-child shared bicycles. Yao studied the impact of factors such as the price of shared bicycles and the distance to find bicycles on the commuter corridor by using the method of behavior analysis [9]; Haider worked out a reasonable bike-sharing pricing strategy through the IPAS (iterative price adjustment scheme) method to save the cost of shared bicycle scheduling, IPAS is a heuristic algorithm, which aims to achieve the goal of minimizing the number of imbalanced stations through price incentives, it divides stations into different categories and sorts them according to the current inventory status of stations and the difficulty of achieving the balance between supply and demand, and takes those stations that are not easy to achieve balance as hub stations, then adjusts route prices in each iteration to balance stations with moderate inventory [10]; Peng studied the pricing of shared bicycles under the duopoly model through game theory [11]; Podgorniak-Krzykacz built a multi-level shared bicycle evaluation framework based on the concept of public value to evaluate the reliability and price rationality of bike sharing [12].

However, the above research results consider the existing bike sharing, and do not consider the traveler's choice behavior towards the emerging parent-child bike sharing; moreover, previous studies rarely considered the heterogeneity of travelers' perception of use costs; in addition, previous studies usually combined latent variables with MNL model or NL model, and rarely studied the joint modeling of latent variables and RPL model.

Therefore, first of all, through SP (stated preference) survey and Likert scale, this study learned travelers' attitudes and choice behaviors towards parent-child bike sharing; second, the RPL model considering individual heterogeneity and latent variables is established and calibrated; third, this study establishes a pricing model that maximizes the revenue of operator; finally, this paper uses the survey data as the representative to expand the sample, and uses the Monte Carlo integration method to solve the model.

2 Investigation on the intention of children's picking-up and dropping-off modes

This study mainly considers two choices, namely, parent-child shared bicycle and other ways, and other ways include but are not limited to walking, private parent-child bicycle, private electric bicycle, car, etc. The selected limb of the RPL model is shown in Figure 1.

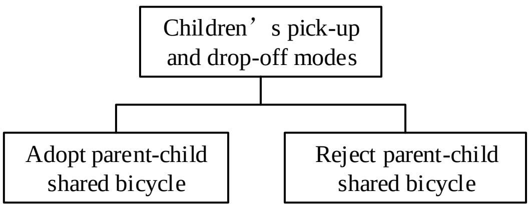

Fig. 1. The selected limb of the RPL model.

The SP questionnaire is divided into two parts. The first part is the mode choice part, where the children's relatives choose whether they are willing to use the parent-child shared bicycle when the price is explicitly indicated; the second part is about personal information and uses attitude, including statistics of respondents' gender, age, income, one-way distance from the community to the kindergarten, whether they generally use private transportation to pick up and drop off children, and their willingness to shared bicycles. The intention to use question is in the form of a Likert scale, that is to say, "5, 4, 3, 2, and 1" in turn correspond to the attitude statements of "really want to use", "prefer to use", "average", "not too want to use", and "do not want to use". For monthly income, "1, 2, 3, 4, and 5" correspond to "less than 3000 yuan", "3000 yuan (inclusive)~5000 yuan", "5000 yuan (inclusive)~7000 yuan", "7000 yuan (inclusive)~9000 yuan", "9000 yuan and above".

In 2022, the researcher obtained 1000 valid questionnaires through field distribution of questionnaires in many kindergartens and preschool education institutions in various districts of Beijing, and selected the questions by answering three questions by one person, so a total of 3000 valid data pieces were obtained. The personal information of the respondents is shown in Table 1.

Table 1. Personal Information Distribution of Respondents

Questionnaire items	Options	Proportion of options /%
Gender	male	49
	female	51
Age	≤22	4
	[23,35)	29
	[35,50)	27
	[50,60)	21
	≥60	19
Monthly income	<3000 yuan	10
	[3000,5000) yuan	18
	[5000,7000) yuan	23
	[7000,9000) yuan	22
	≥9000 yuan	27
One-way distance from the community to the kindergarten	<200 m	11
	[200,300) m	19
	[300,400) m	31
	[400,500) m	20
	[500,600) m	8
	≥600 m	11
Private transportation is generally used to pick up children	Yes	19
The willingness to use parent-child bike sharing	don't want to use	19
	not too want to use	17
	average	25
	prefer to use	20
	really want to use	19

3 Modeling of latent variable model

3.1 Modeling of the ordered probit model

The form of the latent variable is shown in Equation (1):

$$y^* = \beta_{\text{inc}} \cdot x_{\text{inc}} + \beta_{\text{ebik}} \cdot x_{\text{ebik}} + \varepsilon \ . \tag{1}$$

Where y^* is the latent variable; x_{inc} is the ranking data of the respondents' monthly income; x_{ebik} is a 0-1 variable, and when it is equal to 1, it means that children are generally picked up by private modes. $\varepsilon \sim \text{N}(0,1)$. β_{inc} and β_{ebik} are the model parameters to be calibrated.

The scoring rules of parent-child shared bicycle use intention are shown in Equation (2):

$$y = \begin{cases} 1, y^* \le \text{r}_1 \\ 2, \text{r}_1 < y^* \le \text{r}_2 \\ 3, \text{r}_2 < y^* \le \text{r}_3 \\ 4, \text{r}_3 < y^* \le \text{r}_4 \\ 5, \text{r}_4 < y^* \end{cases} . \tag{2}$$

In the equation, y is the score of respondents' willingness to use parent-child shared bicycles; $\text{r}_i \, (i = 1, 2, 3, 4)$ is the cutoff point.

The model considers that the cutoff points are symmetrical, and the following relationship exists between them, as shown in Equations (3)~(6):

$$\text{r}_1 = \delta_0 - \delta_1 - \delta_2 \ . \tag{3}$$

$$\text{r}_2 = \delta_0 - \delta_1 \ . \tag{4}$$

$$\text{r}_3 = \delta_0 + \delta_1 \ . \tag{5}$$

$$\text{r}_4 = \delta_0 + \delta_1 + \delta_2 \ . \tag{6}$$

Where, $\delta_i \, (i = 1, 2)$ is a positive number, and $\delta_i \, (i = 0, 1, 2)$ is the parameter to be calibrated.

3.2 Parameter calibration of the ordered probit model

The parameters of the model are calibrated by the quasi-Newton method, and the calibration results are shown in Table 2.

Table 2. Parameter calibration results of the ordered probit model

Parameter	Parameter value	t-value
β_{ebik}	-2.12	-19.8
β_{inc}	0.376	13.5
δ_0	0.886	9.01

δ_1	0.44	18
δ_2	0.763	21.7
Adjusted goodness of fit	0.408	
Number of valid data	1000	

In the calibration results, the sign of β_{inc} is positive, which means that the higher the income of children's relatives, the more willing they are to adopt the new parent-child bicycle sharing mode and consume. The symbols of the calibration results of all parameters are reasonable and have a confidence level of more than 95%. The adjusted goodness of fit is 0.408 greater than 0.2, which indicates that the calibration results are reasonable.

4 Choice Model of children's picking-up and dropping-off modes

4.1 RPL model modeling

The part of each selected limb that does not contain the error term subject to the extreme value distribution is shown in Equations (7)~(8):

$$V_1 = (\mu_c + \varepsilon_c \cdot \sigma_c) \cdot c + \beta_{dis} \cdot d + \beta_{y^*} \cdot y^* + \alpha \ . \tag{7}$$

$$V_2 = 0 \ . \tag{8}$$

In the equation, V_1 and V_2 are the parts of the utility that do not contain the error term that obeys the extreme value distribution when the parent-child shared bicycle is selected and when the parent-child shared bicycle is not selected respectively; c is the usage fee of the parent-child shared bicycle, and the unit is yuan; d is the one-way distance from the children's community to the kindergarten, in meters. $\varepsilon_c \sim N(0,1)$. μ_c, σ_c, β_{dis}, β_{y^*}, and α all are parameters of the model to be calibrated.

The selected probability P_1 of parent-child shared bicycle is shown in Equation (9):

$$P_1 = \int_{-\infty}^{+\infty} \rho \frac{e^{V_1}}{e^{V_1} + e^{V_2}} \, d\varepsilon_c \ . \tag{9}$$

Where ρ is the probability density function of ε_c.

4.2 RPL model parameter calibration

The model uses the quasi-Newton method to calibrate parameters. The calibrated parameters of the ordered probit model are substituted into the RPL model, and then the RPL model is calibrated. The parameter calibration results are shown in Table 3.

Table 3. Calibration Results of RPL Model Parameters

Parameter	Parameter value	t-value
μ_c	-1.46	-5.99

σ_c	0.624	1.99
β_{dis}	0.623	6.94
β_{y^*}	1.56	7.03
α	-2.3	-6.66
Adjusted goodness of fit	0.242	
Number of valid data	3000	

In the calibration result, the sign of α is negative, which reflects the preference of the child carrier for the previous mode. The symbols of the calibration results of each parameter are reasonable and have a confidence level above 95%. The adjusted goodness of fit is 0.242, which is greater than 0.2, indicating that the calibration results are reasonable. At the same time, the calibration results show that different people have different feelings about the cost of parent-child shared bicycle.

5 Pricing model and solution of parent-child shared bicycle

5.1 Modeling of parent-child shared bicycle pricing model

This model maximizes the revenue of the operator. If the number of parents who pick up and drop off children is N, the operator's average maximum income per person is shown in Equation (10):

$$\max f(x) = \frac{\sum_{i=1}^{N} P_1^{(i)} \cdot x}{N} \quad . \tag{10}$$

In the equation, i refers to the parents who pick up and drop off children, $P_1^{(i)}$ refers to the probability of their choosing parent-child shared bicycle, x refers to pricing, and the probability distribution of personal attribute variables of i is the same as that of this SP survey.

5.2 Solution to the pricing model of parent-child shared bicycles

In this study, the Monte Carlo integration method is used to solve the model. The value of N is 100000, and the model solution results are shown in Figure 2.

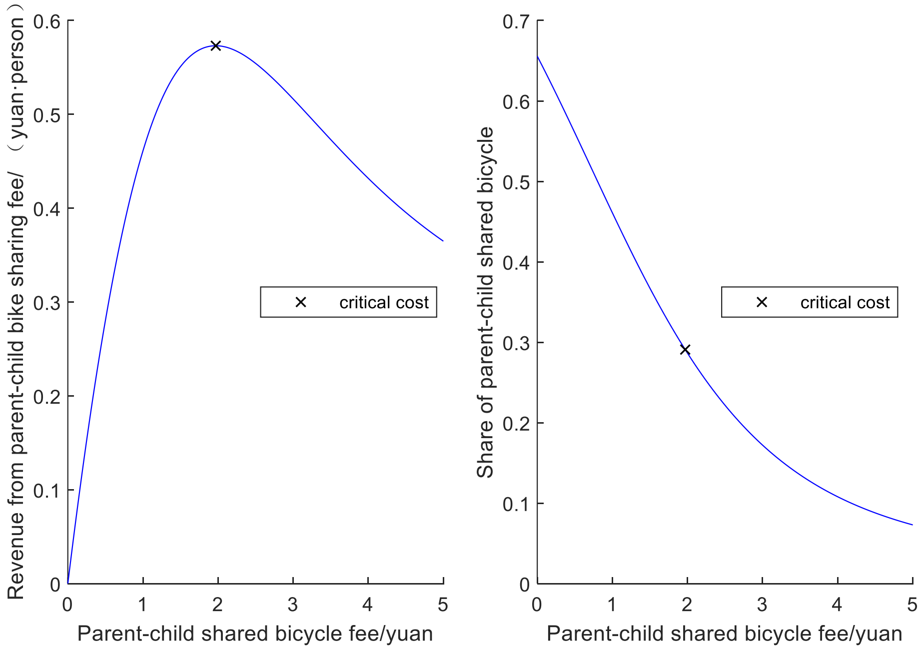

Fig. 2 Model Solution Results

When the price of parent-child shared bicycle is 1.97 yuan, the average maximum single income of the operator reaches the maximum of 0.57 yuan. At this time, 29.09% of parents of children choose parent-child shared bicycle to pick up and drop off children. The price of parent-child shared bicycles is higher than the current average price of shared bicycles in Beijing, which indicates that it is necessary to make differentiated pricing for parent-child shared bicycles and commonly shared bicycles.

When the income of the operator reaches its peak, this study obtains the share of parent-child shared bicycles at different one-way pick-up distances, as shown in Figure 3.

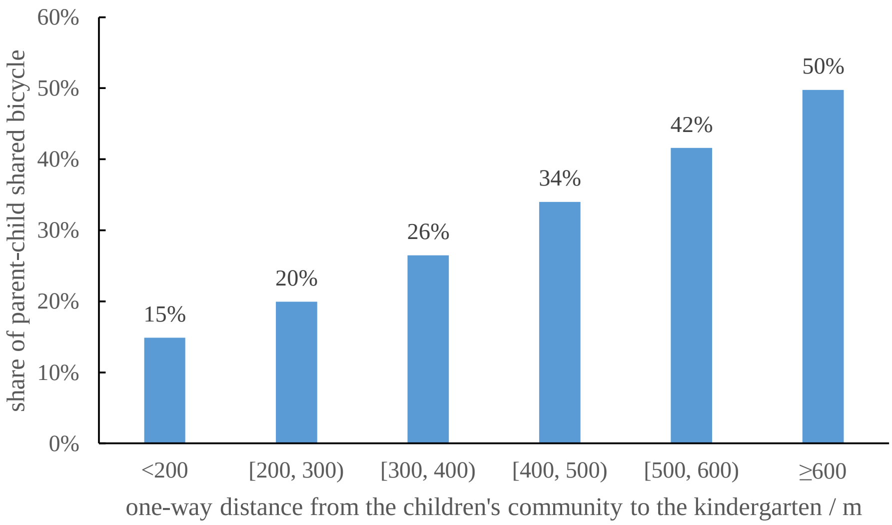

Fig. 3 Share of Parent-child Shared Bicycles at Different One-way Pick-up Distances

The overall average share of the bicycle is 29.09%, indicating that the bicycle plays a greater role in one-way pick-up distance not less than 400 meters. Moreover, this provides a reference for the bicycles' delivery, after knowing the number of children in a community, they can determine the amount of bicycles.

6 Conclusion

The purpose of this study is to maximize the revenue of parent-child bike-sharing operator through reasonable pricing. First of all, based on the SP survey in Beijing, this study established a latent variable RPL joint model considering individual heterogeneity and attitude latent variable to describe the choice behavior of children's parents' pickup and drop-off modes, which was calibrated by quasi-Newton method; secondly, this paper establishes a pricing model to maximize the revenue of operator, and expands the sample represented by SP survey data, and determines the pricing through Monte-Carlo integration. The research results show that when the price of parent-child shared bicycle is 1.97 yuan, the average single income of the operator just reaches the maximum of 0.57 yuan. At this time, 29.09% of children's parents choose parent-child shared bicycle to pick up and drop off children. The research results also show that it is necessary to implement differential pricing for parent-child bike sharing and common bike sharing, and provide a delivery ratio under different pick-up distances for operator reference.

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