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A Behavioral Model of Work-trip Mode Choice in Shanghai

Abstract:
This paper analyzes travelers' choice behavior by using data from a stated preference survey on work-trip mode choice in Shanghai. Several versions of a multinomial choice model are specified and estimated. According to the estimation results the utility function with money cost divided by income adjusted by an equivalence scale is chosen as the preferred model. Based on the estimation results from the preferred model, value of time, elasticities of aggregate mode choice with respect to income, cost, travel and waiting time, are computed. The conditional elasticities given low, middle and high adjusted income levels are calculated and discussed as well. The results obtained may be useful for transportation policy makers in Shanghai.

Keywords: work-trip mode choice, stated preference survey, multinomial choice model, choice probability and elasticity

JEL classification: C25, C42, C52, R41

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1. Introduction

As one of the economic centers in China, Shanghai's rapid economic growth in recent years has induced enormous intra- and inter-city transportation demand. To ensure the development of an efficiently functioning market economy, the government has decided to continuously promote the construction and management of transportation systems in Shanghai (Zhou, 1998). To this end, it is of crucial importance to acquire as much information about travelers' behaviour as possible. Only if the decisions associated with transportation construction and management are based on this information, can economic efficiency be achieved.

In this paper, we carry out an econometric analysis on work-trip mode choices based on data obtained from a survey conducted in Shanghai in the summer of 2001. Probabilistic discrete choice models based on random utility representations are applied.[1] In such models, a traveler is typically assumed to derive his/her utility from the attributes of work-trip mode alternatives. To account for the fact that some of these attributes may not be observed by the researcher, the utility function is allowed to depend on a random error term. This random error term also represents unobserved heterogeneity in preferences across observationally identical travelers.
Information from work-trip mode choice analyses is of great help for decision-makings. For instance, the value of time that measures the trade-off between travel time and travel cost can be derived from the analyses and used by decision makers to undertake a priori evaluation among alternative transportation construction projects and/or management measures. Such models can also be applied to assess the responsiveness of demand for various transportation modes to changes in policy relevant variables such as travel cost or travel time. This is typically done by calculating the elasticities of choice probabilities with respect to the relevant attributes of transportation modes.

When formulating empirical models, researchers usually have limited information about the structure of the utility functions of the travelers. For example, it is not clear whether and how a traveler's income should enter the utility function.

In some cases (e.g., Jara-Diaz and Ortuzar, 1989) travel cost is divided by the traveler's income to reflect the presumption that a traveler with a high income is less concerned about money cost than a traveler with a low income. In other cases travel time is multiplied by the traveler's income to reflect the presumption that a traveler with a high income is more concerned with time lost than a traveler with a low income (e.g., McFadden, 1974).

[1] Applications in urban transportation analysis of discrete choice models were pioneered by Warner (1962), Lisco (1967), McFadden (1974), Domencich and McFadden (1975), among others.

Train and McFadden (1978) presented a goods/leisure trade-off model that enabled one to find how wage should enter a representative utility function by estimation rather than specified *a priori*. Jara-Diaz (1991) generalized this approach to a generalized expenditure rate model. In Liu (2003), an approach similar with Jara-Diaz (1991) was employed to specify different models for analysing work-trip mode choice in Shanghai. However, in all the models mentioned above the direct utility functions are restricted as either Cobb-Douglas or its generalized functional forms from which the corresponding indirect utility functions were derived.

In this paper, we depart directly from a general indirect utility function without imposing any restrictions on its functional form. In addition, by allowing for heteroscedastic error terms in the utility function, we show that whether and how income should enter a utility function can be tested against our sample data.

The rest of the paper is organized as follows. Section 2 provides a brief overview of the survey and the data obtained. In section 3, the model specifications are discussed. Section 4 presents the empirical model evaluation and estimation results. Based on the results from the preferred model, the value of time and sample aggregate elasticities of choice probability are computed in Section 5. Some discussions on elasticities of the choice probabilities within the sample are also made. Section 6 concludes.

2. Surveying Work-trip Transportation Modes in Shanghai

The data used in this paper comes from a survey conducted in Shanghai in the summer of 2001 and is reported in Liu (2001). In the survey, totally 100 respondents were selected in the central Shanghai area. The survey consists of three parts, of which only two are relevant to this paper. One part concerns respondents' household characteristics such as age, gender, education, occupation, family size, number of family workers and income level, etc. The other part yields information about the respondents' actual and potential work-trip mode choices.

In order to obtain as much information as possible from a small size sample, the stated preference (SP) method was combined with the conventional revealed preference (RP) method. While the RP method emphasizes respondents' observed (real) choice behavior, the SP method yields respondents' *stated* choices in hypothetical choice situations, and thus, has the advantage of cost-effectiveness.[2] In particular, the use of the SP method enables one to obtain ranking choice data, and at the same time, obtain information about the respondent's specific choice set. In contrast, the RP

[2] For a general discussion of stated preference method and its applications in transport economics, see Bates (1988).

method only yields the (revealed) first choice. Since ranking choice data contain more information, such data can improve the efficiency of the model estimation.

The survey was carried out by face-to-face interviews. First, we asked each respondent which transportation mode he/she usually chose for going to work place among a universal choice set. The universal set of choice alternatives consists of 16 transportation mode alternatives: 1 = “Walk”; 2 = “Bicycle”; 3 = “Bus”; 4 = “Subway” [3]; 5 = “Company owned bus or car”; 6 = “Taxi”; 7 = “Motorcycle”; 8 = “Scooter” [4]; 9 = “Private car”; 10 = “Bicycle + Bus”; 11 = “Bicycle + Subway”; 12 = “Bicycle + Company owned bus or car”; 13 = “Bus + Subway”; 14 = “Bus + Company owned bus or car”; 15 = “Bus + Taxi”; 16 = “Taxi + Subway”. Subsequently, we asked the respondent to specify the attribute values associated with the chosen alternative mode, i.e., “In-vehicle time”, “Out-of-vehicle time” and “Money cost”, for a one-way work trip. The “Out-of-vehicle time” comprises mainly walking and waiting time.

Second, we asked what his/her second preferred choice would be on the assumption that his/her most preferred choice was not available. Third, we asked what his/her third preferred choice would be in the case when his/her previously preferred two choices were not available. For the second and third questions, we also asked the respondent about the attributes of the respective alternative modes.

We continued this procedure until the respondent told us that no more alternatives were left in his/her choice set. In this way we in fact obtained the actual individual choice sets. After the survey was finished, we found that there was no one in the sample who perceived they had more than three transportation modes in their choice sets. However, individual specific choice sets of the travellers varied a lot across the sample.

Among the 100 respondents, a few of them specified only one mode in their choice set and some told that the same transportation mode appeared more than once in the sequential ranking choices, all of which were considered not to conform to our model settings. Therefore, we removed these respondents and ended up with a sample of 91 respondents.

[3] There were two different types of intra-city train systems in Shanghai when we conducted the survey. One was underground and the other was above the ground. We grouped them together as one “subway” mode although we distinguished them on the survey questionnaire.

[4] The reason why we treated "Motorcycle" and "Scooter" differently is that by regulation in Shanghai scooters could only be driven on bicycle paths while motorcycles could be driven on motorways as normal automobiles.

Table 1: Number of Observations for Alternative Modes in the Sample

Number of Observations	Work-trip Mode																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Sum
First Choice	4	20	30	13	3	4	4	2	1	0	0	1	6	2	1	0	91
Second Choice	5	8	32	2	0	31	0	2	1	1	1	0	3	2	1	2	91
Third Choice	2	0	6	3	0	29	0	0	0	0	0	0	2	0	1	0	43
Sum	11	28	68	18	3	64	4	4	2	1	1	1	11	4	3	2	225

Table 1 presents the distribution of the sample observations across all the 16 work-trip modes for the first choice, second choice, third choice and the sum of these three choices across the sample. For the first choice, which is the actual choice made by the travelers, "Bus"(3), "Bicycle"(2), "Subway"(4) and "Walk"(1) accounts for 74 percent of the 91 observations. If taking into account the combination modes, the ratio of these four modes will be even higher, which is consistent with other research results in Shanghai (Chen and Xie, 2001).

On the assumption that the first choice is not available for the respondents, we found most respondents would switch to take taxi instead. As a result, "Bus"(3), "Taxi"(6), "Bicycle"(2) and "Subway"(4) account for 79 percent of the sum of all observations. The fact that the number of the third choices is 43 (less than 91) is due to the reason that many respondents in the sample only have two alternative transportation modes in their choice sets.

Table 2: Summary of Some Characteristics of Respondents in the Sample

Characteristics	Age (year)	Family Income (yuan/month)	Family Size (person)	Number of Workers in Family (person)
Range	21 - 56	1500 – 15500	1 - 6	1 - 4
Mean	34	6874	2.60	1.87

In Table 2 we display a summary statistics of individual and households' characteristics of the sample, which are relevant to the empirical estimation in Section 4. In Table A1 in appendix A, more information on the characteristics as well as the specific choice sets of all the 91 respondents are reported.

3. Model Specifications

Consider a traveler *n* having income I_n. Let $S_n \subset S$, denote traveler *n*'s specific work-trip mode choice set, where *S* is the universal set of transportation mode alternatives, consisting of the 16 transportation modes as outlined in Section 2. Transportation mode j, $j \in S$, is described by "Money cost" c_j and two different time attributes, "In-vehicle time", t_{ij}, and "Out-of-vehicle time (including mainly walking and waiting time)", t_{oj}.

Let $\tilde{U}_{nj}$ be traveler n's utility of choosing transportation mode j. The utility $\tilde{U}_{nj}$ is assumed to be a sum of a deterministic part $\tilde{V}_{nj}$ and an additive random error term μ_{nj}, which accounts for the effect of the unobservable part of utility (Manski, 1977). Assume $\tilde{V}_{nj}$ has the following general form:

(1) $$\tilde{V}_{nj} = \tilde{V}\left(I_n - c_j, p, t_{ij}, t_{oj}\right)$$

where $\left(I_n - c_j\right)$ is the net (after expense on transportation) expenditure on all other goods for which the price index is p. Recall that $\tilde{V}_{nj}$ is an indirect utility function and should therefore, have the property of being homogeneous of degree zero with respect to income and price. Thus it can be rewritten as:

(2) $$\tilde{V}_{nj} = \tilde{V}\left(1 - \frac{c_j}{I_n}, \frac{p}{I_n}, t_{ij}, t_{oj}\right).$$

By taking first order Taylor expansion of $\tilde{V}_{nj}$ in (2), we obtain

(3) $$\tilde{V}_{nj} = \beta_1 \frac{c_j}{I_n} + \beta_2 t_{ij} + \beta_3 t_{oj}$$

where β_1, β_2 and β_3 are parameters to be estimated. Note that we have omitted all terms that are not transportation mode specific since only utility differences matter when the traveler compares alternatives (See (9) and (10) below).

To account for possible heteroscedasticity, assume further that the random error term μ_{nj} has the structure as follows:

(4) $$\mu_{nj} = I_n^{\gamma} \varepsilon_{nj}$$

where ε_{nj}, $j = 1, 2, ...,$ are assumed to be i.i.d. with the standard extreme value distribution,

(5) $$\Pr\left(\varepsilon_{nj} < x\right) = \exp\left(-\exp\left(-x\right)\right),\ x \in \left(-\infty, \infty\right),$$

and γ is a parameter to be estimated.

We note that when $\gamma > 0$ the variance of the error term increases by income, and this may be interpreted as that a traveler with higher income tends to care more about unobserved attributes such as comfort, punctuality, flexibility, etc. than costs and traveling times. As a result, he/she may take taxi one day for the purpose of comfort and switch to bicycle riding another day just for exercise.

Certainly, the real situation could very well be the other way around. One may argue that a decreasing variance by income when $\gamma < 0$ may be due to that the traveler with higher income is more conscious about costs and traveling times when making choice compared with his/her counterpart with lower income. Clearly, when $\gamma = 0$, there is no heteroscedasticity in the error term.

Combining (3) and (4) and making use of the property that utility is invariant under re-scaling, the utility function $\tilde{U}_{nj}$ is equivalent to

(6) $$U_{nj} = V_{nj} + \varepsilon_{nj}$$

where

(7) $$V_{nj} = \beta_1 I_n^{-\gamma-1} c_j + \beta_2 I_n^{-\gamma} t_{ij} + \beta_3 I_n^{-\gamma} t_{oj}$$

Eq. (7) has a functional form similar with those adopted in Train and McFadden (1978) and Jara-Diaz (1991). However, the motivation differs from theirs. In both Train and McFadden (1978) and Jara-Diaz (1991), the Cobb-Douglas (or its generalized) functional forms are assumed for the direct utility function from which the corresponding indirect utility function was derived. The approach employed in this paper departs directly from a general indirect utility function (1), with no restrictions on its functional form, but approximated by first order Taylor expansion. In addition, we allow for heteroscedastic error terms in the utility function.[5]

Eq. (7) also encompasses earlier specifications on how income should enter the utility function. For example, in Jara-Diaz and Ortuzar (1989) travel costs are divided by the traveler's income to reflect the presumption that a traveler with a high income is less concerned about money cost than a traveler with a low income. In other cases travel times are multiplied by the traveler's income to reflect the presumption that a traveler with a high income is more concerned with time lost than a traveler with a low income (McFadden, 1974).

[5] An approach similar with that in Train and McFadden (1978) and Jara-Diaz (1991) has been employed in Liu (2003) to specify different models for analysing work-trip mode choice in Shanghai.

Clearly, the restriction of $\gamma = 0$ in (7) corresponds to the case where costs are divided by income; we label it as Model 1. With the restriction of $\gamma = -1$, (7) corresponds to the case where travel times are multiplied by income and we label it as Model 2. The case with no restriction on the value of γ is referred to as Model 3. Thus, Model 3 encompasses Model 1 and Model 2, which enables one to test statistically which model, Model 1 or Model 2, is better (more consistent with the data) than the other.

In order to examine whether income should enter into the utility function or not, we also construct a model without income term in the specification of V_{nj}, namely,

$$V_{nj} = \beta_1 c_j + \beta_2 t_{ij} + \beta_3 t_{oj} \tag{8}$$

As a matter of fact, (8) can also be derived by taking first order Taylor expansion of $\tilde{V}_{nj}$ in (1) and neglecting all terms that are not transportation mode specific. The specification in (8) is referred to as Model 4 in this paper.

Under the above assumptions, the probability $P_{nj}(S_n)$ that traveler n chooses alternative j from his/her choice set S_n can be written as (McFadden, 1984)

$$\mathrm{P}_{nj}(S_n) = \Pr\left(U_{nj} = \max_{q \in S_n} U_{nq}\right) = \frac{\exp(V_{nj})}{\sum_{q \in S_n} \exp(V_{nq})}, \quad j \in S_n. \tag{9}$$

In the present study, we will also make use of the rank ordering data that comes from a deliberately designed survey (see Section 2). Now suppose we can observe traveler n's second preferred choice, it also follows from the setup above that the probability $Q_{njk}(S_n)$ that traveler n sequentially chooses alternative j first and k second is (Strauss, 1979; Beggs *et al*, 1981; McFadden, 1984)

$$\begin{aligned} Q_{njk}(S_n) &= \Pr\left(U_{nj} = \max_{q \in S_n} U_{nq}, U_{nk} = \max_{r \in S_n \setminus \{j\}} U_{nr}\right) = \frac{\exp(V_{nj})}{\sum_{q \in S_n} \exp(V_{nq})} \cdot \frac{\exp(V_{nk})}{\sum_{r \in S_n \setminus \{j\}} \exp(V_{nr})} \\ &= \mathrm{P}_{nj}(S_n) \cdot \mathrm{P}_{nk}(S_n \setminus \{j\}), \quad j \in S_n, \ k \in S_n \setminus \{j\}. \end{aligned} \tag{10}$$

4. Empirical Results

Given the probability of traveler n choosing alternative mode j as shown in (9), the maximum likelihood estimation method will be used and the relevant Log likelihood function for the sample, $L(\boldsymbol{\beta})$, can be written as

$$(11) \qquad L(\boldsymbol{\beta}) = \sum_{n=1}^{N} \sum_{j \in S_n} Y_{nj} \log P_{nj}(S_n),$$

where

$$Y_{nj} = \begin{cases} 1 & \text{if } n \text{ chooses } j \\ 0 & \text{otherwise}, \end{cases}$$

and N is the sample size and equal to 91 in this paper.

When rank ordering data are used, the choice probabilities are given by (10) and the correspondent log likelihood function for the sample can be written as

$$(12) \qquad L^{*}(\boldsymbol{\beta}) = \sum_{n=1}^{N} \sum_{j,k \in S_n} Y_{njk} \log Q_{njk}(S_n),$$

where

$$Y_{njk} = \begin{cases} 1 & \text{if } n \text{ chooses } j \text{ first and } k \text{ second} \\ 0 & \text{otherwise}. \end{cases}$$

The maximum likelihood estimates obtained by maximizing (11) and (12) are reported in Tables B1, B2 and B3 in Appendix B. Note that the small size of the sample and the relatively large universal choice set makes it impossible for us to estimate alternative mode specific constants in our models.

It can be observed from Tables B1, B2 and B3 that the coefficient estimates by using only first choice data differ not considerably from those by using rank ordering data, which may indicate that the property of the independence from irrelevant alternatives (IIA) assumed by the error terms in (6) holds true.[6]

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[6] However, this is not a strict IIA test that we are not able to implement here due to the data limitation. For a discussion on the implications and limitations of the IIA property, see e.g. Train (2003), 49-54.

Compared with Model 1, 2 and 3, exclusion of income in the model specification (Model 4) uniformly decreases the Log likelihood, which may indicate that income is indeed an important variable in work-trip mode choice decisions.

As regards the income term I_n in (7), we have tried total family income, income per capita as well as family income divided by an equivalence scale equal to the square root of family size in the estimations. This type of equivalence scale is used in many countries. Taking Model 1 as an example, the intuition of using per capita income instead of family income is to reflect that traveler n's disutility resulting from money cost in a family with larger size might be greater than that in a family with smaller size. The purpose of using family income divided by square root of family size is to reflect possible decreasing return of disutility with respect to family size.

In general, the estimation results indicate that, compared with those by using total family income, the Log likelihood increases, though not so much, as a result of using either income per capita or income adjusted by the equivalence scale both for the case with first choice data and for the case with rank ordering data.

To test statistically which one, Model 1 or Model 2, is better (more consistent with the data) than the other, the usual likelihood ratio tests are implemented with restrictions being $\gamma = 0$ for Model 1 and $\gamma = -1$ for Model 2. The critical value at the 5 percent significance level is 3.84 for the chi-square distribution with one degree of freedom. The test statistics for Model 1 by employing the three income definitions (family income, income per capita, family income adjusted by the equivalence scale) are 2.366, 0.004 and 0.214, respectively. All three values are less than the critical value 3.84, which implies that we cannot reject the null hypothesis of $\gamma = 0$ at the 5 percent significance level. For Model 2, the test statistics are 4.802, 5.514 and 5.926, corresponding to the three income definitions respectively. Therefore, at the 5 percent significance level, we may reject the hypothesis of $\gamma = -1$.

To summarize, the evidence points towards Model 1 being the model that fits the sample data best among the model specifications estimated in this paper. Accordingly, we take Model 1 as our preferred model.

Table 3. Estimation results for the preferred model (Model 1) with rank ordering data and income adjusted by the equivalence scale

Variable name	Coefficient estimate	Asymptotic standard error	Asymptotic *t*-statistic
One-way work-trip money cost (yuan)	-0.067	0.012	- 5.57
In-vehicle time (minute)	-0.041	0.013	-3.05
Out-of-vehicle time (minute)	-0.055	0.019	-2.83
Number of observations	91		
Log likelihood	-69.607		
McFadden's ρ_1^2	0.37		
McFadden's ρ_2^2	0.81		

Considering the income term in the preferred Model 1, the log likelihood seems to be larger when using income per capita than using income adjusted by the equivalence scale. However, the difference is not substantial, given the size of our sample. Furthermore, because of two reasons, we finally end up with using income adjusted by the equivalence scale in the model estimation. The first reason is that family income divided by an equivalence sale (here square root of family size) is more reasonable, especially for households who have small children or old people as dependents. In that situation, income per capita may not reflect the true budget constraints faced by the households. The other reason is of empirical concern. By using rank ordering data, the estimated coefficients using income per capita in the general model (Model 3) are not significant except for parameter γ; in contrary, all coefficient estimates are significant when using income adjusted by the equivalence scale.

In Table 3 we report the parameter estimates and other statistical information for the preferred model (Model1) by using income adjusted by the equivalence scale.

We see that all the estimated parameters in Table 3 are highly significant and with expected sign. Although larger (absolute) value of the coefficient of "Out-of-vehicle time" compared with that of "In-vehicle time" may suggest that "Out-of-vehicle time" is more burdensome than "In-vehicle time", they are, however, not significantly different from each other.[7]

The value of McFadden's ρ^2 is a measure of goodness-of-fit and similar to the familiar R^2 used in conventional regression analysis (cf. Ben-Akiva and Lerman, 1985). It is defined as

[7] The calculated statistic for testing the restriction of the coefficients of "In-vehicle time" and "Out-of-vehicle time" being equal is 0.451, which is within the 95 percent acceptance region of (0.001, 5.024) for the chi-square distribution with one degree of freedom.

(13) $$\rho^2 = 1 - \frac{L(\hat{\boldsymbol{\beta}})}{L(\mathbf{0})}$$

where $L(\hat{\boldsymbol{\beta}})$ is the estimated Log likelihood and $L(\mathbf{0})$ is the Log likelihood for the reference case. Due to the presence of heterogeneity across individual's choice sets in the sample, we computed two versions of McFadden's ρ^2 corresponding to two reference cases. McFadden's ρ_1^2 is obtained by using the case of a reference where each respondent faces his/her own actual choice set with equal choice probabilities within each choice set; McFadden's ρ_2^2 is obtained by using as reference the case where each respondent faces the same choice set of 3 alternatives with equal choice probabilities within each choice set.

Thus, while ρ_1^2 is based on the information about the sizes of the observed specific choice sets for each respondent in the sample as the reference case, ρ_2^2 simply ignores this information and uses as reference a choice set of 3 alternatives with choice probability equal to 1/3. Therefore, the difference between the two "goodness of fit" measures reflects the importance of the heterogeneity in the sizes of the individual choice sets across the sample.

5. Value of Time and Elasticities of Choice Probability

5.1. Value of Time

Value of time measures the trade-off between travel time and travel cost to keep a traveler's utility unchanged on the margin. The values of "In-vehicle time" and "Out-of-vehicle time" can be calculated as follows:

(14) $$\text{Value of "In-vehicle time"} = \frac{\partial V_{nj} / \partial t_{ij}}{\partial V_{nj} / \partial c_j} = (\beta_2 / \beta_1) I_n ,$$

(15) $$\text{Value of "Out-of-vehicle time"} = \frac{\partial V_{nj} / \partial t_{oj}}{\partial V_{nj} / \partial c_j} = (\beta_3 / \beta_1) I_n .$$

For the purpose of comparison, we also calculate the sample wage (R_{nw}) as

(16) $$R_{nw} = \hat{I}_n / m_n ,$$

where $\hat{I}_n$ is the total family income per month and m_n is the number of employed workers in individual n's household.

Taking the sample average yields values of "In-vehicle time" and "Out-of-vehicle time" equal to 15.1 yuan per hour and 20.2 yuan per hour, respectively, while the mean wage across the sample is 21.7 yuan per hour.

Comparing the mean sample wage with the value of "In-vehicle time" and the value of "Out-of-vehicle time", we find that the value of "In-vehicle time" is 75 per cent of the mean wage while that of "Out-of-vehicle time" is equal to the mean wage, approximately.

5.2. Elasticities of Choice Probability

As with any demand study, elasticity measures the responsiveness of demand to changes in policy-relevant variables and is of great importance. In defining elasticities for discrete choice models, we must distinguish between disaggregate and aggregate elasticities. A disaggregate elasticity represents the responsiveness of an individual n's choice probability of choosing alternative j, P_{nj}, to a change in the value of some attribute of alternative j, x_{jw} (own-elasticity) or some attribute of other alternative q, x_{qw} (cross-elasticity). It can be calculated as

(17) $$\frac{\partial \ln P_{nj}}{\partial \ln x_{qw}} = \left(\eta_{jq} - P_{nq}\right) x_{qw} \beta_w ,$$

where $\eta_{jq} = 1$ if $j = q$ and zero otherwise; $x_{jw}, w = 1,2,3$, correspond to $I_n^{-1} c_j$, t_{ij} and t_{oj}, respectively. The income elasticity of choice probability can be similarly calculated as

(18) $$\frac{\partial \ln P_{nj}}{\partial \ln I_n} = \beta_1 I_n^{-1} \left\{ \sum_{q \in S_n} P_{nq} c_q - c_j \right\} .$$

The aggregate elasticities summarize the responsiveness of the population of decision makers rather than that of an individual. It is clearly of more importance in providing information for planners about the aggregate. There are several ways of calculating aggregate elasticity in discrete choice model settings.[8] One approach is based on a uniform percentage change in x_{jw} across all members of the population in which case the corresponding aggregate elasticity can be calculated as (Ben-Akiva and Lerman, 1985).

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8 For a general discussion on these issues see Koppelman (1976), McFadden and Reid (1976), Talvitie (1976), Dunne (1984).

(19)
$$\frac{\partial \ln \overline{P_j}}{\partial \ln x_{qw}} = \frac{\partial \ln\left(\left(\sum_{n=1}^{N} P_{nj}\right)\Big/N\right)}{\partial \ln x_{qw}} = \frac{\sum_{n=1}^{N} P_{nj}\left(\dfrac{\partial \ln P_{nj}}{\partial \ln x_{qw}}\right)}{\sum_{n=1}^{N} P_{nj}}.$$

Clearly, this definition of aggregate elasticity is simply a weighted average of the disaggregate elasticity using the choice probabilities as weights. Aggregate income elasticity of choice probability can be easily derived similar to (19).

In Table 4 we report predicted aggregate choice probabilities and aggregate income elasticities as well as own- and cross-elasticities of choice probabilities of choosing "Bicycle", "Bus", "Subway" and "Taxi" with respect to "Money cost", "In-vehicle time" and "Out-of-vehicle time".[9] The elasticities in the table can be read such that the value –0.270 in the fourth row and the fifth column refers to the own-elasticity of choice probability of choosing “Bicycle” with respect to "In-vehicle time" and the value 0.058 in the same row and the sixth column is the cross-elasticity of choice probability of choosing “Bicycle” with respect to "Money cost" of choosing “Bus”.

Table 4: Aggregate Choice Probabilities and Elasticities in the Sample

	Actual Share[1]	Predicted Choice Probability	Elasticity of Choice Probability[2]									
			Income[6]	Bicycle[3]	Bus			Subway[4]			Taxi[5]	
				t_i	c	t_i	t_o	C	t_i	t_o	c	t_i
Bicycle	0.220	0.191	-0.172	-0.270	0.058	0.122	0.141	-	-	-	0.109	0.027
Bus	0.330	0.309	-0.172	0.105	-0.166	-0.528	-0.298	0.037	0.069	0.080	0.228	0.054
Subway	0.143	0.141	-0.089	-	0.084	0.299	0.108	-0.100	-0.193	-0.229	0.103	0.025
Taxi	0.044	0.086	1.420	0.116	0.077	0.340	0.237	0.018	0.042	0.052	-1.598	-0.427

Notes:

[1] For the first choice in the sample (See Table 1);

[2] Attributes for transportation modes are c – “One-way work-trip money cost (yuan)”, t_i – “In-vehicle time (minute)” and t_o – “Out-of-vehicle time (minute)”;

[3] “Money cost” and “Out-of-vehicle time” by taking "Bicycle" are zero;

[4] No cross-elasticity of "Bicycle" with respect to attributes of "Subway" due to only a few observations;

[5] “Out-of-vehicle time” by taking "Taxi" is zero;

[6] Income adjusted by the equivalence scale (10000 yuan per month).

Recall that even the sample in this study is far from representative for the Shanghai city, the model can still be consistently estimated provided the random error terms in the utility function are identically and independently distributed as well as independent of the systematic part of the utility function. However, when we make prediction beyond the sample, due caution must be taken.

[9] Because the observations for the other alternative modes are limited, we don’t report them in the table.

Therefore, it should be noted that the aggregate results in Table 4 are probably not representative for the corresponding elasticities for Shanghai.

Table 4 reveals that the predicted choice probabilities are quite close to the actual shares of choosing "Bicycle", "Bus", "Subway" as the first choice in the sample.[10] The higher predicted probability of choosing "Taxi" is due to the dominance of this transportation mode in the second and third preferred modes in the rank ordering choices, of which we make use for the model estimation. Aggregate income elasticities suggest that "Bicycle", "Bus" and "Subway" seem to be "inferior" modes while "Taxi" seems to be a "luxury" one for individuals in the sample.

The own-elasticity, –0.528, of the choice probability of choosing “Bus” with respect to "In-vehicle time" is the largest one compared to those to other attributes, which indicates that “Bus” riders in the sample are most sensitive to the length of time onboard. In regard to the attributes of "Subway", it seems that "Out-of-vehicle time" (waiting and walking time) is the most important. Concerning the mode of "Taxi", the respondents seem to be more sensitive to the money expense since the own-elasticity of the probability of choosing "Taxi" with respect to "Money cost" has the largest (absolute) value even in the whole table (-1.598).

Next we report the elasticities of choice probabilities with respect to income as well as the attributes of various transportation modes conditional on given income levels and the distribution of attributes of various transportation modes. Due to the presence of heterogeneity across individuals' choice sets, it is difficult to find a representative traveler in order to illustrate the effect of different income level on these conditional elasticities. Instead, we choose to report conditional aggregate elasticities, given low, middle and high income adjusted by the equivalence scalel as (per month) 1250 yuan, 4500 yuan and 8750 yuan, respectively. These elasticities are computed by aggregating across the choice sets conditional on the respective income levels and the distribution of choice sets. Thus, the results presented in Table 5 can be interpreted as being relevant for a population with the respective income levels, and where the distribution of the choice sets and levels of attributes are the same as in our sample.

[10] The standard errors of the actual shares for “Bicycle”, “Bus”, “Subway” and “Taxi” are calculated as 0.043, 0.049, 0.037 and 0.022, respectively.

Table 5: Aggregate Choice Probabilities and Elasticities Conditional on Different Income Levels[1]

Income[2]		Choice Probability	Elasticity of Choice Probability									
			Income	Bicycle		Bus			Subway		Taxi	
				t_i	c	t_i	t_o	c	t_i	t_o	c	t_i
Low	Bicycle	0.217	0.217	-0.120	-0.181	0.103	0.094	0.118	-	-	-	0.009
	Bus	0.343	0.343	0.039	0.088	-0.298	-0.359	-0.201	0.094	0.055	0.069	0.008
	Subway	0.138	0.138	0.051	-	0.209	0.281	0.100	-0.269	-0.154	-0.193	0.000
	Taxi	0.012	0.012	0.455	0.022	0.024	0.015	0.020	0.001	0.000	0.000	-0.491
Middle	Bicycle	0.181	0.181	-0.175	-0.290	0.036	0.129	0.145	-	-	-	0.136
	Bus	0.318	0.318	-0.227	0.100	-0.128	-0.528	-0.297	0.032	0.070	0.082	0.269
	Subway	0.140	0.140	-0.062	-	0.066	0.311	0.114	-0.093	-0.196	-0.235	0.083
	Taxi	0.084	0.084	1.657	0.144	0.097	0.373	0.262	0.015	0.029	0.041	-1.860
High	Bicycle	0.161	0.161	-0.167	-0.357	0.017	0.124	0.134	-	-	-	0.148
	Bus	0.261	0.261	-0.335	0.104	-0.090	-0.707	-0.402	0.016	0.071	0.080	0.366
	Subway	0.126	0.126	-0.273	-	0.031	0.287	0.107	-0.071	-0.292	-0.345	0.295
	Taxi	0.198	0.198	0.947	0.112	0.043	0.332	0.218	0.018	0.076	0.092	-1.055

Notes:
[1] See Notes in Table 4;
[2] Low, Middle and High income adjusted by the equivalence scale are chosen as (per month) 1250 yuan, 4500 yuan and 8750 yuan, respectively.

Table 5 shows that conditional on given income, the higher the income is, the larger the share choosing "Taxi" will be but the smaller the shares choosing "Bicycle" and "Bus" will be. The share choosing "Subway" increases with income from low to middle level but decreases from middle to high level. Conditional income elasticities show that "Bicycle", "Bus" and "Subway" are "inferior" alternative modes for those with high and middle income levels while for those with low income only "Bicycle" is an "inferior" alternative. "Bus" and "Subway" are "normal" goods for them. "Taxi" seems to be a "normal good" for all income levels and a "luxury" good specifically for those with middle income.

In terms of own-elasticities, the results in Table 5 show that individuals with high and middle income levels care more about the time cost than those with lower income levels. Individuals with high and middle income also care less about the money lost than those with lower income except for those with low income choosing "Taxi". It might be due to the very low choice probability of choosing "Taxi" alternative for those with low income. This explanation is also supported by the low cross-elasticities of choosing "Taxi" with respect to the attributes of other transportation modes for those with low income.

Individuals with high and middle income levels care most about "In-vehicle time" of choosing "Bus" and "Money cost" of choosing "Taxi". For individuals with low income, the "Money cost" and "In-vehicle-time" of choosing "Bus" seem to be more important attributes.

6. Conclusions

By means of data from a stated preference survey, this paper analyzes work-trip mode choice behavior in Shanghai. Several versions of a multinomial choice model have been specified and estimated. Estimation results indicate that the utility function with money cost divided by income per capita fits the data best. However, the differences of fitness (in terms of either Log likelihood or McFadden's ρ^2) are not substantial by using income per capita or income adjusted by an equivalence scale (square root of family size). Furthermore, due to both theoretical and empirical concerns, we end up with choosing money cost divided by income adjusted by the equivalence scale as the most preferred model. Based on the estimation results from the most preferred model, value of time, different type of elasticities of choice probabilities are calculated.

Although larger (absolute) value of the coefficient of “Out-of-vehicle time” compared with that of “In-vehicle time” may suggest that “Out-of-vehicle time” yields more disutility than “In-vehicle time”, the respective estimates are not significantly different. In general, travelers with higher income care more about time loss and less about money cost than those with lower income. "Bicycle" seems to be an "inferior" mode for all the income levels while "Bus" and "Subway" are also "inferior" for higher income levels. "Taxi" is a "normal" mode for all the income levels and a "luxury" mode in particular for the middle income level.

The results also show that "In-vehicle time" of choosing "Bus" and "Money cost" of choosing "Taxi" are more important attributes for those with higher income levels. While for those with lower income, "Money cost" and "In-vehicle time" of choosing "Bus" seem to be more important. Therefore, if the model is correct, these attributes may be used as policy-relevant variables by transportation policy makers in Shanghai.

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Appendix A

Table A1: Characteristics and Rank Ordering Choices of the Respondents in the Survey

Respondent	Gender[1]	Age (Year)	Education[2]	Family Size (Person)	Workers (Person)	Family Income (1000 yuan/month)	First Choice[3]	Second Choice	Third Choice[4]	Choice Set
1	F	24	D	2	2	>15.5	3	6	-	{3,6}
2	F	26	D	2	2	8.0 - 9.5	3	6	-	{3,6}
3	F	22	D	1	1	1.0 - 2.0	3	6	-	{3,6}
4	F	23	D	1	1	2.0 - 3.0	3	13	-	{3,13}
5	F	26	D	4	4	11 - 12.5	13	16	-	{13,16}
6	M	27	G	2	2	12.5 - 14	4	11	6	{4,6,11}
7	M	29	F	1	1	5.0 - 6.5	4	3	6	{3,4,6}
8	M	34	F	1	1	8.0 - 9.5	3	6	-	{3,6}
9	M	39	F	6	2	11 - 12.5	4	6	-	{4,6}
10	F	41	F	3	2	8.0 - 9.5	3	6	-	{3,6}
11	M	30	E	2	2	12.5 - 14	9	6	-	{6,9}
12	M	25	E	3	1	4.0 - 5.0	2	3	6	{2,3,6}
13	F	38	E	2	1	2.0 - 3.0	2	3	6	{2,3,6}
14	F	23	E	1	1	1.0 - 2.0	3	2	1	{1,2,3}
15	F	27	G	1	1	3.0 - 4.0	1	6	-	{1, 6}
16	M	27	E	1	1	3.0 - 4.0	2	3	6	{2,3,6}
17	F	27	E	1	1	1.0 - 2.0	3	4	-	{3,4}
18	M	29	E	1	1	5.0 - 6.5	3	6	4	{3,4,6}
19	F	25	E	2	2	6.5 - 8.0	3	6	-	{3,6}
20	M	54	E	3	2	6.5 - 8.0	4	3	6	{3,4,6}
21	M	30	E	4	3	9.5 - 11	3	6	-	{3,6}
22	M	41	B	3	2	4.0 - 5.0	5	3	6	{3,5,6}
23	F	26	E	3	2	5.0 - 6.5	3	6	-	{3,6}
24	F	31	D	3	2	2.0 - 3.0	3	13	6	{3,6,13}
25	M	37	D	5	2	11 - 12.5	7	6	-	{6,7}
26	M	35	D	2	2	5.0 - 6.5	7	6	-	{6,7}
27	M	26	E	2	2	3.0 - 4.0	3	2	4	{2,3,4}
28	M	24	D	2	2	4.0 - 5.0	4	3	-	{3,4}
29	F	37	D	3	2	8.0 - 9.5	6	3	-	{3,6}
30	M	39	C	3	2	14 - 15.5	13	3	6	{3,6,13}
31	F	27	D	2	2	6.5 - 8.0	4	3	6	{3,4,6}
32	M	52	E	3	3	3.0 - 4.0	12	3	6	{3,6,12}
33	M	26	D	1	1	2.0 - 3.0	3	6	-	{3,6}
34	M	27	F	3	2	9.5 - 11	4	6	-	{4,6}
35	F	55	D	3	3	8.0 - 9.5	4	3	-	{3,4}
36	F	32	D	2	2	4.0 - 5.0	13	3	6	{3,6,13}

Table A1 (cont.)

Respondent	Gender[1]	Age (Year)	Education[2]	Family Size (Person)	Workers (Person)	Family Income (1000 yuan/month)	First Choice[3]	Second Choice	Third Choice[4]	Choice Set
37	F	25	E	2	2	5.0 - 6.5	2	3	6	{2,3,6}
38	F	30	F	2	2	9.5 - 11	3	2	6	{2,3,6}
39	F	50	E	3	2	8.0 - 9.5	14	6	-	{6,14}
40	F	47	D	3	2	5.0 - 6.5	2	1	-	{1,2}
41	M	56	E	4	2	2.0 - 3.0	2	3	-	{2,3}
42	M	23	D	3	3	5.0 - 6.5	7	3	-	{3,7}
43	F	27	E	1	1	3.0 - 4.0	8	3	6	{3,6,8}
44	M	35	E	5	2	9.5 - 11	4	3	6	{3,4,6}
45	F	35	F	4	1	9.5 - 11	1	6	-	{1,6}
46	M	36	G	2	2	9.5 - 11	15	3	-	{3,15}
47	M	39	F	3	2	4.0 - 5.0	2	3	6	{2,3,6}
48	F	21	B	3	3	3.0 - 4.0	3	13	15	{3,13,15}
49	M	25	D	3	3	8.0 - 9.5	7	8	3	{3,7,8}
50	F	33	E	3	2	8.0 - 9.5	3	14	-	{3,14}
51	M	33	D	3	2	6.5 - 8.0	6	3	-	{3,6}
52	M	37	B	3	2	5.0 - 6.5	3	6	-	{3,6}
53	F	34	E	3	2	9.5 - 11	3	6	-	{3,6}
54	M	38	E	3	2	4.0 - 5.0	4	3	-	{3,4}
55	F	33	E	1	1	4.0 - 5.0	1	3	6	{1,3,6}
56	M	30	F	2	2	6.5 - 8.0	3	10	6	{3,6,10}
57	M	48	E	3	2	3.0 - 4.0	8	2	3	{2,3,8}
58	F	45	B	3	2	2.0 - 3.0	2	3	6	{2,3,6}
59	F	51	F	3	2	6.5 - 8.0	2	6	3	{2,3,6}
60	F	44	E	3	2	6.5 - 8.0	2	3	6	{2,3,6}
61	M	50	G	3	2	8.0 - 9.5	2	3	6	{2,3,6}
62	F	52	F	3	2	4.0 - 5.0	13	14	3	{3,13,14}
63	F	42	D	3	2	5.0 - 6.5	2	6	3	{2,3,6}
64	M	53	F	4	2	6.5 - 8.0	2	6	-	{2,6}
65	F	23	E	4	2	2.0 - 3.0	1	2	-	{1,2}
66	M	25	E	1	1	1.0 - 2.0	2	6	1	{1,2,6}
67	M	27	F	2	1	4.0 - 5.0	2	1	-	{1,2}
68	F	31	F	3	2	6.5 - 8.0	3	6	-	{3,6}
69	M	31	F	2	2	8.0 - 9.5	2	1	-	{1,2}
70	M	28	F	1	1	>15.5	6	16	13	{6,13,16}
71	F	27	F	3	1	3.0 - 4.0	14	3	6	{3,6,14}
72	F	29	E	3	2	5.0 - 6.5	5	9	-	{5,9}
73	M	31	G	3	2	8.0 - 9.5	3	6	4	{3,4,6}
74	M	32	F	2	2	5.0 - 6.5	2	3	6	{2,3,6}

Table A1 (cont.)

Respondent	Gender[1]	Age (Year)	Education[2]	Family Size (Person)	Workers (Person)	Family Income (1000 yuan/month)	First Choice[3]	Second Choice	Third Choice[4]	Choice Set
75	M	26	F	1	1	1.0 - 2.0	3	6	-	{3,6}
76	F	37	F	3	2	5.0 - 6.5	4	15	-	{4,15}
77	F	32	E	3	2	12.5 - 14	13	6	-	{6,13}
78	F	28	G	2	2	14 - 15.5	6	3	13	{3,6,13}
79	F	26	F	4	3	8.0 - 9.5	4	6	-	{4,6}
80	F	30	F	3	2	6.5 - 8.0	4	6	3	{3,4,6}
81	M	25	F	1	1	3.0 - 4.0	5	3	-	{3,5}
82	M	29	G	4	2	8.0 - 9.5	3	2	6	{2,3,6}
83	F	26	E	3	2	6.5 - 8.0	3	2	6	{2,3,6}
84	F	28	G	5	2	>15.5	3	6	-	{3,6}
85	F	28	F	2	2	6.5 - 8.0	13	3	6	{3,6,13}
86	M	35	F	3	2	6.5 - 8.0	3	4	6	{3,4,6}
87	F	53	D	3	2	4.0 - 5.0	3	2	-	{2,3}
88	F	48	D	3	2	3.0 - 4.0	2	3	-	{2,3}
89	F	30	G	2	2	4.0 - 5.0	2	1	-	{1,2}
90	M	47	G	3	2	11 - 12.5	3	8	6	{3,6,8}
91	M	34	F	3	2	4.0 - 5.0	2	1	-	{1,2}

Notes:
[1] F = Female, M = Male;
[2] A = below high school, B = high school, C = middle specified school, D = high specified school, E = undergraduate, F = master, G = doctor;
[3] 1 = "Walk", 2 = "Bicycle", 3 = "Bus", 4 = "Subway", 5 = "Company owned bus or car", 6 = "Taxi", 7 = "Motorcycle", 8 = "Scooter", 9 = "Private car", 10 = "Bicycle + Bus", 11 = "Bicycle + Subway", 12 = "Bicycle + Company owned bus or car", 13 = "Bus + Subway", 14 = "Bus + Company owned bus or car", 15 = "Bus + Taxi", 16 = "Taxi + Subway";
[4] "-" = No third choice.

Appendix B

Table B1: Estimation Results (Using Family Income)[1]

Data type	Variable name	Coefficient estimate			
		Model 1	Model 2	Model 3	Model 4
First choice only	One-way work-trip money cost (yuan)	-0.116 (-4.69)	-0.143 (-4.54)	-0.108 (-3.91)	-0.136 (-4.72)
	In-vehicle time (minute)	-0.046 (-2.63)	-0.068 (-2.74)	-0.040 (-2.18)	-0.040 (-2.63)
	Out-of-vehicle time (minute)	-0.049 (-2.15)	-0.055 (-1.89)	-0.045 (-2.08)	-0.049 (-2.12)
	Parameter γ	0	-1	0.192 (3.74)	-
	Number of observations	91	91	91	91
	Log likelihood	-50.899	-55.757	-50.727	-56.655
	McFadden's ρ_1^2	0.37	0.31	0.37	0.30
	McFadden's ρ_2^2	0.49	0.44	0.49	0.43
Rank data	One-way work-trip money cost (yuan)	-0.091 (-5.39)	-0.142 (-5.44)	-0.115 (-4.52)	-0.141 (-5.47)
	In-vehicle time (minute)	-0.035 (-2.79)	-0.053 (-3.01)	-0.044 (-2.77)	-0.035 (-2.96)
	Out-of-vehicle time (minute)	-0.045 (-2.45)	-0.065 (-2.60)	-0.055 (-2.46)	-0.051 (-2.66)
	Parameter γ	0	-1	-0.390 (-2.34)	-
	Number of observations	91	91	91	91
	Log likelihood	-73.594	-74.812	-72.411	-75.262
	McFadden's ρ_1^2	0.33	0.32	0.34	0.32
	McFadden's ρ_2^2	0.55	0.54	0.56	0.54

Note: [1] Asymptotic *t*-values in parentheses.

Table B2: Estimation Results (Using Per Capita Income)[1]

Data type	Variable name	Coefficient estimate			
		Model 1	Model 2	Model 3	Model 4
First choice only	One-way work-trip money cost (yuan)	-0.047 (-4.60)	-0.151 (-4.57)	-0.022 (-1.21)	-0.136 (-4.72)
	In-vehicle time (minute)	-0.044 (-2.65)	-0.156 (-2.91)	-0.018 (-0.98)	-0.040 (-2.63)
	Out-of-vehicle time (minute)	-0.046 (-2.10)	-0.103 (-1.80)	-0.020 (-1.00)	-0.049 (-2.12)
	Parameter γ	0	-1	0.562 (2.88)	-
	Number of observations	91	91	91	91
	Log likelihood	-50.684	-53.876	-50.187	-56.655
	McFadden's ρ_1^2	0.37	0.33	0.38	0.30
	McFadden's ρ_2^2	0.49	0.46	0.50	0.43
Rank data	One-way work-trip money cost (yuan)	-0.044 (-5.49)	-0.150 (-5.48)	-0.045 (-1.46)	-0.141 (-5.47)
	In-vehicle time (minute)	-0.040 (-3.02)	-0.138 (-3.08)	-0.042 (-1.31)	-0.035 (-2.96)
	Out-of-vehicle time (minute)	-0.053 (-2.81)	-0.143 (-2.36)	-0.055 (-1.41)	-0.051 (-2.66)
	Parameter γ	0	-1	-0.026 (-2.08)	-
	Number of observations	91	91	91	91
	Log likelihood	-69.159	-71.914	-69.157	-75.262
	McFadden's ρ_1^2	0.37	0.35	0.37	0.32
	McFadden's ρ_2^2	0.58	0.56	0.58	0.54

Note: [1] Asymptotic t-values in parentheses.

Table B3: Estimation Results (Using Family Income Divided by Squared Root of Family Size) [1]

Data type	Variable name	Coefficient estimate			
		Model 1	Model 2	Model 3	Model 4
First choiceonly	One-way work-trip money cost (yuan)	-0.075 (-4.71)	-0.151 (-4.65)	-0.050 (-2.16)	-0.136 (-4.72)
	In-vehicle time (minute)	-0.046 (-2.67)	-0.111 (-2.93)	-0.026 (-1.46)	-0.040 (-2.63)
	Out-of-vehicle time (minute)	-0.049 (-2.20)	-0.085 (-2.17)	-0.032 (-1.52)	-0.049 (-2.12)
	Parameter γ	0	-1	0.473 (3.40)	-
	Number of observations	91	91	91	91
	Log likelihood	-50.166	-54.185	-49.614	-56.655
	McFadden's ρ_1^2	0.38	0.33	0.38	0.30
	McFadden's ρ_2^2	0.50	0.46	0.50	0.43
Rank data	One-way work-trip money cost (yuan)	-0.067 (-5.57)	-0.152 (-5.62)	-0.078 (-2.78)	-0.141 (-5.47)
	In-vehicle time (minute)	-0.041 (-3.05)	-0.095 (-3.15)	-0.048 (-2.14)	-0.035 (-2.96)
	Out-of-vehicle time (minute)	-0.055 (-2.83)	-0.106 (-2.85)	-0.063 (-2.20)	-0.051 (-2.66)
	Parameter γ	0	-1	-0.155 (-2.52)	-
	Number of observations	91	91	91	91
	Log likelihood	-69.607	-72.463	-69.500	-75.262
	McFadden's ρ_1^2	0.37	0.34	0.37	0.32
	McFadden's ρ_2^2	0.57	0.56	0.57	0.54

Note: [1] Asymptotic *t*-values in parentheses.

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