Discussion Papers No. 480, October 2006
Statistics Norway, Research Department

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A Framework for Analyzing Rank Ordered Panel Data with Application to Automobile Demand

Abstract:
In this paper we develop a framework for analyzing panel data with observations on rank ordered alternatives that allows for correlated random taste shifters across time and across alternatives. As a special case we obtain a nested logit model type for rank ordered alternatives. We have applied this framework to estimate several model versions for household demand for conventional and alternative fuel automobiles in Shanghai based on rank ordered data obtained from a stated preference survey. The preferred model is then used to calculate demand probabilities and elasticities and the willingness-to-pay for alternative fuel vehicles.

Keywords: Random utility models, Nested rank ordered logit models, Automobile demand, Alternative fuel vehicles

JEL classification: C25, C33, L92

Acknowledgement: The authors would like to thank Olav Bjerkholt, Steinar Strøm and Terje Skjerpen for their valuable comments and Anne Skoglund for the word processing of this paper. The assistance provided by students and staff at the Institute of Population Studies at Fudan University , and Mr. Yuan Zhang (sales manager at a Shanghai car dealership) in designing the questionnaire, is gratefully acknowledged. The authors are particularly grateful to Weizhen Zhu for carrying out the programming and estimation.

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1. Introduction

During the last three decades, there has been rapid development of theoretical and empirical approaches to analyzing individual choice behavior of the demand for differentiated products, such as the choice among brands of cars, types of houses, etc. Important contributions in this area are due to McFadden and collaborators; see for example McFadden (2001). Specifically, random utility models have been applied extensively to analyze urban travel behavior. As regards empirical behavioral analysis, the application of data obtained by means of Stated Preference (SP) type of surveys has become increasingly popular. Recall that by an SP survey, it is understood that individuals in a sample are exposed to hypothetical choice situations. Contrary to the conventional revealed preference method, one important advantage of the SP method is that it can be utilized to elicit information about respondents' complete rank orderings of a set of alternatives.

In this paper we develop a novel methodological contribution in that we derive ranking probabilities for general additive random utility models with three alternatives, with the rank-ordered nested logit model as a special case. By this we mean that we obtain the probabilities of the rank-order of the alternatives in the case when the error terms in the random utilities are additive and have a general joint distribution function. A rank-ordered nested type logit model is used in the empirical analysis. Furthermore, we extend this framework by allowing for random effects. This is of particular interest in situations where one has panel data on individuals' rank ordering of alternatives.

We subsequently apply the framework developed to analyze the demand for conventional and alternative fuel automobiles in the city of Shanghai. In China, the development of the automobile industry and the rapid increase in the demand for private automobiles is a sensitive issue. On the one hand, there is the expressed intention of the Chinese government to use the automobile industry as an engine to promote industrial and economic growth. On the other hand, there is realization of the pressing need to adequately address serious pollution problems owing to automobile traffic in urban areas. There also appears to be growing awareness within China about the role transportation sources play in increasing greenhouse gas emissions. Finally, there is concern that an uncontrolled increase in the number of private cars may lead to very serious congestion problems. Traffic problems in a number of large cities in developing countries may serve as a warning of what may happen if the increase in private cars in China is not kept under control. To the authors' best knowledge, studies on automobile demand undertaken in China are based on historical aggregated data, and these studies are mostly only loosely founded on microeconomic theory (Guo, 2001; Zhai, 2000).

Thus, the empirical analysis in this paper represents the first attempt to undertake a behavioral empirical study of the demand for automobiles in the city of Shanghai, as based on micro data and the theory of discrete choice. The data are obtained from a Stated Preference (SP) survey collected in Shanghai during the summer of 2001. The survey approach we follow is similar to Dagsvik et al. (2002). Specifically, in our survey each household is presented with fifteen choice experiments and is asked to rank-order several hypothetical automobile alternatives characterized by car-specific attributes (price, size, power, fuel expenditure) that vary from one choice experiment to the other. We apply the collected data to estimate several model versions within the framework developed here. Unfortunately, the sample is rather small, and we have therefore only specified and estimated models with rather limited observed population heterogeneity. This is clearly unsatisfactory, and it is desirable to obtain a larger sample in future research.

The behavioral automobile demand model estimated in this paper enables the prediction of demand and the computation of demand elasticities with respect to price and other car attributes conditional on car attributes.

The remainder of the paper is structured as follows. Section 2 sets out the theoretical framework. Section 3 describes the survey method and the data. In section 4, the empirical specification of the different models as well as the estimation results are presented. In section 5, we present the results on demand and their elasticities. In section 6, we use the model to calculate willingness-to-pay estimates for alternative fuel vehicles.

2. The model for rank-ordered alternatives

To analyze panel data on the rank-ordering of alternatives, a particular methodological framework is required. The development of choice models for rank-ordered data originated with work by Luce (1959), Block and Marschak (1960) and Luce and Suppes (1965), while Beggs et al. (1981) represents an early application of such models to SP data and the potential demand for electric vehicles. As in our case, they obtained SP data with information about agents' complete rank-ordering of different car alternatives. However, they only asked the respondents to participate in only a single ranking experiment, in contrast to 15 ranking experiments as in this survey. This is similar to Dagsvik et al. (2002).

We now proceed to derive the probability of specified rank-orderings when the set of feasible alternatives contain three elements. Previous models for rank-ordering data are usually based on the assumption that the random error terms of the utility function are independent across alternatives.[1] A particularly simple expression for the probability of a specific rank-order follows readily when these error terms are i.i. extreme value distributed (see, for example, Beggs et al. 1981). However, when the

[1] An exception is Falmagne (1978) also discussed the structure of ranking and choice probabilities for general random utility models.

set of feasible choices contains at most three alternatives, it follows readily that the ranking probability can generally be expressed in a simple way with the probabilities of the most preferred alternative with specific choice sets. This claim will be proved below.

Let U_j, $j = 1,2,3$, denote the random utility function where U_j is the utility of alternative j. We assume that $U_j = v_j + \varepsilon_j$, where v_j is a deterministic component that will be characterized below, and ε_j, $j = 1,2,3,$ are random terms (taste shifters) with joint cumulative distribution function (c.d.f.) that is independent of $\{v_j\}$. We also assume that the joint c.d.f. of $(\varepsilon_1, \varepsilon_2, \varepsilon_3)$ is continuously differentiable. Consider the probability that alternative 2 is ranked on top, alternative 1 is the second and alternative 3 is the third preference. Evidently, we have that

(2.1)
$$\begin{aligned} &P\left(U_1 = \max_{q\le 3} U_q\right) + P(U_2 > U_1 > U_3) = P(U_2 < U_1, U_1 > U_3) + P(U_2 > U_1, U_1 > U_3) \\ &= P\big((U_2 < U_1) \cap (U_1 > U_3) \cup (U_2 > U_1) \cap (U_1 > U_3)\big) = P(U_1 > U_3). \end{aligned}$$

Consequently, (2.1) implies that

$$P(U_2 > U_1 > U_3) = P(U_1 > U_3) - P\left(U_1 = \max_{q\le 3} U_q\right).$$

Similarly, we obtain that

(2.2)
$$P\left(U_j > U_k > U_r\right) = P(U_k > U_r) - P\left(U_k = \max_{q\le 3} U_q\right)$$

for distinct j, k and r. Equation (2.2) is very useful because it implies that in the case with three alternatives one can express the ranking probabilities in terms of suitable choice probabilities. In the application below, the alternatives are “Not buy a car” (1), “Buy a conventional fuel car” (2), “Buy an alternative fuel car” (3). In the empirical specifications below, we assume that the joint c.d.f. of $(\varepsilon_1, \varepsilon_2, \varepsilon_3)$ is multivariate extreme value distribution of the form

(2.3)
$$F(x_1, x_2, x_3) \equiv P(\varepsilon_1 \le x_1, \varepsilon_2 \le x_2, \varepsilon_3 \le x_3) = \exp\left(-e^{-x_1} - \left(e^{-x_2/\theta} + e^{-x_3/\theta}\right)^{\theta}\right)$$

where θ is a parameter that satisfies $0 < \theta \le 1$ and has the interpretation

(2.4)
$$Corr(\varepsilon_2, \varepsilon_3) = 1 - \theta^2.$$

Moreover, it follows from (2.3) that

$$Corr(\varepsilon_1, \varepsilon_k) = 0$$

for $k = 2,3$. The motivation for allowing for correlation between the error terms associated with the two automobile alternatives is that an unobserved variable, such as the "taste for driving", is common to alternatives 2 and 3 but not relevant for alternative 1.

It is well known that assumption (2.3) leads to the so-called nested logit choice model for the most preferred alternative (see, for example, McFadden 1984). Let $P_j(B)$ denote the corresponding choice probability defined by

$$P_j(B) \equiv P\left(U_j = \max_{q \in B} U_q\right) \tag{2.5}$$

where B is equal to—or a subset of —$\{1,2,3\}$, which contains at least two elements.[2]

Let

$$G(v_1, v_2, v_3) \equiv -\log F(-v_1, -v_2, -v_3). \tag{2.6}$$

Then, by McFadden (1984),

$$P_j(\{1,2,3\}) = \frac{\partial G(v_1, v_2, v_3) / \partial v_j}{G(v_1, v_2, v_3)} \tag{2.7}$$

for $j \in \{1,2,3\}$, and

$$P_j(\{1,2\}) = \frac{\partial G(v_1, v_2, -\infty) / \partial v_j}{G(v_1, v_2, -\infty)} \tag{2.8}$$

for $j \in \{1,2\}$, and similarly for the choice sets $\{1,3\}$ and $\{2,3\}$. The formulas (2.7) to (2.8) hold for a general Generalized Extreme Value (GEV) model, not just for the specification in (2.3). When F is given by (2.3), these formulas imply that

$$P_1(\{1,2,3\}) = \frac{e^{v_1}}{e^{v_1} + \left(e^{v_2/\theta} + e^{v_3/\theta}\right)^{\theta}} \tag{2.9}$$

[2] The family of such sets consists of $\{1,2\}$, $\{1,3\}$, $\{2,3\}$ and $\{1,2,3\}$.

(2.10) $$P_j\left(\{1,2,3\}\right)=\frac{\left(e^{v_2/\theta}+e^{v_3/\theta}\right)^{\theta-1}e^{v_j/\theta}}{e^{v_1}+\left(e^{v_2/\theta}+e^{v_3/\theta}\right)^{\theta}}$$

for $j=2,3$, and

(2.11) $$P_j\left(\{1,k\}\right)=\frac{e^{v_j}}{e^{v_1}+e^{v_k}}$$

for $j\in\{1,k\}$, $k=2,3,$ and

(2.12) $$P_j\left(\{2,3\}\right)=\frac{e^{v_j/\theta}}{e^{v_2/\theta}+e^{v_3/\theta}}$$

for $j=2,3$. From (2.2), and (2.9) to (2.12), we obtain

(2.13) $$P\left(U_j>U_k>U_1\right)=P_k\left(\{1,k\}\right)-P_k\left(\{1,2,3\}\right)=\frac{e^{v_k}}{e^{v_k}+e^{v_1}}-\frac{\left(e^{v_2/\theta}+e^{v_3/\theta}\right)^{\theta-1}e^{v_k/\theta}}{e^{v_1}+\left(e^{v_2/\theta}+e^{v_3/\theta}\right)^{\theta}}$$

for $(j,k)=(2,3),(3,2)$,

(2.14) $$P\left(U_j>U_1>U_k\right)=P_1\left(\{1,k\}\right)-P_1\left(\{1,2,3\}\right)=\frac{e^{v_1}}{e^{v_1}+e^{v_k}}-\frac{e^{v_1}}{e^{v_1}+\left(e^{v_2/\theta}+e^{v_3/\theta}\right)^{\theta}}$$

where $(j,k)=(2,3),(3,2)$, and

(2.15) $$P\left(U_1>U_j>U_k\right)=P_j\left(\{j,k\}\right)-P_j\left(\{1,2,3\}\right)=\frac{e^{v_j/\theta}}{e^{v_2/\theta}+e^{v_3/\theta}}-\frac{\left(e^{v_2/\theta}+e^{v_3/\theta}\right)^{\theta-1}e^{v_j/\theta}}{e^{v_1}+\left(e^{v_2/\theta}+e^{v_3/\theta}\right)^{\theta}}$$

for $(j,k)=(2,3),(3,2)$.

The formulas (2.9) through (2.15) form the basis for specification of one version of the empirical model below and the corresponding likelihood function.

3. Survey method and data

A survey based on the SP approach was conducted in Shanghai during the summer of 2001. Several concerns lead to the use of the SP method instead of the more conventional revealed preference method. First and foremost, market micro data on automobile demand were not available. Second, only a few families in Shanghai actually own cars, although more and more people are planning to buy in the near future. In addition, alternative fuel vehicles (AFV) have not been commercially available in China, while in an SP survey, AFV can be used as one choice alternative. Finally, but by no means least, the SP method is cost effective as a relatively small sample can provide much information. For instance, if appropriately designed the researcher can obtain data on individual rankings while conventional revealed preference methods only yield data for the most preferred alternative, i.e., the (revealed) choice. The disadvantage is that households (represented by a single person in the household denoted the respondent) respond to hypothetical questions, not directly related to actual budget constraints and other choice restrictions that may apply in the market. (See the Appendix for the survey questionnaire). Some descriptive statistics are presented in Table 1 below and Table 1A in the Appendix.

Table 1. Sample income distribution

Income group	Income range (yuan/month)	Frequency
1	< 1,000	0
2	1,000–2,000	5
3	2,000–3,000	7
4	3,000–4,000	12
5	4,000–5,000	14
6	5,000–6,500	14
7	6,500–8,000	14
8	8,000–9,500	13
9	9,500–11,000	9
10	11,000–12,500	4
11	12,500–14,000	3
12	14,000–15500	2
13	> 15,500	3
Sum		100

To ensure the quality of the survey, we implemented face-to-face interviews where the interviewer was able to control the interview process and explain the context presented in the questionnaire as clearly and realistically as possible. In total, 100 households were selected, among which there were 46 male and 54 female respondents. The survey comprises three parts, of which only two are relevant to this paper; namely, those parts containing basic household and automobile demand information. The former was designed to collect information on the respondent's background characteristics such as age, gender, education, occupation, household size and monthly income, etc.

Table 2. Range of automobile attributes

	Price (1,000 yuan)	Power (Horsepower)	Fuel consumption (Liter/100 km)	Size (Number of seats)
Range (Gas)	60–200	90–140	6–12	4–7
Range (AFV)	80–250	90–150	2–4	4–7

After discussing with local automobile sales companies and salesmen the automobile attributes car buyers in Shanghai were most concerned with, we decided to choose price, power, fuel consumption and size (in terms of number of seats) as the attributes of the automobiles presented in the survey. The range of the four attributes is listed in Table 2.

Table 3. Summary statistics of the survey results

Experiment		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
First choice	# of "Not Buy"	76	73	72	54	54	69	66	56	75	64	73	67	75	65	68
	# of "Buy Gas"	19	15	8	31	5	5	23	31	7	21	8	9	9	26	5
	# of "Buy AFV"	5	12	20	15	41	26	11	13	18	15	19	24	16	9	27
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Second choice	# of "Not Buy"	14	15	12	26	18	19	20	22	13	12	16	11	16	18	13
	# of "Buy Gas"	44	43	28	41	32	18	42	39	16	33	19	23	12	41	26
	# of "Buy AFV"	42	42	60	33	50	63	38	39	71	55	65	66	72	41	61
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

The SP survey is based on a series of 15 experimental settings presented to each respondent. In each experiment, we presented the choice setting to the respondent in the form of a card with three choice alternatives, namely "Not buy a car", "Buy a gasoline car", and "Buy an alternative fuel vehicle" (AFV). Each car alternative was characterized by given attribute values. First, the interviewee was required to choose his or her most preferred alternative. If the respondent chose the alternative of "Not buy a car", then the following was asked: "Suppose now you are able to buy, which one do you prefer between the remaining two alternatives?" If the respondent chose the alternative of either a gasoline car or an AFV, then we asked the following: "Suppose now the alternative you just chose is not available, which one do you prefer among the remaining two alternatives, namely, either the vehicle not chosen in the first place and 'not buy'?" By changing the automobile attributes with sufficient variation from one experiment to the next, we obtained a panel of rank-ordered data for each respondent in the sample. Table 3 displays summary statistics of the survey results.

4. Empirical results

This section contains details of the empirical specification of the different versions of the model as well as the estimation results.

4.1. Model with fixed coefficients (Model 1)

Recall that each household in the sample is presented with 15 experiments. Let $U_{hj}(t)$ denote the utility of household *h* of alternative *j* in experiment *t*, $j=1,2,3$, $t=1,2,...,15$. Let $Z_{1j}(t)$ represent "User cost", $Z_{2j}(t)$ "Fuel costs", $Z_{3j}(t)$ "Size" and $Z_{4j}(t)$ "Power", of alternative *j* in experiment *t*, for $j=1,2,3$, with $Z_{r1}(t)=0$ for $r=1,2,3,4$, and let y_h be the income of household *h*. Note here that we have replaced automobile price with the corresponding user cost. Because the maximum regulated lifetime of an automobile in China is 10 years, we define the user cost per month as

$$Z_{1j}(t)=\frac{w_j(t)\cdot r}{12(1+r)\left(1-(1+r)^{-10}\right)},$$

$j=2,3$, where $w_j(t)$ is the purchase price of automobile *j* in experiment t and *r* is the annual discount rate, assumed to be 10 percent. Thus, user cost accounts for about one percent of the total price. The reason why we have converted the purchase price into its corresponding user cost is because we use the user costs to assess whether a specific car is available (affordable) to the household. Specifically, we assume that a car is available to the household if the user cost of the car is less than household income. Otherwise, it is unavailable. The notion of user cost requires well-functioning financial markets such that the agents can obtain loans to purchase durables at a given interest rate. In Shanghai, the financial markets function quite well in this respect.

Consistently with Section 2, we assume that

$$U_{hj}(t)=v_{hj}(t)+\varepsilon_{hj}(t) \tag{4.1}$$

where $\boldsymbol{\varepsilon}_h(t)\equiv\left(\varepsilon_{h1}(t),\varepsilon_{h2}(t),\varepsilon_{h3}(t)\right), t=1,2,...,15, h=1,2,...,N,$ are i.i.d. vectors with c.d.f. as in (2.3). The structural term $v_{hj}(t)$ has the interpretation as the indirect utility of alternative *j*. Assume moreover that

(4.2) $$v_{hj}(t) = \mu_j + \gamma_1\left(y_h - Z_{1j}(t)\right) + \gamma_2 Z_{2j}(t) + \gamma_3 Z_{3j}(t) + \gamma_4 Z_{4j}(t),$$

$j = 2,3$, and $v_{h1}(t) = \mu_1 + y_h\gamma_1$. As mentioned above, we assume that car alternative *j* is only available to household *h* if $y_h > Z_{1j}(t)$ for $j = 2,3$. To account for this, we define

(4.3) $$D_{jt}\left(y_h\right) = \begin{cases} 0 & \text{if} \quad y_h > Z_{1j}(t) \\ -30 & \text{if} \quad y_h \le Z_{1j}(t). \end{cases}$$

As income cancels when comparing utilities, we get that $v_{hj}(t)$ is equivalent to the modified version, $\tilde{v}_{hj}(t)$, which is defined as

(4.4) $$\tilde{v}_{hj}(t) \equiv \mu_j + \gamma_1 Z_{1j}\left(t\right) + \gamma_2 Z_{2j}\left(t\right) + \gamma_3 Z_{3j}\left(t\right) + \gamma_4 Z_{4j}\left(t\right) + D_{jt}\left(y_h\right)$$

for $j = 2,3$, where $\gamma = \left(\gamma_1, \gamma_2, \gamma_3, \gamma_3\right)$. Note that the variable $D_{jt}\left(y_h\right)$ yields so low utility to alternatives with income less than user cost that they never will be chosen. The parameters μ_2 and μ_3 represent the mean pure taste for conventional and alternative fuel vehicles, respectively, and μ_1 is normalized to zero. We expect the parameters γ_1 and γ_2 to be negative while γ_3 and γ_4 are expected to be positive.

Let

(4.5) $$Q_{hjk}(t) \equiv P\left(U_{hj}(t) > U_{hk}(t) > U_{hr}(t)\right)$$

for distinct $j,k,r \in \{1,2,3\}$. Thus, $Q_{hjk}(t)$ is the probability that household *h* shall rank alternative *j* on top and alternative *k* second best in experiment *t*. Let $Y_{hjk}(t)$ be equal to one if household *h* ranks alternative *j* on top and alternative *k* second best in experiment *t*. The corresponding likelihood function is given by

(4.6) $$L \equiv \prod_{h=1}^{N} \prod_{t=1}^{15} \prod_{j,k} \left(Q_{hjk}(t)\right)^{Y_{hjk}(t)}$$

where $Q_{hjk}(t)$ is obtained by replacing $v_{hj}(t)$ in (2.13) to (2.15) by $\tilde{v}_{hj}(t)$ given by (4.4). Maximum likelihood estimates are reported in Table 4.

We decided to use the observations on first and second choices only for those who chose an AFV or gasoline car as their first choice. The motivation is that it may be difficult for those who choose “not buy” as their first choice to rank the two remaining alternatives. This may be because most of those who rank "not buy" on top can probably ill afford purchasing a car. As a result, it may be difficult for them to rank alternatives that are viewed as costly. If so, the variability of these observations may be greater than the other observations where one of the car alternatives is ranked on top. Altogether, this yields 1,500 observations on first choices and 493 observations on second choices. In the sample, there are nine observations on first choices, and three observations on second choices that are inconsistent with the availability criteria defined in (4.3). These observations are removed. After the 11 inconsistent observations are removed, the remaining sample used in the estimations consists of 1,982 observations.

Table 4. Parameter estimates of Model 1*

Attribute	Parameter	Estimate	Standard error	t-statistic
User cost	γ_1	–0.941	0.094	–10.0
Fuel cost	γ_2	–0.466	0.232	–2.0
Size	γ_3	–0.034	0.064	–0.5
Power	γ_4	0.491	0.231	2.1
Mean taste (conventional car)	μ_2	0.229	0.241	1.0
Mean taste (alternative fuel car)	μ_3	0.345	0.212	1.6
Correlation parameter	θ	0.520	0.030	17.5
Log likelihood		–1,514.9		
McFadden's ρ^2		0.23		
Number of observations (first choices)		1,491		
Number of observations (second choices)		491		

* The unit of user cost is 1,000 yuan, fuel cost is measured in liters per 10 km, and the unit of power is 100 horsepower.

From Table 4, we note that "size" appears to be of no importance to the consumers. Also the mean taste parameters μ_2 and μ_3 are not significantly different from zero. The coefficients associated with most of the remaining variables have the expected sign and are relatively precisely determined.

The coefficient of fuel cost is not very precisely determined. This is not surprising, as most consumers in our sample have no experience with driving their own car. As a measure of goodness-of-fit, we used McFadden's ρ^2. Recall that ρ^2 is defined as

(4.7) $$\rho^2 = 1 - \frac{\log \hat{L}}{\log L_0}$$

where $\hat{L}$ is the estimated likelihood and L_0 is the likelihood for the "reference" case, which corresponds to a completely random ranking. That is, in the reference case the choice probabilities for the first choice are equal to 1/3 and the choice probabilities for the second choice are equal to 1/2.

We have also experimented with a more general specification of the functional form of the utility function. Specifically, we have postulated a so-called Box–Cox type of specification given by

$$(4.4)^* \qquad \tilde{v}_{hj}(t) = \mu_j + \gamma_1 \left(\frac{\left(y_h - Z_{1j}(t) + \beta\right)^{\alpha} - 1}{\alpha} \right) + \gamma_2 Z_{2j}(t) + \gamma_3 Z_{3j}(t) + \gamma_4 Z_{4j}(t) + D_{jt}(y_h)$$

where $\alpha \le 1$ and $\beta \ge 0$. Note that when $\alpha = 1$, the Box–Cox specification reduces to the model (4.4), whereas when $\alpha = 0$, the Box–Cox transformation $\left(x^{\alpha} - 1\right)/\alpha$ becomes equal to $\log(x)$. After some experimentation, we concluded that α values different from one appear to yield lower likelihood values than when $\alpha = 1$, as assumed in the analysis in this paper.

4.2. Model with random technology parameters (Model 2)

In this section, we extend the model considered above by allowing the technology parameters $\{\mu_j\}$ to be individual specific and distributed according to the normal distribution. Thus we now assume that

$$(4.8) \qquad \tilde{v}_{hj}(t) = \mu_{jh} + \gamma_1 Z_{1j}(t) + \gamma_2 Z_{2j}(t) + \gamma_3 Z_{3j}(t) + \gamma_4 Z_{4j}(t) + D_{jt}\left(y_h\right) \equiv \mu_{jh} + \boldsymbol{Z}_j(t)\gamma + D_{tj}(y_h)$$

where $\mu_{jh} = \bar{\mu}_j + \sigma_j \eta_{jh}$, and η_{jh}, $j = 1,2,3,\ h = 1,2,...,N$, are i.i.d. standard normally distributed and $\bar{\mu}_j$ and $\sigma_j > 0,\ j = 1,2,3$, are parameters to be estimated. As above, we can normalize so that $\bar{\mu}_1 = 0$. In this model version there are altogether 10 parameters to be estimated, namely θ, $\bar{\mu}_2$, $\bar{\mu}_3$, σ_1, σ_2, σ_3, γ_1, γ_2, γ_3 and γ_4. This model is similar to Model 5 in Dagsvik et al. (2002). However, it differs from this model in that it allows for correlation between the random taste shifters of the two car alternatives. Whereas Model 5 in Dagsvik et al. (2002), in addition to random effects, allows for random taste shifters that are serially correlated, our Model 2 assumes serially independent taste shifters.

For notational convenience let $\boldsymbol{\eta}_h = \left(\eta_{1h}, \eta_{2h}, \eta_{3h}\right)$ and let $Q_{hjk}\left(t, \boldsymbol{\eta}_h\right)$ denote the probability obtained from $Q_{hjk}(t)$ by replacing $\bar{\mu}_j$ by μ_{jh}, for given $\boldsymbol{\eta}_h$. The corresponding conditional likelihood for household h, given $\boldsymbol{\eta}_h$, equals

$$(4.9) \qquad L_h\left(\boldsymbol{\eta}_h\right) \equiv \prod_{t=1}^{15} \prod_{j,k} Q_{hjk}\left(t, \boldsymbol{\eta}_h\right)^{Y_{hjk}(t)}.$$

The total unconditional likelihood is therefore equal to

$$\tilde{L} \equiv \prod_{h=1}^{N} E\, L_h(\boldsymbol{\eta}_h) \tag{4.10}$$

where the expectation in (4.10) is taken with respect to $\boldsymbol{\eta}_h$. To compute (4.10), the following simulation procedure is practical. Draw M independent vectors $\boldsymbol{\eta}_h^r$, $r = 1,2,...,M$, with i.i.d. standard normal components. Then the approximation

$$E\, L_h(\boldsymbol{\eta}_h) \approx \frac{1}{M} \sum_{r=1}^{M} L_h(\boldsymbol{\eta}_h^r) \equiv L^* \tag{4.11}$$

is good when M is large, and consequently one can obtain consistent estimates by maximizing

$$\log L^* \equiv \sum_{h=1}^{N} \log\left(\frac{1}{M} \sum_{r}^{M} L_h(\boldsymbol{\eta}_h^r) \right) \tag{4.12}$$

with respect to the unknown parameters.

In Table 5, we report the estimation results based on model specification (4.8). Recall that the correlation parameter θ is restricted to the interval $0 < \theta \le 1$. In fact, the estimation procedure yields an estimate that equals the upper boundary, that is $\theta = 1$. Thus, we conclude that the random effects in Model 2 in fact account for the correlation-across-alternatives effect found for Model 1.

From Table 5 we see that the parameter associated with the user cost is rather sharply determined; moreover, whereas "Power" and "Fuel cost" appear to matter, "Size" does not seem to matter at all. The alternative specific constants $\bar{\mu}_2$ and $\bar{\mu}_3$ are not found to be significantly different from zero. This means that the average value (across the sample) of the respective car alternatives is fully captured by the observed attributes. Similarly to the results above, this also suggests that Shanghai households are, on average, unconcerned about the possible environmental benefits of alternative fuel cars. However, the variation in the random effects $\{\eta_{ij}\}$ is substantial. This means that some households may value alternative fuel technology higher than gasoline technology and vice versa.

Table 5. Parameter estimates of Model 2

Attribute	Parameter	Estimate	Standard error	t-value
User cost	γ_1	–3.367	0.239	–14.1
Fuel cost	γ_2	–1.233	0.532	–2.3
Size	γ_3	–0.166	0.147	–1.1
Power	γ_4	1.950	0.564	3.5
Mean random effect (conventional car)	$\bar{\mu}_2$	0.081	0.781	0.1
Standard error of random effect (conventional car)	σ_2	1.396	0.423	3.3
Mean random effect (alternative fuel car)	$\bar{\mu}_3$	0.208	0.723	0.3
Standard error of random effect (alternative fuel car)	σ_3	2.575	0.408	6.3
Standard error of random effect (not buy)	σ_1	5.700	0.592	9.6
Correlation parameter	θ	1		
McFadden's ρ^2		0.61		
Log-likelihood		–778.5		
Number of observations (first choices)		1,491		
Number of observations (second choices)		491		
Number of draws	M	10,000		

Note: The unit of user cost is 1,000 yuan, fuel cost is measured in liters per 10 km, and the unit of power is 100 horsepower.

As discussed, the correlation in the random taste shifters across alternatives—found to be substantial for Model 1—vanishes in Model 2. It is perhaps surprising that the correlation between the error terms of the utilities of the alternative fuel and the conventional car is zero $(\theta = 1)$. A reasonable *a priori* conjecture is that the two car alternatives could be close substitutes. The estimates of the standard errors (σ) of the respective random effects differ substantially across alternatives. A possible explanation for this may be as following: As individuals in general are used to conventional gasoline car technology, the heterogeneity in tastes with respect to this technology may be less than for the alternative fuel technology, which most people know to only a limited degree. The random effect associated with the "no purchase" decision has very large variance, which may reflect the fact that we have no information about the user cost of other durables and fixed family expenditures such as housing, etc. Compared with Model 1, Model 2 implies a substantial increase in goodness-of-fit; ρ^2 increases from 0.23 to 0.61.

Table 6. Parameter estimates of Model 2. Low-income group*

Attribute	Parameter	Estimate	Standard error	t-value
User cost	γ_1	–3.360	0.378	–8.9
Fuel cost	γ_2	–1.104	0.824	–1.3
Size	γ_3	–0.252	0.227	–1.1
Power	γ_4	2.184	0.853	2.6
Mean random effect (conventional car)	$\bar{\mu}_2$	–0.428	1.047	–0.4
Standard error of random effect (conventional car)	σ_2	0.270	0.572	0.5
Mean random effect (alternative fuel car)	$\bar{\mu}_3$	0.160	0.987	0.2
Standard error of random effect (alternative fuel car)	σ_3	1.211	0.320	3.8
Standard error of random effect (not buy)	σ_1	6.083	1.028	5.9
Correlation parameter	θ	1		
McFadden's ρ^2		0.66		
Log-likelihood		–325.2		
Number of observations (first choices)		771		
Number of observations (second choices)		177		
Number of draws	M	10,000		

* The unit of user cost is 1,000 yuan, fuel cost is measured in liters per 10 km, and the unit of power is 100 horsepower.

In order to check if our specification (4.8) is independent of income (apart from the feasibility index $D_{jh}(t)$) we estimated the model separately for high- and low-income families. The high-income group consists of those with a monthly income above 5,750 yuan, while low-income families have a monthly income between 1,000 and 5,750 yuan. There are 52 households in the low-income group and 48 in the high-income group. The corresponding estimates are reported in Tables 6 and 7. When comparing Tables 5 to 7, we realize that the estimates are quite similar (when taking into account the standard deviation), apart from the parameter estimates associated with the random effects. Specifically, the mean random effects are significantly positive for the high-income group in contrast to the low-income group where they are insignificant. This result may be due to a misspecification of the model, or it could be due to the fact that high-income households may put greater value on car ownership than low-income households. However, when we consider the size of the respective standard errors, the differences between the high-income and low-income groups are negligible (apart from the estimates of σ_3).

Table 7. Parameter estimates of Model 2. High-income group*

Attribute	Parameter	Estimate	Standard error	t-value
User cost	γ_1	–3.372	0.313	–10.8
Fuel cost	γ_2	–1.221	0.733	–1.7
Size	γ_3	–0.094	0.194	–0.5
Power	γ_4	1.747	0.752	2.3
Mean random effect (conventional car)	$\bar{\mu}_2$	2.309	0.942	2.5
Standard error of random effect (conventional car)	σ_2	0.310	0.664	0.5
Mean random effect (alternative fuel car)	$\bar{\mu}_3$	2.010	1.017	2.0
Standard error of random effect (alternative fuel car)	σ_3	3.693	0.630	5.9
Standard error of random effect (not buy)	σ_1	5.324	0.877	6.1
Correlation parameter	θ	1		
McFadden's ρ^2		0.56		
Log-likelihood		–444.9		
Number of observations (first choices)		720		
Number of observations (second choices)		314		
Number of draws	M	10,000		

* The unit of user cost is 1,000 yuan, fuel cost is measured in liters per 10 km, and the unit of power is 100 horsepower.

5. Conditional demand and elasticities

The model estimated above is a disaggregate model that is supposed to capture individual (or household) behavior with respect to demand for automobiles, conditional on household income and attributes of the vehicle. The estimated model can now be applied to predict the demand for automobiles and to calculate elasticities for specified levels of the attributes, conditional on attribute values and household income. In Table 8 below, we display the predicted choice probabilities and corresponding elasticities among those households that can afford to buy a car (that is, $D_2(y_h)=0$). Here we only assume that conventional gasoline (or diesel) cars are available in the market. The probability of buying a car can in this case be expressed as

$$P_2(\boldsymbol{Z}_2) \equiv E\left\{\frac{\exp(\mu_{2h}+\boldsymbol{Z}_2\gamma)}{\exp(\mu_{1h})+\exp(\mu_{2h}+\boldsymbol{Z}_2\gamma)}\right\} \tag{5.1}$$

where the expectation is taken with respect to $(\mu_{1h},\mu_{2h})=(\sigma_1\eta_{1h},\bar{\mu}_2+\sigma_2\eta_{2h})$, and the attribute vector is equal to Z_2 . To compute (5.1), we use stochastic simulation similarly to the simulation of the likelihood function in Section 4.2.

Table 8. Elasticities and choice probabilities by car attributes given that income is higher than user cost*

Car attributes					Elasticity			Choice probability	
Price	User cost	Power	Fuel	Size	Price	Power	Fuel	Not buy	Buy
60	0.740	1.2	1.2	2	-0.404	0.379	-0.240	0.619	0.381
110	1.356	1.2	1.2	2	-0.929	0.476	-0.301	0.740	0.260
145	1.788	1.2	0.8	2	-1.334	0.518	-0.219	0.787	0.213
145	1.788	1.2	1.2	2	-1.396	0.543	-0.343	0.810	0.190
145	1.788	1.0	1.2	2	-1.447	0.469	-0.356	0.827	0.173
160	1.973	1.2	1.2	2	-1.634	0.576	-0.364	0.837	0.163
180	2.219	1.2	1.2	2	-1.989	0.623	-0.394	0.868	0.132
200	2.466	1.2	1.2	2	-2.334	0.658	-0.416	0.894	0.106
200	2.466	1.0	0.8	2	-2.318	0.544	-0.275	0.891	0.109
200	2.466	1.0	1.2	2	-2.393	0.562	-0.427	0.905	0.095

* The unit of user cost is 1,000 yuan, fuel cost is measured in liters per 10 km, and the unit of power is 100 horsepower.

From (5.1), it follows that the elasticity with respect to attribute component Z_{r2}, $r=1,2,3$ and 4, can be expressed as

$$\frac{\partial \log P_2(\boldsymbol{Z}_2)}{\partial \log Z_{r2}} = Z_{r2}\gamma_r\left[1-E\left(\frac{\exp(\mu_{2h}+\boldsymbol{Z}_2\gamma)}{\exp(\mu_{1h})+\exp(\mu_{2h}+\boldsymbol{Z}_2\gamma)}\right)^2\frac{1}{P_2(\boldsymbol{Z}_2)}\right]. \tag{5.2}$$

From Table 8 we see that when, for example, the price equals 145,000 yuan, power is 120 hp, and fuel cost is 1.2 (size does not matter) then the probability of buying a car for those who can afford a car is predicted to be 18.7 percent. The corresponding price elasticity in this case is –1.44.

6. The value of alternative fuel vehicles

By means of the estimated model it is possible to assess the value of alternative fuel vehicles as measured in money metric amounts. Specifically, this means how much it is necessary to reduce the user cost for a household so that the utility of conventional cars is equal to the utility of AFV, given that the attributes of both types of cars are the same. Let K_h denote the amount of reduction for household h. This amount is determined by

$$\boldsymbol{Z\gamma} + \mu_{3h} + \varepsilon_{3h} = -K_h\gamma_1 + \boldsymbol{Z\gamma} + \mu_{2h} + \varepsilon_{2h},$$

which leads to

(6.1) $$K_h = \frac{\mu_{3h} - \mu_{2h} + \varepsilon_{3h} - \varepsilon_{2h}}{-\gamma_1}.$$

Due to the distributional assumptions of the error terms $\{\varepsilon_{jh}\}$, the difference $\varepsilon_{3h} - \varepsilon_{2h}$ will be logistically distributed. Hence, for all real x,

(6.2) $$P(K_h \le x) = E\left(\frac{1}{1+\exp(\mu_{3h} - \mu_{2h} + \gamma_1 x)}\right)$$

where the expectation is taken with respect to $\mu_{3h} - \mu_{2h}$. Moreover, from (6.2), the fraction of households with positive compensating amount equals

(6.3) $$P(K_h > 0) = 1 - E\left(\frac{1}{1+\exp(\mu_{3h} - \mu_{2h})}\right) = E\left(\frac{1}{1+\exp(\mu_{2h} - \mu_{3h})}\right).$$

Thus, (6.3) expresses the fraction of households that value AFV higher than conventional fuel cars, *ceteris paribus*. Note that both (6.2) and (6.3) take into account both the random taste shifters and unobserved population heterogeneity in preferences across agents, which is represented by the terms $\mu_{3h} - \mu_{2h}$. It follows furthermore from (6.1) that

(6.4) $$EK_h = \frac{E\mu_{3h} - E\mu_{2h}}{-\gamma_1} = \frac{\bar{\mu}_3 - \bar{\mu}_2}{-\gamma_1}$$

and

$$(6.5) \qquad Var\,K_h = \frac{\pi^2/3 + Var(\mu_{3h} - \mu_{2h})}{\gamma_1^2} = \frac{\pi^2/3 + \sigma_2^2 + \sigma_3^2}{\gamma_1^2}.$$

Although our estimates imply that the mean EK_h is positive, it is very small (38 yuan). However, the individual values of K_h may be both positive and negative. The estimate of the standard deviation, calculated by means of (6.5) is found to be 1,023 yuan. Thus, the compensating variation measure K_h may vary up to about 2,000 yuan below 38 yuan—and 2,000 yuan above 38 yuan. The fraction of households that value AFV higher than conventional fuel cars (based on (6.3)) is estimated as 0.53.

7. Conclusions

In this paper we have developed, random utility modeling framework with random effects for panel data on rank ordered alternatives. This framework contains a nested logit rank ordered model as a special case. We have applied this framework to analyze the demand for conventional and alternative fuel vehicles in the city of Shanghai. Specifically, the model is estimated on data obtained from a stated preference survey conducted in Shanghai in 2001. As far as the authors are aware, there has been no previous application of nested logit models to rank-ordered data. Moreover, discrete choice models do not appear to have been previously applied to the analysis of transportation in China.

We have estimated several model versions and demonstrated that in this application the correlation between the random taste shifters across alternatives vanishes when we allow for random effects. We have also estimated the model for high income- and low income groups separately, and found that the estimates are not very different between the two groups. However, due to the limited sample size one must be cautious with interpretation of these results. Measured in terms of McFadden's ρ^2 the fit of the models turned out to be good. The model is used to calculate elasticities and choice probabilities for selected attributes for those who can afford to own a car. We have also discussed and illustrated how choice probabilities can be calculated, and have employed the model to calculate willingness-to-pay estimates. These estimates show that 53 percent of the households in our sample value AFV vehicles higher than conventional fuel vehicles.

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Information about the survey and the questionnaire

The interviewer is supposed to explain to the respondent about the traditional gasoline car and alternative fuel car (AFV) and their relevant attributes as carefully and sufficiently as possible.

We have 15 experiments. In each experiment, the research will present an option card on which there is a choice set with three alternatives, i.e., not buy; buy gasoline car; buy AFV. In each experiment, the gasoline car and AFV will have a different attribute combination. First, among the three alternatives, please indicate what is the respondent's most preferred one.

If the respondent has chosen the alternative of "not buy", then ask him/her the following question: Suppose now you are able to buy, which one do you prefer between the remaining two alternatives?

If the respondent has chosen the alternative of either gasoline car or AFV, then ask him/her the following question: Suppose now the alternative you just chose is not available, which one do you prefer among the remaining two alternatives (that is: either gasoline car or AFV – whichever was not chosen in your first option-and the option to "not buy".

Table 1A. Some descriptive statistics of household sample basic information

	Age	Household size (persons)
Mean	33.52	2.62
Standard error	0.96	0.10
Minimum	21	1
Maximum	66	6

Table 2A. Option cards (15 designed experiments)

Experiment	Choice set	Price (1,000 yuan)	Power (Horse Power)	Fuel consumption (Liters/100 km)	Size (Number of Seats)
1	Not buy				
	Gasoline car	145	120	12	6 ~7
	AFV	250	100	2	4 ~5
2	Not buy				
	Gasoline car	120	110	8	6 ~7
	AFV	200	150	2	6 ~7
3	Not buy				
	Gasoline car	170	125	6	4 ~5
	AFV	155	95	4	4 ~5
4	Not buy				
	Gasoline car	60	90	6	6 ~7
	AFV	155	120	2	4 ~5
5	Not buy				
	Gasoline car	100	100	10	6 ~7
	AFV	80	95	3	4 ~5
6	Not buy				
	Gasoline car	180	140	10	6 ~7
	AFV	125	90	2	6 ~7
7	Not buy				
	Gasoline car	105	100	8	6 ~7
	AFV	180	100	2	4 ~5
8	Not buy				
	Gasoline car	70	90	7	4 ~5
	AFV	145	120	4	6 ~7
9	Not buy				
	Gasoline car	175	125	10	6 ~7
	AFV	155	90	2	6 ~7
10	Not buy				
	Gasoline car	100	90	6	4 ~5
	AFV	140	120	3	4 ~5
11	Not buy				
	Gasoline car	180	110	6	6 ~7
	AFV	155	95	3	4 ~5
12	Not buy				
	Gasoline car	120	90	8	6 ~7
	AFV	130	120	4	4 ~5
13	Not buy				
	Gasoline car	200	130	6	6 ~7
	AFV	150	100	4	4 ~5
14	Not buy				
	Gasoline car	100	120	10	6 ~7
	AFV	160	100	3	6 ~7
15	Not buy				
	Gasoline car	150	120	8	4 ~5
	AFV	130	90	2	6 ~7

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