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The Motivation behind Behavioral Thresholds: A Latent Class Approach

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Abstract

This paper extends Ito et al. (2010) to reveal whether altruism is an underlying motive of the behavioral thresholds. We also investigate the influence of environmental concern as one of the underlying motives of them. Applying contingent valuation (CV) methods, we conducted a stated preference survey to study people's cooperative behavior in the donation to Green Power Fund (GPF). We use latent class approach in order to examine the underlying motives of the thresholds. The results show that the participation rate in the donation to the GPF, which completely cancels out the amount of CO2 emission from a household's electricity consumption, is estimated as 59.24% at the psychosocial equilibrium when the suggested donation amount is 500 yen. We found that for a latent class with higher altruism and environmental concern there is a statistically significant impact of the equilibrium participation rate through behavioral thresholds.

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1 Introduction

In contrast to the prediction of standard economic theory, numerous studies have documented the irrational cooperative behavior of public goods games in laboratory experiments. These studies have also found cooperation decay during the course of multiple-round games (Davis and Holt 1993).

To date, several studies have attempted to explain the factors that affect these cooperative behaviors. Andreoni (1995) developed an experimental design to distinguish “kindness” from “confusion,” and concluded that reduced confusion explains the decay in cooperation. Houser and Kurzban (2002) extended Andreoni’s experimental design and confirmed this conclusion. Palfrey and Prisbrey (1996, 1997) developed an experimental design to separate altruism, *warm glow* (a willingness to cooperate a certain constant amount independently of others’ cooperation), and errors. They found that altruism does *not* explain cooperative behavior, whereas the impact of *warm glow* is significant and differs between people. The reduced errors again explain the decay in cooperation.

In their laboratory experiments, Fischbacher and Gachter (2010) found that the interaction of heterogeneously motivated types explains a large part of the decay in cooperation. They simulated the dynamic decay in cooperation using the subjects’ heterogeneous social preferences that were elicited in a one-shot game, and show the consistency between their prediction and actual behavior. They conducted two experiments. In one experiment, the subjects were asked to make two types of decisions: an unconditional contribution, which is the willingness to contribute regardless of the amount of other group members’ contribution, and a conditional contribution, in which the willingness to contribute depends on the average contribution of other group members. These decisions were all motivated by financial incentives. In the other experiment, the subjects play the standard linear public goods game ten times under the stranger condition. Here, groups of four subjects are randomly reshuffled in each period (Andreoni 1988; Ledyard 1995). Then, in each period, they elicited the subjects’ beliefs for the average contribution of other members. They simulate the outcome by using the information of conditional cooperation and the beliefs, given the initial value of unconditional cooperation. However, enough attention has not been paid to individual characteristics in determining the cooperation and role of altruism as an underlying motivation.

Although Granovetter’s (1978) *threshold model* (also called the critical mass model) is conceptually similar to that of conditional cooperation, it assumes that each individual distinguishes the same average contributions for different numbers of contributors. The threshold model is a dynamic theory that analyzes *herd behavior* observed among rioting mobs and in consumer behavior. In his theoretical analysis, he assumes that an individual has a *behavioral* threshold (also called critical mass). The threshold is defined as the proportion of the group that the individual would have to see in action before he/she chooses to participate. Granovetter also assumes that individuals have different threshold values. Putting the threshold model into the context of the public goods game, the threshold can be defined as the share of contributors in the group, given the contribution of others.

This paper extends the work of Ito et al. (2010) to identify the heterogeneous preferences for behavioral thresholds to reveal the role of altruism as an underlying motivation behind the thresholds for donation behavior to renewable electricity. We also investigate the influence of environmental concern as an underlying motive. Although several studies have examined people’s willingness to participate in green electricity programs and the motivations behind such willingness (Bergmann et al. 2006; Bergmann et al. 2008; Clark et al. 2003; Ek 2005; Ek and Söderholm 2008; Kotchen and Moore 2007; Longo et al. 2008; Menges et al. 2005; Roe et al. 2001; and Zarnikau 2003), there is little empirical analysis dealing with the equilibrium of social interaction.

2 Methodology

2.1 The Survey

In order to examine the behavioural motivation of participation in the GPF, an internet survey was conducted in January 2009 by Nikkei Research, a private research company. The questionnaires of the survey contain the items of contingent valuation (CV). The respondents were 1,281 randomly sampled households in Japan. They were randomly assigned questionnaires (see appendix) that had different CV scenarios and asked about their inclination to participate in a GPF program.

GPF is a program managed by power companies in Japan to collect donations from customers toward the spread of renewable energy. Matching the consumers’ contributions with their own funds, the companies use the collected money to support those organizations (mostly public facilities and schools) that need financial aid to install solar panels or wind-power facilities. As of 2008, 0.02% to 0.11% of their customers participated in such programs by paying an extra amount (typically 500 Japanese yen) over and above their monthly electricity bills.

Since residential electricity markets have not been deregulated in Japan, households are not free to choose among power companies on the basis of the proportion of renewable electricity to total electricity that each company generates. Thus, households have limited opportunities to support renewable energy. Even though the GPF program offers people an opportunity to consider what they want, the participation rate is low. An investigation into the policy for increasing support for GPF programs would provide an understanding of how best to promote renewable energy.

With regard to people's motives for making voluntary contributions to renewable energy, recent studies have focused on the role of moral and psychological aspects. Clark et al. (2003) examined whether environmentalism and altruism promote participation in a green electricity program that requires individuals to lease at least one 100 W block of solar electricity service for an additional fee of \$6.59 per block per month. They show that both environmentalism and altruism significantly and independently influence the decision to participate in the program. Drawing on insights from social psychology, Nyborg et al. (2006) explored the potential influence of social interdependencies between different consumers' moral motivations in explaining the green consumer phenomenon. They claim that consumers may display herd behavior if green consumerism is motivated by internalized social norms. An empirical analysis of the choice of green electricity undertaken by Ek and Söderholm (2008) supports this suggestion. In order to understand the social interdependencies of consumer behavior, it is necessary to model the psychosocial equilibrium of human interactions.

Questionnaires were assigned exogenously and randomly. The CV scenarios differed among these questionnaires with respect to the hypothetical scenario of predicted participation rates for a GPF program. Thus, respondents were presented with one specific predicted participation rate out of five levels (1%, 25%, 50%, 75%, and 90%). The CV scenarios also varied in accordance with the suggested first bid (that is, donation amount per month). The five levels of the initial bid used in the survey are presented in Table 1. The sets of bid amounts were also assigned to the respondents randomly. Accordingly, 25 scenarios were created to be assigned to each respondent. Each respondent answered only one version in order to eliminate the influences of scenario ordering.

In order to estimate their willingness to pay (WTP) for CO_2 reduction exercises, we asked the respondents to assume that a donation can help reduce the emission of carbon dioxide by 3.6 tons per year. This figure is equivalent to the average CO_2 emissions generated from electricity consumption in a household in Japan. This assumption implies that the donation could cancel out the annual emissions from a single household's electricity consumption. In actuality, the amount of CO_2 reduction by the donation to the GPF depends on the amounts of the donation. Therefore, the participation rates predicted from our estimation results cannot be directly compared to those in the real world.

Table 1: The bid structure in the CV survey (unit: yen/month)

Group of respondents	I	II	III	IV	V
Initial bid	100	500	1,000	3,000	5,000
Follow-up question for "no" response	50	100	500	1,000	3,000
Follow-up question for "yes" response	500	1,000	3,000	5,000	10,000

Note: $1 = ¥90.40 (central rate on of Bank of Japan, as of 20 January 2009)

In the double-bounded dichotomous choice format, after the respondent says "yes" or "no" with regard to the first bid, he/she is additionally asked for his/her reaction to a bid one level higher or lower than the first bid. Thus, if a respondent answered "yes" ("no") to the first bid of 100 yen, he/she was then asked the same question with the higher (lower) bid of 500 (50) yen. Given the hypothetically predicted participation rate, the respondents are expected to answer yes/no as to whether they are willing to donate to a GPF in a double-bounded format. While the double-bounded format improves the efficiency of the questionnaires, empirical evidence has suggested that the approach introduces bias into the results (Mitchell and Carson, 1989). An example is "yea-saying," in which respondents tend to agree with the interviewer and overstate their WTP (DeShazo 2002; Flachaire and Hollard 2006). Although this paper does not pursue detecting the bias potentially introduced by using the double-bounded format, this would not affect our main result as long as the extent of the bias is similar to all latent classes examined in the analysis. A summary of the data obtained is provided in Table 2.

Table 2: Definition of variables and summary statistics

Variable	Definition	Mean	S.D.	Min.	Max.
PRATE	Predicted participation rate (%) given in scenario	47.26	32.20	1	90
RSHARE	Respondent's own guesses of current share of generation of renewable energy in Japan, measured as the ratio to total power generation (%)	5.33	3.70	2.5	17.5
GENDER	Male = 0, female = 1	0.43	0.49	0	1
OVER60	=1 if age ≥60, 0 otherwise	0.22	0.42	0	1
HSIZE	Number of people in household	2.98	1.33	1	9

Note: S.D. = Standard deviation.

2.2 Random Utility Model

We assume that respondent n's utility function is given by the following random utility model:

$$u_{ni} = \boldsymbol{\alpha}_i' \mathbf{z}_n + \beta_i y_n + \varepsilon_{ni} \quad \text{for} \quad n = 1, \ldots, N,$$

where $\mathbf{z}_n$ denotes the characteristics of the hypothetical scenario, including the predicted participation rate exogenously given in the CV scenario and the respondent's own expectation of the share of renewable energy in the electricity generation; $\boldsymbol{\alpha}_i$ denotes the preference parameter vector; y_n denotes respondent n's income; β_i denotes the marginal utility of income; and ε_{ni} denotes a random error term. In addition, the subscript i represents the choice made by the respondent, which has the value 0 if he/she chooses the status quo and the value 1 if he/she donates to a GPF. The derivations of the latent class model of a double-bounded, dichotomous-choice format are given in the appendix.

2.3 The Measurement of Environmental Concern and Altruism

Along with the psychological influences investigated by the predicted participation rate, we considered two internal moral motivations for donating to green energy initiatives. In our analysis, we included scores for two scales: a five-item set for the New Ecological Paradigm (NEP) scale and a five-item set for an altruism scale (Kotchen and Moore 2007). A five-point Likert response scale was used for each item in both the scales. Clark et al. (2003) constructed an altruism scale related to the awareness of consequences, personal norms, and ascriptions of responsibility. Recent economic literature shows that both scales have a positive impact on participation in green electricity programs and the willingness to pay for green electricity (Clark et al. 2003; Kotchen and Moore 2007; Ek and Söderholm 2008). Although the Cronbach's alpha for each scale shows that both scales did not pass the test for internal consistency, we combine the items into a summated scale for the sake of analytical convenience. These statistics are presented in Table 3.

Table 3: Item-total correlations and Cronbach's alpha for NEP and altruism scales

	Correlation
NEP scale (NEP)	
1. Plants and animals have as much right as humans to exist.	0.526
2. The so-called ecological crisis facing humankind has been greatly exaggerated.	0.648
3. Human ingenuity will ensure that we do not make the earth unlivable.	0.204
4. The earth is like a spaceship with very limited room and resources.	0.530
5. The balance of nature is strong enough to cope with the impacts of modern industrial nations.	0.669
Cronbach's alpha	0.308
Altruism scale (ALT)	
1. Contributions to community organizations rarely improve the lives of others.	0.608
2. The individual alone is responsible for his or her well-being.	0.437
3. It is my duty to help other people when they are unable to help themselves.	0.627
4. My responsibility is to provide only for my family and myself.	0.564
5. My personal actions can greatly improve the well-being of people I don't know.	0.534
Cronbach's alpha	0.437

Notes: Responses are based on a five-point Likert scale ranging from "strongly agree" to "strongly disagree." Responses are coded from 1 to 5, such that higher numbers correspond to greater concern about the environment or greater altruism.

3 Result

3.1 Model Estimation

The estimation results for the latent class model are presented in Table 4. The number of latent classes is given exogenously for each estimation. Thus, statistical criteria must be used to select the optimal number of classes in a set of estimations in which the number of imposed classes varies for each estimation. Following Boxall and Adamowicz (2002), we use two criteria to select the optimal number of latent classes: the minimum Akaike Information Criterion (AIC) and the minimum Bayesian Information Criterion (BIC). The calculated results are presented in Table 5. While the BIC indicates that the appropriate number of classes is two, the AIC indicates that it is three. Since the latent class probability of the third class in a three-class model is extremely low, we decided to use two classes. The latent class probabilities are calculated from the sample means of the individual attributes.

The negative coefficients of *BID* indicate that the marginal utility of the expense is negative in both classes, as expected. The marginal utility of income in Class 1 is larger than that in Class 2. The coefficient of *PRATE* is significantly positive in Class 1, but not significant in Class 2[1]. These results indicate that those with the higher latent choice probability of Class 1 have a threshold for their donation to GPF.

The coefficients of *RSHARE* are not significant in both classes. This variable represents the respondent's guesses regarding the percentage of green electricity to total power generation in Japan. We find that the volume of current green electricity predicted by a respondent does not influence his/her donation behavior significantly.

In the membership function, the coefficients of *NEP* and *ALT* are positive and significant for Class 1. This result indicates that the more altruistic the respondent's motivations and the more environmentally concerned they are, the higher their probability to have preference parameters of Class 1. These results demonstrate that environmentalism and altruistic motivation can influence the consumer's donation behavior through the differences in thresholds.

In Class 2, the coefficient of *OVER60*, *HSIZE*, and *GENDER* are not significant at 10% level. These results indicate that household size, gender, and age (over 60 years old) are not determinant factors of heterogeneous preferences for donating to a GPF.

In the next section, we combine the estimated economic model and a threshold model from social psychology to obtain the equilibria of social interactions.

Table 4: The estimation results of the latent class model

	Class 1		Class 2	
Variable	Coeff.	Stand. Err.	Coeff.	Stand. Err.
Parameters of Random Utility Models				
CONSTANT	0.566	0.511	0.501*	0.290
BID	−0.001***	0.000	−0.005***	0.001
PRATE	0.010**	0.005	−0.001	0.004
RSHARE	0.032	0.037	0.010	0.032
Parameters of Membership Functions				
CONSTANT	−6.442***	1.122		
OVER60	0.357	0.258		
HSIZE	−0.040	0.089		
GENDER	0.146	0.222		
NEP	0.127***	0.047		
ALT	0.213***	0.048		
Latent Class Probability	0.270		0.730	
Log-likelihood	−1081.42			
Number of Observations	1110			

Note: *** p < 1%, ** p < 5%, * p < 10%.

[1] Although we also estimated a model that contains the square terms of PRATE, the variables in both the classes are not significant at the 10% level.

Table 5: Information of the converged latent class models

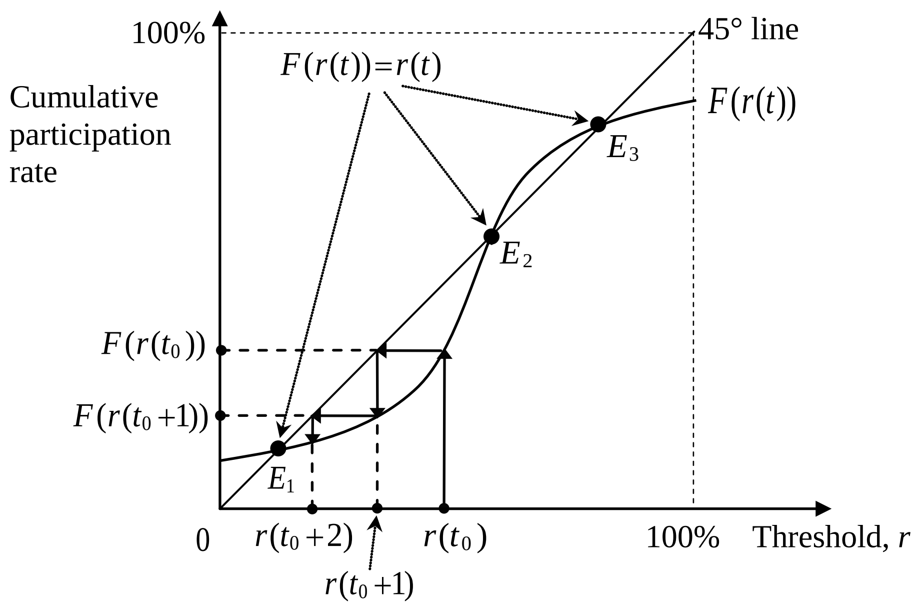
Number of Classes	Number of Parameters	Log likelihood	AIC	BIC
1	4	−1210.45	2428.90	2448.94
2	14	−1081.42	2190.84	2261.01
3	24	−1060.75	2169.51	2289.80
4	34	−1056.94	2181.87	2352.28

Note: AIC = −2(LL−K), BIC = −2LL + Klog(N), where LL is the log-likelihood, K is the number of parameters, and N is the number of observations

3.2 Simulations of Threshold Models

Following Ito et al. (2010), we simulate the threshold models using the preference parameters in our estimated models. The threshold model of Granovetter (1978) is described in Figure 1. In the figure, behavioral threshold values are denoted as x and the cumulative distribution function (cdf) as $F(x)$. The cdf represents the proportion of the population having a threshold less than or equal to *x*. The proportion of the population that has given donations at time t is denoted as $r(t)$. Observing the participation ratio, $r(t)$, there are potentially $F[r(t)]$ people who are willing to participate in a donation drive, from the threshold effect. In such a situation, the proportion of those who are going to donate at time $(t+1)$ is described by $r(t+1)=F[r(t)]$.

Figure 1: The threshold model



Since $r(t+1) = F[r(t)]$, we can find the proportion of those giving donations in period $(t+1)$ by following the arrow from $r(t)$ to the point above it on the cdf. This point is reflected again on the *x*-axis by following the horizontal arrow to the 45º line, $F(x)=x$. This procedure is repeated to find $r(t+2) = F[r(t+1)]$ and continues until it reaches the point E_1, where the cdf crosses the 45º line. This point is the equilibrium, and is denoted by the equation $F(r)=r$. The threshold model given in Figure 1 has two possible equilibria. If the share of participants in the beginning is below E_2, then equilibrium is reached at E_1. If the share in the beginning is above E_2, then the final equilibrium becomes E_3.

Since the cumulative share of participants is equal to the probability of "yes" responses to a suggested amount of donation in a CV survey, $\Pr(yes)$, we can construct the cdf by calculating $\Pr(yes)$ using the various predicted participation rates. The estimated latent class model gives rise to two classes that have different preference parameters. The probabilities that individuals belong to Class 1 and Class 2 are 27.0% and 73.0%, respectively[2]. We constructed the weighted threshold model to reflect the latent class probabilities of Classes 1 and 2. The probabilities of "yes" responses and the simulated threshold models for the different suggested donations are presented in Figure 2. The distributions of the thresholds intersect once with the 45º line for all donation amounts so that we have a unique equilibrium point, regardless of the initial condition. The cumulative share of participants at the point of equilibrium decreases for higher suggested donations. The shares of the participants in a GPF at equilibria, as given by numerical calculations, are presented in Table 6. The table also shows the expected donations by multiplying the suggested donation with the equilibrium participation rate. The highest expected donation is of 500 yen. Therefore, our results support the finding that most GPF programs solicit donations in 500-yen lump sums.

[2] These probabilities were calculated from the sample mean of individual attributes.

Figure 2: The probabilities of yes responses and simulated threshold models

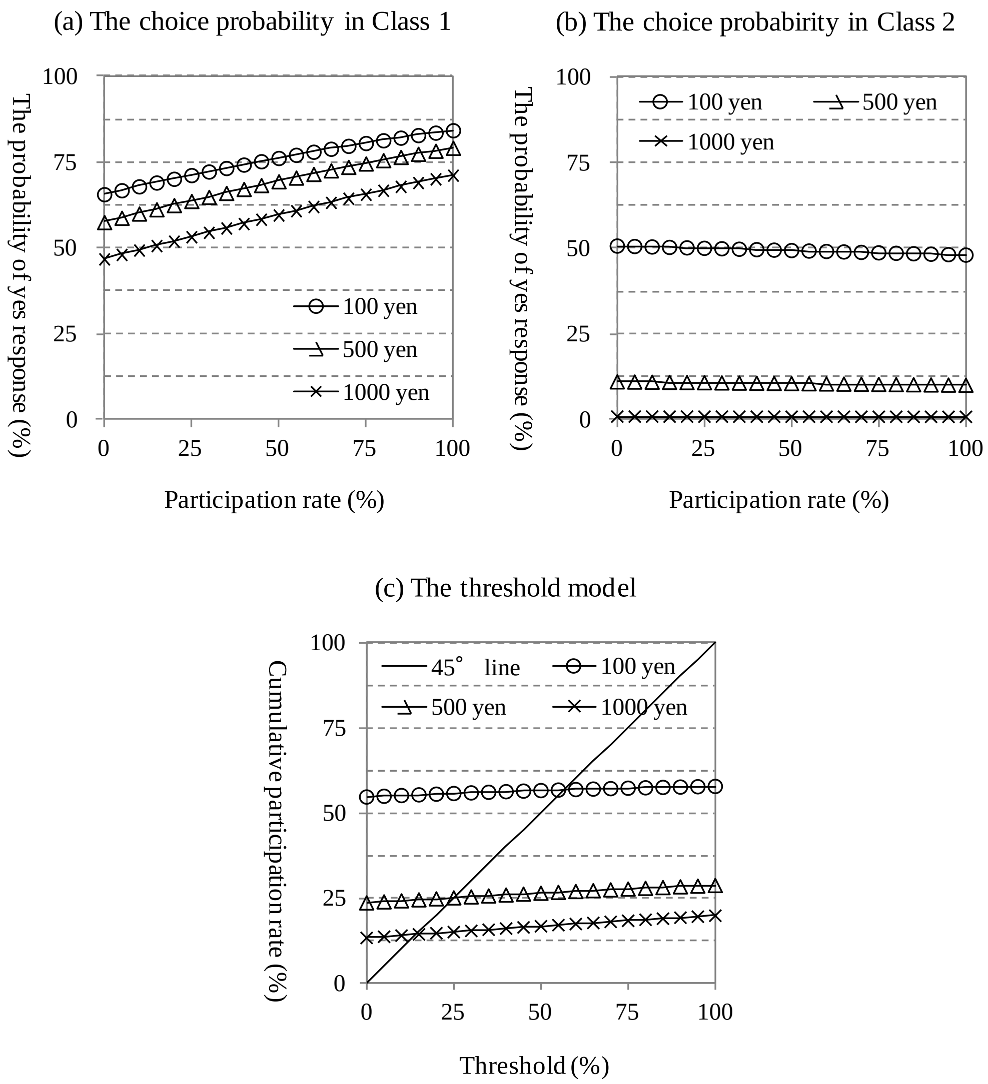


Table 6: Equilibria of the threshold models

Donation amount (yen)	100	500	1,000	3,000	5,000
The equilibrium (%)	74.11	59.24	14.28	3.80	0.74
Expectation of donation (yen)	74.11	296.18	142.78	113.87	37.10

4 Conclusions and Remarks

Our main findings can be summarized in the following manner. First, applying the latent class approach to the threshold model enables us to relax the assumption that all people have thresholds when deciding on whether to participate in a GPF and reveals that altruism and environmental concern are underlying motives of thresholds. Our analysis using the threshold model shows that the expected participation rate influences individual decisions to donate and the resulting psychosocial equilibrium of a GPF program. The psychosocial equilibrium indirectly depends on people's environmental concerns and altruism. A higher participation rate is associated with a higher average donation. Our result also provides new insight that altruism does not directly increase the size of a contribution, but can indirectly increase *conditional cooperation*. Altruism and *warm glow* are possible underlying motives for cooperation.

Second, in our two latent classes, Class 1 has a threshold for participation in the GPF, but Class 2 does not. Further, the altruistic individual has a relatively higher probability of preferring Class 1. Assuming that an altruistic individual perceives the participation rate as a signal of the value of renewable energy to others, the sensitivity of Class 1 to the threshold is reasonable. Furthermore, this assumption suggests that individuals in Class 2 do not respond to such signals and are motivated rather by *warm glow* (Palfrey and Prisbrey 1996, 1997). This might be why the participation rate is significant for one class but not the other.

Third, our results show that higher suggested donations have a lower participation rate equilibrium. In order to maximize total donations, fundraisers should take this effect into account (rather than the participation rate) when suggesting a donation amount. Further, the bid amount of 500 yen, which is proposed by most domestic power companies, is supported by this study.

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Appendices

Survey

"Questionnaire about Environmentally Friendly Energy"

The electric company has established the "Natural Energy Fund" and would like to request a donation of XX yen per month towards this from each customer. The donation will be collected by adding this amount to each customer's monthly electricity bill.

The electric company will meet the total donated amount with its own donation of an equal value and use it for funding the construction costs of providing clean power generation facilities for municipal offices, elementary schools, etc.

Thanks to your donations, annual CO_2 emissions will be reduced by 3.6 tons (almost equal to the annual CO_2 emissions from a single household's electricity consumption). Furthermore, detailed information regarding the recipients of the funds will be disclosed on the internet.

According to preliminary surveys, it is believed that YY percentage of your electricity company's customers will participate in this donation initiative. To enact this drive successfully, we request you to kindly provide your answers to the following questions.

Q1. *Would you want to give a donation of XX yen each month over a one-year period between April 2009 and March 2010 (single answer)? Yes/ No*

Q2. *What if the donation was for ZZ yen each month? Yes/No*

Double-bounded dichotomous choice format

The indirect utility, u, for respondent n can be written as

$$u_{ni} = v_{ni} + \varepsilon_{ni} \tag{1}$$

where v_{ni} is the deterministic part and ε_{ni} is a random error term. Subscript i represents the choice made by the respondent and it becomes zero when he/she chooses the status quo and becomes one when he/she donates to a GPF.

Assuming the linear utility function, we can express the deterministic term v_n by a vector of the hypothetical scenario's characteristics $\mathbf{z}_n$, including the predicted participation rate exogenously given in the CV scenario and respondent's own expectation to the share of renewable energy in the electricity generation. This can be written as follows (Haab and McConnell 2002).

$$v_{n0}(y_n) = \boldsymbol{\alpha}_0' \mathbf{z}_n + \beta_0 y_n \tag{2}$$

When the respondent donates to a GPF, the indirect utility can be written as

$$v_{n1}(y_n - t_n) = \boldsymbol{\alpha}_1' \mathbf{z}_n + \beta_1 (y_n - b_n) \,. \tag{3}$$

Assuming that the marginal utility of income is constant, that is, $\beta = \beta_1 = \beta_0$, the probability that the respondent will answer "yes" in the single-bounded format is written as

$$\begin{aligned} \Pr(yes) &= \Pr\left(v_{n1}(y_n - b_n) + \varepsilon_{n1} \geq v_{n0}(y_n) + \varepsilon_{n0}\right) \\ &= \Pr\left((\boldsymbol{\alpha}_1 - \boldsymbol{\alpha}_0)' \mathbf{z}_n - \beta b_n \geq -(\varepsilon_{n1} - \varepsilon_{n0})\right) \\ &= \Pr\left(-dv_n \leq \varepsilon_n\right) = 1 - \Pr\left(\varepsilon_n \leq -dv_n\right) \end{aligned} \tag{4}$$

where $dv_n \equiv (\boldsymbol{\alpha}_1 - \boldsymbol{\alpha}_0)' \mathbf{z}_n - \beta b_n$, and $\varepsilon_n \equiv \varepsilon_{n1} - \varepsilon_{n0}$. ε_{n1} and ε_{n0} are assumed as independently and identically distributed type I extreme values, each with a mean of zero.

The double-bounded CV starts with an initial bid b_n^f. If the respondent answers "yes," he/she faces a follow-up bid, b_n^h $(b_n^h > b_n^f)$; if he/she answers "no," he/she faces a follow-up bid b_n^l $(b_n^l < b_n^f)$. Thus, there are four possible outcomes: (yes, yes), (yes, no), (no, yes), and (no, no). In terms of the random utility maximizing model given above, the corresponding response probabilities are

$$\begin{aligned} \Pr(yes, yes) &= \Pr\left(dv_n^h + \varepsilon_n > 0\right) \equiv 1 - G(dv_n^h; \theta) \\ \Pr(yes, no) &= \Pr\left(dv_n^h + \varepsilon_n \leq 0 \leq dv_n^f + \varepsilon_n\right) \equiv G(dv_n^h; \theta) - G(dv_n^f; \theta) \\ \Pr(no, yes) &= \Pr\left(dv_n^f + \varepsilon_n \leq 0 \leq dv_n^l + \varepsilon_n\right) \equiv G(dv_n^f; \theta) - G(dv_n^l; \theta) \\ \Pr(no, no) &= \Pr\left(dv_n^l + \varepsilon_n \leq 0\right) \equiv G(dv_n^l; \theta) \end{aligned} \tag{5}$$

where $\theta \equiv (\boldsymbol{\alpha}, \beta)$ and $\boldsymbol{\alpha} \equiv (\boldsymbol{\alpha}_1 - \boldsymbol{\alpha}_0)$. We assume that $G(\bullet\,; \theta)$ is a logistic cumulative distribution function. The double-bounded model can increase the statistical efficiency over a single-bounded dichotomous choice CV (Hanemann et al. 1991).

Latent Class Approach

Applying the latent class model, we relax the assumption of the identical representative utility function. The latent class corresponds to the underlying preference segments, each of which is characterized by a unique preference parameter $\theta_s = (\boldsymbol{\alpha}_s, \beta_s)$ for $s = 1, \ldots, S$. In the latent class model, the probability π_{ns} that individual n is given the preference parameter θ_s is based on the membership function,

$$M_{ns} = \boldsymbol{\lambda}_s \mathbf{Z}_n + \zeta_{ns} . \quad (6)$$

where $\mathbf{Z}_n$ is the vector of the socio-demographic characteristics of respondent n, and $\boldsymbol{\lambda}_s$ is the vector of parameters, ζ_{ns} is a random error term. The probability that respondent n belongs to the class k is assumed as follows,

$$\Pr(n=k) = \pi_{nk} = \frac{\exp(\mu \boldsymbol{\lambda}_k \mathbf{Z}_n)}{\sum_{s=1}^{S} \exp(\mu \boldsymbol{\lambda}_s \mathbf{Z}_n)} . \quad (7)$$

This is the multinomial logit model in which the error terms ζ_{ns} are assumed to be independently distributed across individuals and segments with type I extreme value distribution with a scale parameter μ. The scale parameter is normalized to one.

The log likelihood function for the responses to a CV survey using the double-bounded format is

$$\ln L(\theta) = \sum_{n=1}^{N} \left\{ \begin{array}{l} d_n^{YY} \ln\left[\sum_{k=1}^{S}\left(1 - G(dv_n^h;\theta_s)\right)\pi_{nk}\right] \\ + d_n^{YN} \ln\left[\sum_{k=1}^{S}\left(G(dv_n^h;\theta_s) - G(dv_n^f;\theta_s)\right)\pi_{nk}\right] \\ + d_n^{NY} \ln\left[\sum_{k=1}^{S}\left(G(dv_n^f;\theta_s) - G(dv_n^l;\theta_s)\right)\pi_{nk}\right] \\ + d_n^{NN} \ln\left[\sum_{k=1}^{S} G(dv_n^l;\theta_s)\pi_{nk}\right] \end{array} \right\} \quad (8)$$

where $d_n^{YY} = 1$ if respondent n answers (yes, yes) and 0 otherwise; $d_n^{YN} = 1$ if respondent n answers (yes, no) and 0 otherwise; $d_n^{NY} =$ 1 if respondent n answers (no, yes) and 0 otherwise; $d_n^{NN} =$ 1 if respondent n answers (no, no) and 0 otherwise.