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Ito, Nobuyuki

Takeuchi, Kenji

Tsuge, Takahiro

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A Dynamic Analysis of the Green Electricity Fund: Threshold Models Revisited

Nobuyuki Ito,[a] Kenji Takeuchi,[a*] Takahiro Tsuge,[b] and Atsuo Kishimoto[c]

a Graduate School of Economics, Kobe University, Japan
b Faculty of Economics, Konan University, Japan
c National Institute of Advanced Industrial Science and Technology, Japan

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Abstract

This study applies a threshold model proposed by Granovetter (1978) to analyze the dynamic diffusion process of donating behavior for renewable energy. Using data on people's willingness to donate for renewable energy under various predicted participation rates, we simulate how herd behavior spreads and the participation rate reaches the equilibrium. The participation rate at the equilibrium is estimated as 66.46% when the suggested donation is 500 yen, while it is 25.88% when the suggested amount is 1,000 yen. The influence of environmentalism and altruism is also examined, and we find that these motivations increase the participation rate 43.38% on average.

JEL classification number: H41, Q42, Q51
Keywords: Green electricity fund; Dynamic analysis; Contingent Valuation; Threshold model

[*]Corresponding author. *E-mail address*: takeuchi@econ.kobe-u.ac.jp

1. Introduction

Since 2000 Japanese power companies have established "Green Power Fund" (GPF) programs to raise money from customers who volunteer to contribute to the spread of renewable energy. Adding their own matching contribution, 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 have participated in such programs by paying an extra sum of money (typically 500 Japanese yen) with their monthly electricity bills.

Since residential electricity markets have not been deregulated in Japan, households are not free to choose from among power companies on the basis of the proportion of renewable electricity to total electricity that each company generates. Households thus have limited chances to make a choice for renewable energy. Although a GPF program offers people an opportunity to consider what they want, the participation rate is still low. Investigation of a policy to spread support for GPF programs would be a help towards understanding how to promote renewable energy.

As regards people's motives for making voluntary contributions to renewable energy, recent studies focus on the role of moral and psychological aspects. Clark et al. (2003) examine 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. Drawing on insights from social psychology, Nyborg et al. (2006) explore the potential influence of social interdependency between different consumers' moral motivation 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. However, the dynamics of the social process that follows from such motivation has not been fully addressed in these studies. To understand the social interdependence of consumer behavior, it is necessary to model the dynamics of human interaction.

This paper analyzes such social interaction by examining a threshold model proposed by Granovetter (1978). Granovetter (1978) and Granovetter and Soong (1986) use a dynamic theory to analyze herd behavior found in riots and in consumer behavior. In their theoretical analysis, they assume that an individual has a threshold value that is defined as a proportion of the group he/she would have to see join before he/she would join. They also assume that the value is different for different people. Their conclusion is that the overall influences of the herd behavior depend on the distribution of the threshold values of individuals. Also, in his analysis of voting behavior, Tyran (2004) investigates theoretically and empirically the role of a person's expectation of what others will do, and he finds that voters tend to vote if they expect many others will vote.

Although many studies have examined people's willingness to participate in green electricity programs and the motivations behind that 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 no empirical analysis dealing with the dynamic process of diffusion. A study of dynamic interdependency is important for considering the diffusion of green electricity programs. In this paper, we investigate the influence of predicted participation rate on indivisual support for renewable energy. In addition, we show that environmentalism and altruism can influence the dynamic diffusion of green electricity programs.

2. Methodology

2.1. The survey

Our analysis is based on data from a double-bounded dichotomous choice contingent valuation (CV) survey of 1,281 randomly sampled households in Japan. The respondents were randomly assigned questionnaires (see Appendix) that had different CV scenarios and asked about their intention to participate in a GPF program. The CV scenarios differed with respect to predicted rates of participation in a GPF program, which were assigned exogenously by the researcher. 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 first bid (that is, contribution per month) suggested. The five levels of initial bid used in the survey are shown in Table 1. Accordingly, the total number of scenarios that we created to assign each respondent amounted to 25. Each respondent answered only one version, to eliminate the influences of scenario ordering.

In our double-bounded dichotomous choice format, after the respondent says “yes” or “no” in regard to the first bid, he/she is additionally asked 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 question with the higher (lower) bid of 500 (50) yen.

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)

2.2. Random Utility Model

The indirect utility for respondent j can be written as

$$u_{ij} = v_{ij} + \varepsilon_{ij} \,, \qquad (1)$$

where v_{ij} is the deterministic part and ε_{ij} is a random error term. Subscript i represents the choice made by the respondent, and it becomes 0 when he/she chooses the status quo and becomes 1 when he/she donates to a GPF.

Assuming the linear utility function, we can express the deterministic term v_j by a vector of the respondents' characteristics z_j, including the predicted participation rate exogenously given in the CV scenario, and can write it as follows (Haab and McConnell 2002).

$$v_{0j}(y_j) = \alpha_{0j} z_j + \beta_{0j} y_j \qquad (2)$$

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

$$v_{1j}(y_j - t_j) = \alpha_{1j} z_j + \beta_{1j}(y_j - t_j)\,. \tag{3}$$

Accordingly, the probability that the respondent will answer "yes" in the single-bounded format is written as

$$\begin{aligned}\Pr(yes) &= \Pr\left(v_{1j}(y_j - t_j) + \varepsilon_{1j} \geq v_{0j}(y_j) + \varepsilon_{0j}\right)\\ &= \Pr\left((\alpha_{1j} - \alpha_{0j})z_j + (\beta_{1j} - \beta_{0j})y_j - \beta_{1j}t_j \geq -(\varepsilon_{1j} - \varepsilon_{0j})\right)\\ &= \Pr\left(-dv_j \leq \varepsilon_j\right) = 1 - \Pr\left(\varepsilon_j \leq -dv_j\right)\end{aligned} \tag{4}$$

where $dv_j \equiv (\alpha_{1j} - \alpha_{0j})z_j + (\beta_{1j} - \beta_{0j})z_j - \beta_{1j}t_j$, and $\varepsilon_j \equiv \varepsilon_{1j} - \varepsilon_{0j}$. ε_{1j} and ε_{0j} are assumed as identically and independently distributed with a mean of zero.

The double-bounded CV starts with an initial bid t_j^F. If the respondent answers "yes", he/she faces a follow-up bid $t_j^U > t_j^F$; if he/she answers "no", he/she faces a follow-up bid $t_j^L < t_j^F$. 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

$$\begin{aligned}\Pr(yes, yes) &= \Pr\left(dv_j^U + \varepsilon_j > 0\right) \equiv 1 - G(dv_j^U;\theta)\\ \Pr(yes, no) &= \Pr\left(dv_j^U + \varepsilon_j \leq 0 \leq dv_j^F + \varepsilon_j\right) \equiv G(dv_j^U;\theta) - G(dv_j^F;\theta)\\ \Pr(no, yes) &= \Pr\left(dv_j^F + \varepsilon_j \leq 0 \leq dv_j^L + \varepsilon_j\right) \equiv G(dv_j^F;\theta) - G(dv_j^L;\theta)\\ \Pr(no, no) &= \Pr\left(dv_j^L + \varepsilon_j \leq 0\right) \equiv G(dv_j^L;\theta)\end{aligned} \tag{5}$$

where $\theta \equiv (\alpha_j,\ \beta_j)$, $\alpha_j \equiv (\alpha_{1j} - \alpha_{0j})$, and $\beta_j \equiv (\beta_{1j} - \beta_{0j})$. We assume that $G(\bullet;\theta)$ is a logistic cumulative distribution function. The double-bounded model can increase statistical efficiency over a single-bounded dichotomous choice CV (Hanemann et al. 1991).

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

$$\ln L(\theta) = \sum_{j=1}^{N} \Big\{ d_j^{YY} \ln\left[1 - G(dv^U;\theta)\right] + d_j^{YN} \ln\left[G(dv^U;\theta) - G(dv^F;\theta)\right] + d_j^{NY} \ln\left[G(dv^F;\theta) - G(dv^L;\theta)\right] + d_j^{NN} \ln\left[G(dv^L;\theta)\right] \Big\} \tag{6}$$

where $d_j^{YY} = 1$ if respondent *j* answers (yes, yes) and 0 otherwise, $d_j^{YN} = 1$ if respondent *j* answers (yes, no) and 0 otherwise, $d_j^{NY} =$ 1 if respondent *j* answers (no, yes) and 0 otherwise, $d_j^{NN} =$ 1 if respondent *j* answers (no, no) and 0 otherwise. Using the estimated parameters, the mean willingness-to-donate (WTD) for the logit model is calculated by

$$WTD_{mean} \equiv \int_0^{t_{\max}} \frac{1}{1+e^{-dv}} dt\ . \tag{7}$$

where t_{MAX} is the maximum bid amount (10,000 yen/month in our CV scenario). WTD is the maximum amount that the person is willing to pay if he/she can free-ride on other people's contributions (Menges et al. 2005).

2.3. Data

The data was collected through an Internet survey conducted by a research company; 1,281 people aged between 20 and 69 responded to the questionnaire. A summary of the data is given in Table 2. To investigate the threshold model, each person is assigned a questionnaire that differs with respect to the predicted participation rate (*PRATE*). Given that *PRATE*, the respondents were to answer yes/no as to whether they are willing to donate to a GPF. We assume that a donation is able to reduce the emission of carbon dioxide by 3.6 tons per year.

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
-	Respondent's own expected participation rate (%)	20.13	16.70	0	100
BIAS	*PRATE* minus respondent's own expectation	27.14	29.15	-69	90
CURRENT	Respondent's own guesses at current level of green power generation 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
INCOME	Annual household income in 10 thousands yen	674.28	425.18	150	2500
AGE	Respondent's age	47.28	12.77	20	69
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.

The respondents' expectations (mean is 20.13%) are generally higher than the actual number (between 0.02% and 0.11%). Household income was elicited in categories, with income levels coded at the midpoints of the income ranges. Those samples that had some data missing were omitted in the analysis, so that the number of samples used in our analysis was 1,110.

2.4. New Ecological Paradigm Scale and Altruism Scale

Along with the psychological influences investigated by the predicted participation rate, we considered two internal moral motivations for donating to green energy. We included in our analysis 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 scales. The

NEP scale is an instrument that has been developed in the social and behavioral sciences for measuring concern about the environment (Dunlap et al., 2000). An altruism scale was constructed by Clark et al. (2003), and it relates to 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 a willingness to pay for green electricity (Clark et al. 2003; Kotchen and Moore 2007; Ek and Söderholm, 2008). Although the Cronbach's alpha of each scale shows that both scales did not pass the test of internal consistency, we combine the items into a summated scale for ease of analysis. These statistics are shown in Table 3.

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

	Correlation
NEP scale	
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 insure 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	
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 in life.	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 result for the double-bounded logit model is shown in Table 4. Model 1 considers income, household size, gender, and age as sociodemographic characteristics of respondents. After the testing of several combinations of cross terms between income and individual attributes, Model 2 has a smaller AIC and BIC. The coefficient for income is significant and has the expected sign in this model.

The negative coefficients of *PRICE* mean that the marginal utility of the expense is negative as expected. While the coefficients of *PRATE* are significantly positive, the squared terms of *PRATE* are not significant. This result suggests that decisions to donate depend on others' behavior and that the marginal utility increases constantly with others' participation rate.

The coefficients for the *BIAS* variable are negative and significant. When the difference between the assigned participation rate in the scenario and the respondent's own prediction is large, the credibility of the CV scenario decreases. Thus, the *BIAS* variable can be interpreted as representing the bias created by an incredible hypothetical participation rate. Wiser (2007) shows that a respondent's expectation of others' participation has a significantly positive impact on the willingness to pay for renewable energy. Our analysis assigns a predicted participation rate and controls the impact of self-prediction by this variable. The result indicates that when the respondent's expectation exceeds the assigned prediction, the probability of agreeing to the suggested donation to a GPF decreases.

The coefficient of *CURRENT* is positive, but not significant. This variable represents guesses by respondents regarding the percentage of green electricity to total power generation in Japan. We find that the amount of current green electricity predicted by a respondent does not influence donation behavior significantly.

Table 4. Estimation results for double-bounded logit models

	Model 1		Model 2	
Variable	Coefficient	Standard Error	Coefficient	Standard Error
CONSTANT	-4.32070***	0.74243	-4.82093***	0.76112
PRICE	-0.00122***	0.00004	-0.00122***	0.00004
PRATE	0.03174***	0.00965	0.03117***	0.00960
$PRATE^2$	-0.00004	0.00009	-0.00004	0.00009
BIAS	-0.03370***	0.00479	-0.03348***	0.00477
CURRENT	0.00593	0.02017	0.00883	0.01973
INCOME	0.00026	0.00019	0.00115***	0.00043
HSIZE	-0.04326	0.06020	0.14630	0.10235
GENDER	0.23443	0.15371	0.23396	0.15394
AGE	0.00522	0.00592		
OVER60			0.31108*	0.17597
HSIZE·INCOME			-0.00026**	0.00012
NEP	0.09315***	0.02959	0.09673***	0.02959
ALTRUISM	0.10768***	0.03001	0.10850***	0.03024
Log-likelihood	-1148.19		-1143.73	
AIC	2320.38		2313.46	
BIC	2380.53		2378.62	
N	1110		1110	

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

While the coefficients of *AGE* and *GENDER* in Model 1 and *GENDER* in Model 2 are not significant, the coefficients of *OVER60* and *HSIZE·INCOME* are significant. The negative significance found for the coefficient of *HSIZE·INCOME* shows that the higher income of individuals with a higher household size diminishes the probability of them agreeing to the suggested amount. The positive and significant results of *NEP* and *ALTRUISM* show that respondents who have higher values for these indices tend to agree to donate.

The mean of WTD is 567.98 yen per month when calculated using the mean value as the exogenous variable in Model 2. In the next section, we combine the economic model estimated as Model 2 and a threshold model in social psychology in order to analyze the possibility of a dynamic diffusion of a GPF.

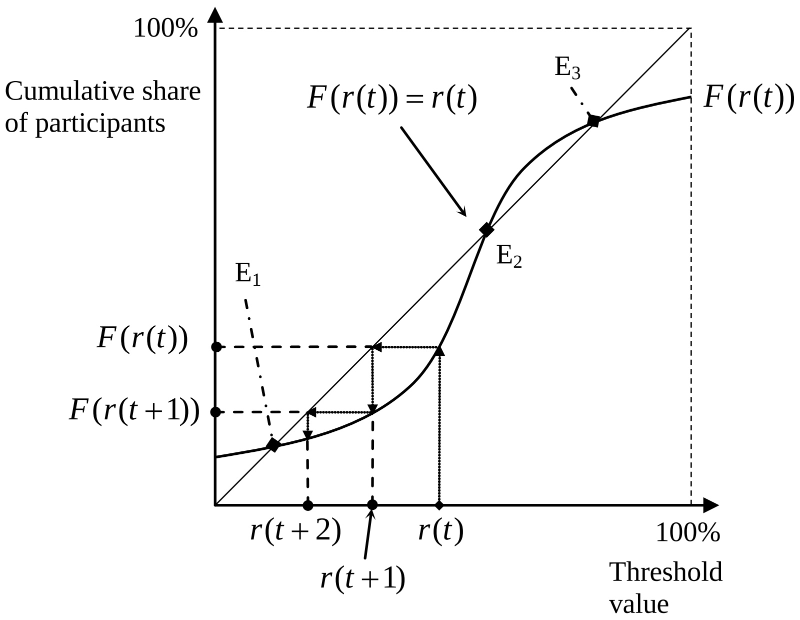
3.2. Simulations by threshold models

We begin by simulating dynamic changes in the participation rate using the coefficients of the estimated models. In accordance with the discussion by Granovetter (1978), the concept of threshold models can be explained by Figure 1. Let us denote threshold values by x and the cumulative distribution function (cdf) by F(x). The cdf indicates the proportion of the population having a threshold less than or equal to x. The proportion of the population who have participated in a donation by time t is denoted as r(t). Then the proportion of those who are going to donate at t+1 is described by r(t+1)=F[r(t)].

Since r(t+1) = F[r(t)], we can find the proportion of those donating 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 reaching the point E_1 where the cdf crosses the 45º line. This point is an equilibrium denoted by the equation

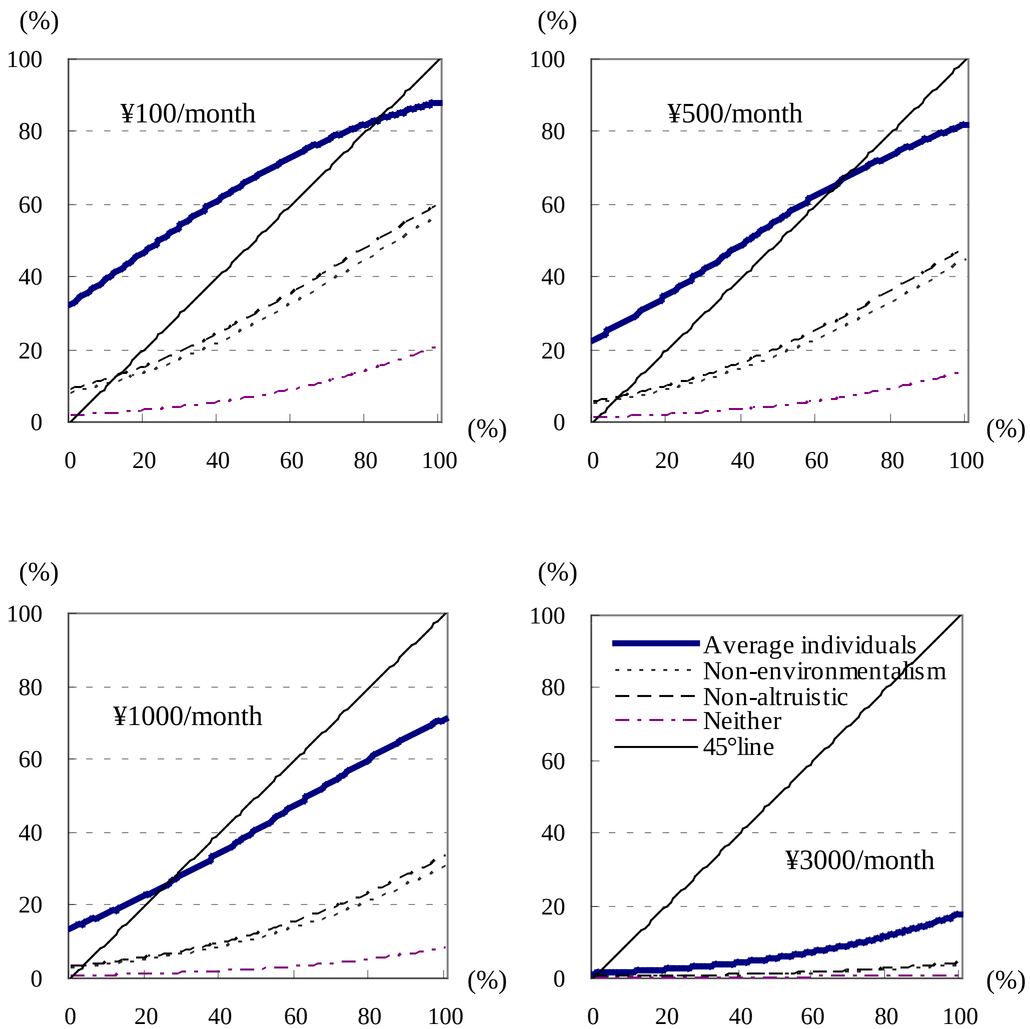
F(r)=r. Figure 1 has two possible equilibria. If the share of participants in the beginning is below E_2, equilibrium is reached at E_1. If the share at the initial period is given above E_2, the final equilibrium becomes E_3.

Figure 1. Threshold model



Since the cumulative share of participants equals 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) with various predicted participation rates. Simulated threshold models for different suggested amounts of donation are shown in Figure 2. The cdf intersects with the 45º line once in all models, so that we have a unique equilibrium point regardless of the initial condition. The cumulative share of participants at dynamic equilibrium decreases for higher suggested amounts of donation. The share of participants at equilibrium is 83.22% when the suggested amount is 100 yen, then decreases to 66.46%, 25.88% and 1.42% when the amount increases to 500, 1,000, and 3,000 yen. This result indicates that the amount of donation asked can harm the process of dynamic diffusion. Among the four suggested amounts, the highest expected value of donation at equilibrium is 332.3 in the case of 500 yen.

Figure 2: Simulated threshold model



Note: Simulations are based on Model 2 in Table 4. We calculate the cumulative distribution functions by assuming mean values for all variables (except the *BIAS* variable, which takes zero). For the case of “Non-environmentalism”, “Non-altruistic”, “Neither”, we give zero values to *NEP*, *ALTRUISM*, and both variables.

The equilibrium is also influenced by the existence of environmental concern and altruistic motivation. We show in Figure 2 the cdfs will shift downward when the score for the NEP scale, the altruism scale, or both of them become zero. On average, the existence of these motivations increases the equilibrium participation rate by 43.38%. This result suggests that a policy to enhance them has important implications for the diffusion of donating behavior.

4. Conclusions and remarks

Our main findings can be summarized as follows. First, a decision to donate to a GPF program depends on the overall participation rate. Second, a higher predicted participation rate attracts those who have not participated in green electricity programs. Third, environmentalism and an altruistic motivation can play a role in driving the equilibrium participation rate higher. Fourth, the impact of the predicted participation rate at equilibrium depends on the bid amount.

Our analysis by threshold models shows that the expected participation rate influences individual decisions to donate and the resulting dynamic equilibrium of a GPF program. The dynamic equilibrium also depends on the impact on people's motivation of their environmental concern and altruistic views. On the other hand, our analysis does not directly address why people follow other people's behavior. Ek and Söderholm (2008) suggest that the choice of a green electricity company is determined both by economic factors and by the presence of social norms. Investigation of the motivation for herd behavior is a topic needing further study.

Our results show that the higher the suggested amount of donation, the lower the participation rate in equilibrium. Fund raisers should take into account this effect when setting the suggested amount to be donated, if they wish to maximize the total amounts donated, rather than the participation rate. Further developments from empirical studies based on threshold models would be important for examining the successfulness of voluntary contributions for expanding green energy.

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Appendix:

“Questionnaire about Environmentally-Friendly Energy”

The following situation is hypothetical. It has absolutely nothing to do with the operations of the electric company with which you are registered. It is hypothetical, but for the purposes of this survey please respond after carefully imagining if “these events were to actually occur.”
Please imagine that the electric company you are registered with is attempting to further promote the spread of clean power generation methods such as wind power and solar power.

Since these new power generation methods have higher costs in comparison to thermal power generation and nuclear power generation, there has been little progress in making them widespread.

Therefore, the electric company has established the “Natural Energy Fund” and will request a donation of XX yen each month from each customer. The monthly donation will be collected by adding the amount to be donated to each customer’s monthly electricity bill.

The electric company will meet the total donated amount with its own donation of that same amount, and use it toward the construction costs of clean power generation facilities for municipal offices and elementary schools, etc.

Thanks to your donation, 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,_____percentage of your electricity company’s customers would participate in this donation system.

Q1. Do you think you would want to give a donation of ___X___yen each month over the one year period between April 2009 and March 2010 (single answer)?

What if the donation was for ___Y___yen each month?