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Conjoint analysis of Japanese households' energy-saving behavior after the earthquake: the role of the preferences for renewable energy

Shin Kinoshita

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Faculty of Economics,
Ryukoku University

67 Tsukamoto-cho, Fukakusa, Fushimi-ku,
Kyoto, Japan
612-8577

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Abstract

Energy savings among households are the important energy problems in Japan. After the Great East Japan earthquake in March 2011, nuclear power plants were forced to cease operations. We Japanese have worried about electricity shortages and has been requested to save electricity usage in case of a sudden outage.

This paper analyzes the conditions that households save electricity usage by a conjoint analysis. I presented three energy-saving plans with several attributes to households. As the conditions, an annual electricity bill, CO_2 emissions, a stable electricity supply and energy sources which generate electricity are considered. Especially, I focus on the relation between preferences for energy sources and energy-saving behavior. If renewable energy sources such as solar and wind power are used in the electricity generation, households who support renewable energy might save electricity usage. I used a random parameter logit model and a nested logit model for estimation.

The promotion of renewable energy and energy savings should be solved as a Japan's official energy policy. If households that prefer renewable energy tend to reduce their electricity usage, the promotion of renewable energy and energy savings could be solved simultaneously.

The estimation results indicated that households largely respond to an annual electricity bill. In addition, they also respond to CO_2 emissions and a stable electricity supply to save electricity usage. If nuclear power is used in the electricity generation, they don't save electricity usage. If renewable energy is provided as a main energy source, they tend to save electricity usage. Thus, the use of renewable energy gives incentives for households to save electricity usage. It is possible to promote energy savings and renewable energy simultaneously by utilizing their interest in renewable energy.

Key words: energy savings, conjoint analysis, renewable energy
JEL Classification : C25, L51, L94, L95, Q28

[1] Faculty of Economics, Ryukoku University
67 Tsukamoto-cho, Fukakusa, Fushimi-ku, Kyoto, Japan, 612-8577
skinoshita@econ.ryukoku.ac.jp, 81 (075) 645-8517

Conjoint analysis of Japanese households' energy-saving behavior after the earthquake: the role of the preferences for renewable energy [2]

1. Introduction

Energy savings among households are the important energy problems in Japan. After the Great East Japan earthquake in March 2011, due to the serious accidents in nuclear power plants in Fukushima prefecture, nuclear power plants were forced to cease operations. People who live in the Kanto-area around Tokyo experienced planned power outages because nuclear power plants stopped operation. We Japanese have worried about electricity shortages especially at times of peak of demand in summer and winter and has been requested to save electricity usage in case of sudden outages. Electricity shortages will continue until nuclear power plants resume operation. To avoid electricity shortages, energy savings are needed. Climate change is also one of the reasons of energy saving. If we reduce electricity usage, we reduce global greenhouse gases (GHG) such as CO_2.

I present three energy-saving plans with several attributes to households and analyze the conditions that households save electricity usage by a conjoint analysis. Households choose the most desirable energy-saving plan. As the conditions, an annual electricity bill, CO_2 emissions, a stable electricity supply and energy sources are considered. An annual electricity bill is a monetary factor, while CO_2 emissions, a stable electricity supply and energy sources are non-monetary factors. If an annual electricity bill is reduced, households may choose the energy-saving plan which saves more electricity usage. Households might save more electricity usage to reduce CO_2 emissions. If a stable electricity supply is secured, they will save more electricity usage.

Especially, I focus on the role of energy sources which are used in generation of electricity and the relation with their preferences for renewable energy and energy-saving behavior. If renewable energy sources such as solar and wind power are used as a main energy source, households might save more electricity usage. Households who support renewable energy might save more electricity usage.

To promote renewable energy is another important energy problem. After the earthquake, Japan has relied on fossil fuels such as oil, natural gas (LNG) and coal. However, fossil fuels emit GHG such as CO_2. Instead of nuclear power and fossil fuels, renewable energy should be promoted as alternatives. To promote renewable energy, the Japanese government introduced a feed-in-tariff system in July 2012. Moreover, the Japanese government published the desirable composition of energy sources called the "best-mix" in fiscal year 2030 as an energy plan[3]. This plan states that the share of renewable energy will be raised to around 22–24%. However, despite the feed-in-tariff system, the share of renewable energy except water power is only 3.2%[4].

Accordingly, the promotion of renewable energy and energy savings should be Japan's official energy policy. To promote renewable energy, the penetration of photovoltaic panels and wind generators among households is essential. If we find that households who support renewable energy tend to save more electricity usage, these two problems could be solved simultaneously.

Kinoshita (2016) used a conjoint analysis to reveal a high willingness to pay (WTP) for renewable energy sources such as solar and wind power. Kinoshita (2017) then clarified the factors that lead households to reduce electricity usage. One of the factors was energy sources used in electricity generation. However, I couldn't find the clear relation between energy sources and saving behavior. The present paper revises the previous work and makes clear the relation between households' preference for renewable energy sources and their energy-saving behavior as an extension of those studies.

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[3] The Agency for Natural Resources and Energy in the Ministry of Economy, Trade and Industry

[4] The Federation of Electric Power Companies of Japan

In the short-term, energy savings can help avoid the tightness of electricity demand and supply, whereas in the long-term energy savings can help alleviate global warming and long-term energy-shortage problems. In this paper the long-term energy savings are discussed.

This paper is consisted of the following section. In section 2, related literature is introduced. In section 3, a conjoint analysis and profiles are illustrated. In section 4, econometric methods are explained. In section 5, estimation results are presented. In section 6, conclusions and policy implications are discussed.

2. Related literature

I analyze energy-saving behavior of Japanese households after the earthquake. Specifically, I focus on the relation with their preferences for renewable energy. Households who support renewable energy might save more electricity usage. We find several studies about energy savings in Japan after the earthquake.

Tanaka and Ida (2013) is the first study which analyzed Japanese households' electricity-saving behavior after the earthquake by a conjoint analysis. They asked households the settings of air conditioners, refrigerator, and standby power of electrical appliances in the areas of the Tokyo Electric Power Company (TEPCO) and the Kansai Electric Power Company (KEPCO). They found that in both areas households tend to save electricity usage after the earthquake and in TEPCO area households save more electricity usage because they experienced the planned outages. However, they don't mention non-monetary factors such as CO_2 emissions and especially the relation between energy savings and renewable energy.

Some studies examined energy-saving behavior of Japanese households by a field experiment. Mizobuchi and Takeuchi (2012) analyzed the effects of economic incentives on energy-saving behavior in Matsuyama. They found that only 34 % of participants reduced their electricity usage. Mizobuchi and Takeuchi (2013) considered non-monetary factors as well as monetary factors. They found that monetary factors have more effects on households' energy savings than non-monetary factors. Ito et al. (2015) also noted non-monetary factors which they called moral suasion. They also found that households in the economic incentive group saved more electricity usage than those in the moral suasion group. These studies note non-monetary factors, but don't note the effects of energy sources on energy-saving behavior.

These studies were conducted after the earthquake in Japan. Some studies emphasize the social norms in energy-saving analysis. The social norms are like non-monetary factors. Poortinga et al. (2003) found the effects of social and psychological factors on energy savings by a conjoint analysis. Allcot (2011) is also one of the famous studies about the social norms in energy savings. Non-price intervention has the same impact as raised prices on electricity savings of households from a field experiment.

Lastly, I introduce some studies about households' preferences for renewable energy. Morita and Managi (2013) used a conjoint analysis to estimate preferences for energy sources, particularly renewables, after the earthquake. They estimated the Willingness to Pay (WTP) for each energy source and suggested policy implications vis-à-vis the Japanese government's energy mix. They obtained negative WTP for nuclear power, but positive WTP for renewable energy sources such as solar and wind power. Murakami et al. (2015) estimated consumers' WTP for renewable energy and nuclear power in the US and Japan. They used a conjoint analysis and found that consumers in both countries showed negative preferences for nuclear power and positive preferences for renewable energy.

I analyze the conditions that households save electricity usage. Especially, I focus on the role of renewable energy as an energy source used in electricity generation. Households who support renewable energy might save more electricity usage. There are many studies about energy savings and preferences for renewable energy. However, they don't mention the relation though these two problems are essential in Japan.

3. Conjoint analysis

I use a conjoint analysis to analyze households' energy-saving behavior.[5] A conjoint analysis is one of the stated preference methods (SPM) to analyze the individual choice for several alternatives under future and hypothetical conditions. Individual preferences can be estimated for hypothetical goods or services which have several attributes. We present several alternatives and respondents choose the most desirable alternative of the hypothetical goods or services. A conjoint analysis is one of the choice experiments.

In this paper, three alternatives are presented to households and they choose the most desirable one. Sometimes, the goods or services have not yet prevailed, and this method is often used in marketing research. I analyze households' energy-saving behavior under hypothetical conditions wherein an annual electricity bill changes as an example. In a conjoint analysis, households are presented with goods or services, each of which has several attributes. The researcher decides the number of attributes and their levels to make profiles. A profile that has few attributes is not enough to describe a good object of study, but a profile with too many attributes makes it difficult for respondents to choose among options. In general, five or six attributes are suitable. After attributes and their levels are decided, their profiles are compiled. However, if all the combinations of attributes and levels are adopted, the patterns are too many and strong correlation between some attributes is caused, which is called multicollinearity. To avoid these problems, profiles are created by the orthogonal planning method. From various cards that we obtain through the orthogonal planning method, selecting cards and their combinations, profiles are made after deleting unrealistic and dominant cards. I used *SPSS* conjoint version 17.0 for the orthogonal planning.

Contingent Valuation Method (CVM) is another popular stated preference method, but it is not a choice experiment. CVM can be used to evaluate users' valuation of non-marketable targets such as forests and beaches. CVM evaluates the value of one target and doesn't evaluate the value of each attribute.

I presented the following three alternatives to households in the questionnaire.

Alternative 1: Energy-Saving Plan A: keep temperature at 26℃ in summer and 18℃ in winter (Households don't save electricity usage).
Alternative 2: Energy-Saving Plan B: keep temperature at 28℃ in summer and 16℃ in winter (Households slightly save electricity usage.).
Alternative 3: Energy-Saving Plan C: keep temperature at 30℃ in summer and 14℃ in winter (Households substantially save electricity usage.).

Households choose the most desirable alternative. They use an air conditioner. Temperatures in their room is used as examples to allow respondents to visualize clearly the trade-off inherent in each scenario. In alternative 1, they might feel more comfortable, but they don't save electricity usage. In alternative 2, they slightly save electricity usage, but they feel less comfortable at the trade-off of experiencing less moderate temperatures. In alternative 3, they save a great deal of electricity usage at the cost of increased discomfort. These alternatives have several attributes and conditions whose levels are changeable. As the conditions, an annual electricity bill, CO_2 emissions, a stable electricity supply, and energy sources which are used in electricity generation are included. These attributes and their levels will now be discussed.

1. Annual electricity bill

When households save electricity usage, they can save money for electricity compared with

[5] I refer to Louviere, Hensher and Swait (2000), Kuriyama and Shoji (2005), Tsuge, Kuriyama and Mitani (2011), and Kuriyama, Tsuge and Shoji (2013) for a conjoint analysis.

current payments. The levels are −30%, −20%, −10%, 0 (unchanged), +10%, and +20%. The levels will change under the degrees of saving and some conditions. If households save more electricity usage, they can save more money. If households don't save electricity usage in the case that alternative 1 should be chosen, an annual electricity bill may rise under some conditions. If nuclear power is used as a main energy source, an annual electricity bill might be reduced even if households don't save electricity usage. If fossil fuels are used, sometimes an annual electricity bill might be higher through rising fuel prices. If renewable energy is used, an annual electricity bill might be higher through the feed-in-tariff system. An annual electricity bill is a monetary factor. "Annual" electricity bill is adopted so that households can imagine long-term electricity savings.

2. CO_2 emissions

Some households save electricity usage to reduce CO_2 emissions. If households are interested in helping combat global warming, they might save more electricity usage to reduce CO_2 emissions. CO_2 emissions are non-monetary factors. The reduction levels are −20%, −10%, 0% (unchanged), and +10%. If households don't save electricity usage or fossil fuels are used as a main energy source, CO_2 emissions may increase.

3. Stable electricity supply

When electricity is supplied without interruption, no outages occur in a year. When electricity isn't stable, short-term outages may occur a few times a year, or lights in their house may become dimmer. A dummy variable is used which equals 1 for no outages and is 0 otherwise. If renewable energy is used, electricity-supply interruptions may arise due to weather conditions. If households don't save electricity usage, it may cause regular interruptions due to planned outages by electric power companies stemming from electricity shortages.

4. Main energy sources

Households use electricity generated by a main energy source. The main energy sources which are used in electricity generation is following: nuclear power, fossil fuel such as LNG, solar power, and wind power. The main energy source has the highest share in the composition of energy sources. The share is assumed more than 50%. Households use electricity generated by each energy source from an electric power and gas company. A dummy variable is used for each energy source where fossil fuels are the base category. Households might change their electricity-saving behavior by energy sources.

Table 1 summarizes the levels of each variable.

Table 1 Levels of each variable

Variables	Level
Annual Electricity bill	-30%, -20%, -10%, 0 (unchanged), +10%, and +20%
CO_2 emissions	-20%, -10%, 0% (unchanged) and +10%
Stable electricity supply	Yes (1), no (0)
Energy sources	nuclear power, fossil fuel (LNG), solar power, and wind power

Respondents were informed of the questionnaire's purposes to facilitate data collection. Nuclear power plants ceased operation after the earthquake but the plans to start them again are difficult to implement. More use of fossil fuels such as LNG, coal and oil, which emit CO_2, makes it difficult to avoid global warming. In these situations, renewable energy sources such as solar and wind power should be promoted urgently. At the same time, households need to reduce electricity usage.

Through the orthogonal planning method, I made profiles after deleting unrealistic and dominant cards. One of the examples of unrealistic cards is that CO_2 emissions increase even though nuclear power or renewable energy is used. One of the examples of dominant cards is that an electricity bill is reduced even if households don't save electricity usage and the main energy source is renewable energy. Table 2 presents an example of profile.

Table 2 Example of profile

Attribute	Alternative 1 （don't save）	Alternative 2 （save a little）	Alternative 3 （save a lot）
	Set temperature at 26℃ in summer and 18℃ in winter	Set temperature at 28℃ in summer and 16℃ in winter	Set temperature at 30℃ in summer and 14℃ in winter
Annual electricity bill (JPY)	-10%	-30%	-10%
CO_2 emissions	unchanged	-10%	-20%
Stability	stable	stable	stable
Energy source	nuclear	LNG	wind

Households choose the most desirable alternative. They answer with respect to 10 choice questions. Each question has various levels of attributes. The data were collected via a web-based questionnaire, utilizing the services of the Rakuten Research Company. The sample size is 750 households in Kanto[6], Kansai[7], and Chukyo[8] areas which are three major urban areas in Japan. In Kanto area households purchase electricity from the Tokyo electric power company (TEPCO). TEPCO has some nuclear power plants. Households in Kanto area experienced planned outages after the earthquake. In Kansai area households purchase electricity from the Kansai electric power company (KEPCO). KEPCO also has some nuclear power plants in Fukui prefecture. Households in Kansai area didn't experience planned outages but were requested to save electricity usage because the nuclear power plants stopped operation. In Chukyo area households purchase electricity from the Chubu electric power company (CEPCO). CEPCO has the Hamaoka nuclear power plant. CEPCO doesn't largely depend on nuclear power compared with TEPCO and KEPCO. The three areas are different in the dependence on nuclear power and the experiences of planned outages, thus are also different in households' behavior toward energy savings. The sample is weighted by each area's population. Respondents' age is under 59 because we are interested in long-term energy savings. Data were collected in February 2017. Table 3 shows the socio-demographic attributes of sample households. Respondents who are unemployed and whose income is less than 2 million JPY are more observed than the population.

Table 3 Socio-demographic attributes

		Number	%
	Total	750	100
Occupation	Employed	578	77.1
	Unemployed	172	22.9
Household income (thousand JPY)	Less than 2,000	205	27.3
	2,000-3,990	162	21.6
	4,000-5,990	168	22.4
	6,000-7,990	91	12.1
	8,000-9,990	64	8.5
	More than 10,000	60	8
Educational background	Junior high school, high school	199	26.5

[6] Tokyo, Chiba, Kanagawa and Saitama prefecture
[7] Osaka, Kyoto, Hyogo, Shiga and Nara prefecture
[8] Aichi, Gifu and Mie prefecture

	Technical school, junior college	177	23.6
	University, graduate school	374	49.9
Family composition	Single	163	21.7
	Couple	160	21.3
	Three	189	25.2
	Four	164	21.9
	Five	51	6.8
	More than six	23	3.1
Dwelling type	Detached house (including two households house)	348	46.4
	Collective housing (condominium, apartment, housing complex etc.)	374	49.9
	company housing, dormitory housing etc.	28	3.7
Living area	Kanto	435	58
	Chukyo	114	15.2
	Kansai	201	26.8
Sex	Male	382	50.9
	Female	368	49.1
Age (years old)	20-29	154	20.5
	30-39	192	25.6
	40-49	227	30.3
	50-59	177	23.6
	Average	40.57	
	Minimum	20	
	Maximum	59	

In the questionnaire, I surveyed households' opinions and perceptions about energy problems. 54.7% households feel that an electricity bill has become higher after the earthquake. 66.1% save electricity usage after the earthquake. 90.8% think they should reduce global greenhouse gases. On the most desirable future energy source, 39.2% think solar power is the most desirable energy source. Only 7.5% think wind power is the most desirable one, but 20.9% think it is second desirable one. On the other hand, only 17.2% think nuclear power is the most desirable energy source. 11.9% think LNG is the most desirable one. I also surveyed households' opinions and perceptions of energy-saving appliances. 38.9% have energy-saving air conditioners and 32.5% have energy-saving refrigerators. 50.7% aren't interested in solar panels and 67.7% aren't interested in a wind power generator.

4. Econometric analysis

4.1 Random parameter logit model

In a choice experiment, the dependent variable is discrete. To estimate the choice model, therefore, a discrete choice econometric model should be used. A conditional logit model is a popular model in this context. However, this model assumes an Independent and Identical Distribution (IID), and this assumption derives from the Independence of Irrelevant Alternatives (IIA). This assumption is restricted and easily violated in many cases. Consequently, a random parameter logit model (mixed logit model) is used as a general discrete choice econometric model. This model allows the random variation of individual preferences, unrestricted substitution patterns, and correlation among unobserved factors over time.[9]

A random parameter logit model assumes that each parameter has a specific distribution. The utility is specified as

$$U_{nj} = \alpha' x_{nj} + \beta_n' z_{nj} + \varepsilon_{nj}$$

This function specifies that individual *n* chooses alternative *j*, where α is a non-random parameter and $\beta_n$is random parameters that represent the preference of each individual and varies among individuals. In this paper, a constant term and the parameter of an annual electricity bill, which is a price parameter, are non-random parameters. x_{nj} is a variable vector that includes an annual electricity bill. On the other hand, the parameters of CO_2 emissions, a stable electricity supply, and energy sources are random parameters. z_{nj} is a variable vector that includes CO_2 emissions, a stable electricity supply, and energy sources. ε_{nj} is a random error term and has an IID extreme value.

The probability conditional on β_n is

$$L_{ni}(\beta_n) = \frac{\exp(\beta_n' x_{ni})}{\sum_j \exp(\beta_n' x_{nj})}$$

The random parameter logit probability is

$$P_{ni} = \int \left(\frac{\exp(\beta' x_{ni})}{\sum_j \exp(\beta' x_{nj})} \right) f(\beta) d\beta$$

This probability is the unconditional choice probability calculated as the integral of $L_{ni}(\beta_n)$ over all β_n.

The distribution of β_n must be assumed. Usually, a normal, lognormal, or triangular distribution, etc., can be assumed. In this paper, a normal distribution is assumed.

Simulation methods were used for estimation. The simulated probability is

$$\widetilde{P_{ni}} = \frac{1}{R} \sum_{r=1}^{R} L_{ni}(\beta^r)$$

where R is the number of draws. This simulated probability is an unbiased estimator of P_{ni}. The simulated log likelihood (SLL) is

$$SLL = \sum_{n=1}^{N} \sum_{j=1}^{J} d_{nj} \ln \widetilde{P_{nj}}$$

where d_{nj} is an indicator. It equals 1 if individual *n* chooses alternative *j* or is 0 otherwise. SSL was maximized to capture the maximum simulated likelihood estimator. In addition, 100 Halton draws were used for simulation. For estimation, *Limdep NLOGIT 5* was used.

4.2 Nested logit model

In alternative 1, households don’t save electricity usage, while in alternatives 2 and 3, they save electricity usage. When respondents face these alternatives, they first choose to save or not to save electricity usage. Then, if they decide to save, they choose the degrees of savings. Alternatives 2

[9] Train (2003) and Louviere et al. (2000) are referred for the explanation of a random parameter logit model.

and 3 are included in the same category or nest. A nested logit model is applicable. In a nested logit model, the cumulative distribution of error term ε_{nj} is assumed in following formula:

$$\exp(-\sum_{k=1}^{K}(\sum_{j\in B_k} e^{-\varepsilon_{nj}/\lambda_k})^{\lambda_k})$$

This distribution is a kind of generalized extreme value (GEV) distribution, where *K* is the number of nests and *k* is a nest number. Unobservable error term ε_{nj} is correlated among alternatives within a nest and isn't correlated outside a nest. λ_k is a scale parameter that measures the correlation between error terms within a nest *k*. The higher the value, the lower the correlation is. When $\lambda_k = 1$, error terms aren't correlated within the same nest. In a conditional logit model, all scale parameters between alternatives have the same value. The probability that individual n chooses alternative I is

$$P_{ni} = \frac{e^{V_{ni}/\lambda_k}(\sum_{j\in B_k} e^{V_{nj}/\lambda_k})^{\lambda_k - 1}}{\sum_{l=1}^{K}(\sum_{j\in B_l} e^{V_{nj}/\lambda_k})^{\lambda_l}}$$

where V_{ni} is a deterministic term in utility function. The maximum likelihood method was used for estimation. Using this choice probability, a likelihood function is formed, a log-likelihood function is maximized, and estimates are obtained. The choice probability can be written using this formula:

$$P_{ni} = P_{ni|B_k} P_{nB_k}$$

where $P_{ni|B_k}$ is a conditional probability that individual *n* chooses alternative *i* under the condition that individual *n* chooses an alternative within a nest and individual *n* chooses a nest *k*. P_{nB_k} is the probability that individual n chooses an alternative within a nest k. This means that an individual chooses a nest and then chooses an alternative within the nest. P_{ni} is the product of a conditional probability and a marginal probability; these probabilities are written in the following formula:

$$P_{nB_k} = \frac{e^{W_{nk} + \lambda_k I_{nk}}}{\sum_{l=1}^{K} e^{W_{nl} + \lambda_l I_{nl}}}$$

$$P_{ni|B_k} = \frac{e^{Y_{ni}/\lambda_k}}{\sum_{j\in B_k} e^{Y_{ni}/\lambda_k}}$$

where W is a set of variables representing the attributes of a nest and Y is a set of variables representing the attributes of each alternative. I is called an inclusive value (IV) in a nest and is written as follows:

$$I_{nk} = \ln \sum_{j\in B_k} e^{Y_{ni}/\lambda_k}$$

In a nested logit model, IV parameters are estimated. IV is also called a log-sum variable or an expected maximum utility. IV parameters lie between 0 and 1. When all IV parameters are 1, the model is a conditional logit model. When an IV parameter is above 1, the structure of nest isn't suitable. This means that the correlation between alternatives outside the nest is stronger than inside the nest.

In a nested logit model, scale parameters are normalized in upper or elemental nest level to 1. The upper nest level is "save" or "don't save". The elemental nest level is each alternative. Random utility model 1 (RU1) is the model where scale parameters in an elemental nest level are normalized to 1. Random utility model 2 (RU2) is the model where scale parameters in upper nest level are normalized to 1 and scale parameters in an elemental nest level are free. RU2 is used in this paper.

5. Estimation results

In this section, I explain the estimation results and discuss households' energy-saving behavior. Firstly, I show the results of a random parameter model and a nested logit model. Next, I show the results of differences in households' socio-demographic attributes.

5.1 Estimation results

Table 4 expresses the choice number and choice probability for each alternative.

Table 4 Choice probability

	Alternative 1	Alternative 2	Alternative 3	total
Number	1513	4254	1733	7500
Choice probability	0.202	0.567	0.231	1

The choice probability for alternative 2 (save a little) is the highest, whereas the choice probability for alternative 1 (don't save) is the lowest. Households tend to save electricity usage.
In this subsection, the estimation results of a random parameter logit model are explained. Table 5 illustrates the estimation results of a random parameter logit model.

Table 5 Estimation results (random parameter logit model)

Variable	Coefficient	Standard Error	Z value	P value
Random parameters (mean)				
CO_2 emissions	-0.00954	0.00429	-2.22	0.026
Stability	0.76946	0.07451	10.33	0.000
Nuclear	-0.66369	0.09301	-7.14	0.000
Solar	0.56977	0.09425	6.05	0.000
Wind	0.26894	0.08795	3.06	0.002
Non-random parameters				
Annual electricity bill	-0.01197	0.00176	-6.8	0.000
Constant for alt 1	0.64926	0.10105	6.43	0.000
Constant for alt 2	1.82583	0.07126	25.62	0.000
Standard deviation				
CO_2 emissions	0.07935	0.00371	21.38	0.000
Stability	0.16572	0.25612	0.65	0.518
Nuclear	1.88915	0.10476	18.03	0.000
Solar	1.25790	0.09619	13.08	0.000
Wind	0.58279	0.14764	3.95	0.000
Log likelihood	-6297.451			
McFadden R^2	0.236			

The annual electricity bill coefficient has a negative sign and is significant at the 1% level. If an annual electricity bill is reduced, households might choose the energy-saving plan which saves more electricity usage. This finding implies that under the condition that their annual electricity bill can be reduced they might exert their efforts to save more electricity usage. An annual electricity bill is a monetary factor. Households respond significantly to a monetary factor, and it induces their incentives to save electricity usage. The CO_2 emissions coefficient has a negative sign and is significant at the 5% level. To reduce CO_2 emissions, households might save more electricity usage. The coefficient associated with a stable electricity supply has a positive sign and is significant at the 1% significance level. Households value heavily a stable electricity supply in energy saving. If a stable electricity supply is secured, households might save more electricity usage. CO_2 emissions and a stable electricity supply are non-monetary factors. Households also respond to non-monetary factors.

Next is the estimation results of energy sources. Dummy variables for each energy source are used, with fossil fuels as the base category. The nuclear power coefficient has a negative sign and is significant at the 1% level. If the main energy source is nuclear power instead of fossil fuels, households don't save electricity usage. On the other hand, the coefficient associated with renewable energy, which is both solar and wind power, has a positive sign and is significant at the 1% level. If the main energy source is renewable energy instead of fossil fuels, households might choose the energy-saving plan which saves more electricity usage. This finding implies that households might save more electricity usage if renewable energy is used as a main energy source and households who support renewable energy might save more electricity usage. This result indicates that renewable energy and energy savings can be promoted simultaneously.

A random parameter logit model represents the variations in individuals' preferences. The standard deviations of random parameters except a stable electricity supply are significant. Almost all the households need a stable electricity supply. In terms of other variables, some households need them whereas others do need not.

I tried the estimation by a nested logit model because the alternatives have a nest structure. Alternative 1 is "don't save" and alternative 2 and 3 are "save". This choice set has a nest structure where alternative 2 and 3 are within the same category as "save". Households choose "save" or "don't save" at the first stage, and then they choose the degrees of savings at the next stage if they choose "save." Random utility model 2 (RU2) is used where a scale parameter in the upper level whose alternative is "save" or "don't save" is normalized to 1, while a scale parameter in the lower level which is each alternative is free. Table 6 illustrates the estimation results of a nested logit model.

Table 6 Estimation results (nested logit model)

Variable	Coefficient	Standard Error	Z value	P value
Annual electricity bill	-0.0090	0.0017	-5.19	0.000
CO_2 emissions	-0.0095	0.0027	-3.47	0.001
Stability	0.4065	0.0679	5.99	0.000
Nuclear	-0.4038	0.0676	-5.97	0.000
Solar	0.4149	0.1070	3.88	0.000
Wind	0.0863	0.0695	1.24	0.214
Constant for alt 1	0.5395	0.3796	1.42	0.155
Constant for alt 2	1.2935	0.2661	4.86	0.000
IV parameter				
Don't save	1			
Save	1.0388	0.2316	4.49	0.000
Log likelihood	-7285.98			
McFadden R^2	0.221			

The estimation results are almost the same as the results of a random parameter logit model. The IV parameter is significant at 1% level. However, it exceeds 1. It should be between 0 and 1. This result indicates that the nest structure isn’t suitable. This means that substitution between alternatives 1 and 2, or alternatives 1 and 3 is larger than that occurring between alternatives 2 and 3. Households don’t choose between whether to save or not to save, and don’t consider alternative 2 and 3 to be similar even if these alternatives are in the same category.

5.2 Differences in households’ socio-demographic attributes

I asked households about their socio-demographic attributes and perceptions of energy problems in the questionnaire. I examine the differences of energy-saving behavior across households’ socio-demographic attributes and perceptions. I divided the sample into two subsamples to balance the sample size in two subsamples. Table 7 is the list of subsamples. I use a dummy variable for each subsample. I assign 1 or 0 for each subsample. I show the assignment in table 7.

Table 7 List of subsamples

Attributes	Subsamples (dummy variable)	Definition	Sample size
Household income	Low income (0)	Under 4 million JPY	367
	High income (1)	More than 4 million JPY	383
Family composition	Small family (0)	Single and couple family	323
	Big family (1)	Married parents and unmarried children family, and more than two adult generations family	427
Residential type	Detached house (1)	Detached house (two household houses are included)	348
	Collective house (0)	Condominium, apartment, housing complex and a company and dormitory housing	402
Living area	Kanto (1)	Households who live in Kanto area	435
	Chukyo (0)	Households who live in Chukyo area	114
	Kansai (0)	Households who live in Kansai area	201
Age	Younger age (1)	Less than 39 years old (average)	346
	Older age (0)	More than 40 years old	404
Perception of electricity bill	High bill (1)	Households who think electricity bill is higher after the earthquake	410
	Low bill (0)	Households who don't think electricity bill is higher after the earthquake	340
Perception of energy-saving	Save (1)	Households who save electricity usage after the earthquake	496
	Don’t save (0)	Households who don't save electricity usage after the earthquake	254
Desirable energy source	Renewable energy (1)	Households who prefer renewable energy	512
	Non-renewable energy (0)	Households who prefer non-renewable energy	238

I use the cross terms of each independent variable and dummy variable to examine the differences. Table 8 expresses the estimation results. A random parameter logit model is used for estimation.

Table 8 Estimation results with cross terms

	Household income		Family composition		Residential type		Living area	
CO_2 emissions	-0.009		-0.016	***	-0.015	**	-0.002	
Stability	0.792	***	0.557	***	0.712	***	0.618	***
Nuclear	-0.66	***	-0.539	***	-0.607	***	-0.531	***
Solar	0.599	***	0.623	***	0.623	***	0.449	***
Wind	0.36	***	0.192		0.241	**	0.155	
Annual electricity bill	-0.014	***	-0.01	***	-0.014	***	-0.011	***
Cross term								
Annual electricity bill	0.004		-0.003		0.003		-0.001	
CO_2 emissions	-0.001		0.012		0.011		-0.013	
Stability	-0.046		0.373	***	0.127		0.26	**
Nuclear	-0.009		-0.22		-0.123		-0.239	
Solar	-0.058		-0.096		-0.104		0.23	
Wind	-0.181		0.136		0.064		0.191	
Constant for alt 1	0.648	***	0.645	***	0.652	***	0.659	***
Constant for alt 2	1.826	***	1.828	***	1.829	***	1.836	***
McFadden R^2	0.236		0.236		0.236		0.237	
	Age		Perception of electricity bill		Perception of energy-saving		Desirable energy source	
CO_2 emissions	-0.006		-0.013	**	-0.012	*	-0.007	
Stability	0.785	***	0.629	***	0.438	***	0.305	**
Nuclear	-0.786	***	-0.586	***	-0.344	**	-0.143	
Solar	0.719	***	0.329	***	0.126		-0.16	
Wind	0.416	***	0.154		-0.109		-0.434	***
Annual electricity bill	-0.012	***	-0.011	***	-0.005	**	-0.004	
cross term								
Annual electricity bill	-0.0004		-0.002		-0.009	***	-0.012	***
CO_2 emissions	-0.008		0.007		0.007		-0.002	
Stability	-0.03		0.266	**	0.53	***	0.667	***
Nuclear	0.278		-0.144		-0.514	**	-0.744	***
Solar	-0.308	**	0.455	***	0.614	***	1.065	***
Wind	-0.308	**	0.222		0.577	***	1.014	***
Constant for alt 1	0.657	***	0.654	***	0.6	***	0.644	***
Constant for alt 2	1.832	***	1.831	***	1.794	***	1.843	***
McFadden R^2	0.237		0.237		0.238		0.243	

Note) *** 1%, ** 5%, *10% significant level

There is no significant cross term in household income and residential type. We don't observe any differences in household income and residential type. Households who have more family members positively evaluate a stable electricity supply in savings. Households who live in Kanto area also positively evaluate a stable electricity supply. This is because they suffered from outages after the earthquake. They save more electricity usage if a stable electricity supply is secured.

Younger households don't prefer renewable energy of both solar and wind power compared with older households. Younger households don't save electricity usage compared with older households even if the main energy source is renewable energy. Households who think an electricity bill is higher after the earthquake positively evaluate a stable electricity supply and solar power in savings. Households who save more electricity usage after the earthquake evaluate a lower annual electricity bill, a stable electricity supply and solar and wind power in savings. They negatively evaluate nuclear power. They might save more electricity usage if the main energy source is renewable energy, a stable electricity supply is secured, and an annual electricity bill is reduced.

Next, I examine the differences between households who support renewable energy as the most desirable one and who support non-renewable energy. I asked households the most desirable future energy source in the questionnaire. Renewable energy sources include solar, wind, geothermal, biomass and hydraulic power, while non-renewable energy sources include nuclear, coal and natural gas. The aim of this paper is to examine the relation between households' preferences for renewable energy and energy-saving behavior. Households who prefer renewable energy may save more electricity usage. From the estimation results, households who support renewable energy positively evaluate a lower annual electricity bill, a stable electricity supply and renewable energy of both solar and wind power. If the main energy source is renewable energy, households who support renewable energy save more electricity usage. They negatively evaluate nuclear power.

Parameter differences are tested to examine that energy-saving behavior is different or not between two subsamples. For the parameter differences test, the likelihood test and the following test statistic are used.

$$-2[LL(A+B) - (LL(A)+LL(B))]$$

LL(A+B) is the log likelihood which is obtained after estimation by pooling data of two subsamples. LL(A) and LL(B) are the log likelihoods for each subsample. The null hypothesis is that parameters or behavior between two subsamples are equal. The alternative hypothesis is that parameters or behavior are not equal. The test statistic is chi-squared distributed with degrees of freedom equal to the number of parameters. The critical values for 1%, 5% and 10% significance level are respectively 27.69, 22.36 and 19.81 for 13 degrees of freedom. Table 9 expresses the results of the parameter differences test. If the calculated statistic is inside the rejection area, the null hypothesis is rejected. Parameters between two subsamples are, thus, significantly different and households in two subsamples show different energy-saving behavior.

Table 9 Results of the parameter differences test

	test statistics	
Household income	50.136 ***	different
Family composition	22.339 *	different
Residential type	34.652 ***	different
Living area	50.105 ***	different
Age	57.963 ***	different
Perception of electricity bill	22.050 *	different
Perception of energy-saving	92.126 ***	different
Desirable energy source	190.150 ***	different

Note) *** 1%, ** 5%, *10% significant level

In all the socio-demographic attributes and perceptions, households' energy-saving behavior between two subsamples is different. For example, in the questionnaire, three major city areas in

Japan are selected as a sample; Kanto, Kansai and Chukyo area. However, the electric power companies in each area have their different power source composition. Especially, the ratio of nuclear power is different. The Tokyo electric power company in Kanto area has several nuclear power plants in Fukushima and Niigata prefecture. The Kansai electric power company in Kansai area has also several nuclear power plants in Fukui prefecture. But the Chubu electric power company in Chukyo area has only one Hamaoka nuclear power plant and doesn't depend on nuclear power. Moreover, households in Kanto area experienced planned outages after the earthquake. Households in Kansai area didn't experience planned outages but were requested to save electricity usage because the nuclear power plants stopped operation. From these different situations, households' energy-saving behavior might be different.

6. Conclusions and policy implications

I analyzed households' energy-saving behavior in Japan after the earthquake. To avoid energy shortages and the global heating, energy savings among households are urgent and essential. The prevalence of renewable energy such as solar and wind power is also urgent and essential. I analyzed the conditions that households save electricity usage through a conjoint analysis and used a random parameter logit model and a nested logit model for estimation. I included an annual electricity bill as a monetary factor, and CO_2 emissions, a stable electricity supply and main energy sources as non-monetary factors. The estimation results indicated that households largely respond to an annual electricity bill. If an annual electricity bill is reduced, households might save more electricity usage. In addition, regarding non-monetary factors, if CO_2 emissions are reduced and a stable electricity supply is secured, households have incentives to save more electricity usage.

Especially, I focus on the role of energy sources used in the electricity generation when households save electricity usage. I analyze the relation between households' preferences for renewable energy and energy-saving behavior. If the main energy source is renewable energy, households may save more electricity usage. From the estimation results, if the main energy source is nuclear power, they don't choose to save electricity usage, and if the main energy source is renewable energy, they tend to save more electricity usage. If households support renewable energy, they choose an energy-saving plan which uses renewable energy as a main energy source in electricity generation and saves more electricity usage. Thus, renewable energy gives incentives for households to save electricity usage.

The promotion of energy savings and renewable energy are urgent in Japan's energy policy. Households have been shown to highly evaluate renewable energy. It is possible to promote energy savings by appealing to their interests in renewable energy. Our findings indicate that renewable energy and energy savings can be promoted simultaneously. However, electricity generated by solar and wind power depends on weather conditions. Storage batteries are needed to ensure a stable electricity supply.

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