ISSN 1881-6436

Discussion Paper Series

No. 18-03

What is the most desirable energy source in Japan after the earthquake and the deregulation: suggestions through conjoint analysis

Shin Kinoshita

September 2018

Faculty of Economics,

Ryukoku University

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

What is the most desirable energy source in Japan after the earthquake and the deregulation: suggestions through conjoint analysis

Shin Kinoshita[1]

Abstract

Aftermath the great East Japan earthquake on March 11th, 2011, nuclear power plants ceased operations. We depended on fossil fuels after the earthquake. However, fossil fuels increase greenhouse gases emissions. We need other energy sources in place of nuclear power and fossil fuels. Thus, we specifically focus on renewable energy such as solar and wind power as an alternative energy source. We estimate households' preferences for energy sources by conjoint analysis and calculate willingness to pay (WTP) after estimation by random parameter logit model. We find that households negatively evaluate nuclear power, while positively evaluate renewable energy both solar and wind power. Further, the stability of electricity supply is highly evaluated. Their preferences are different across their socio-demographic attributes and perceptions for energy problems. We proposed our future energy supply after the earthquake and the deregulation from our results.

Keywords
conjoint analysis, renewable energy, deregulation of electricity retail sales

JEL classification
C25, L51, L94, L95, Q42

[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

What is the most desirable energy source in Japan after the earthquake and the deregulation: suggestions through conjoint analysis[2]

1. Introduction

Aftermath the great East Japan earthquake in March 2011, Japan has faced drastic energy and environmental changes and many problems. After the earthquake, the Fukushima nuclear facility ceased operation due to serious accidents. Other nuclear power plants in Japan also stopped operation and were subjected to inspections. Though the Sendai nuclear power plant of Kyushu electric power company recommenced operations in 2015, other nuclear power plants haven't been operated yet. We urgently should promote alternative energy sources in place of nuclear power. Since the earthquake, we Japanese have relied on fossil fuels such as natural gas (LNG), oil and coal, importing more fossil fuels. However, fuel prices are too volatile and too vulnerable to exchange rate dynamics. Higher costs are shifted to electricity bill that households pay. Moreover, fossil fuels emit global greenhouse gases (GHG) such as CO_2.

After the earthquake, people who live in Kanto area around Tokyo experienced planned outages because nuclear power plants in Fukushima had ceased operations. Electricity shortage is another serious problem. We have been requested to save electricity usage when electricity demand hits its peak in the summer and winter in case of a sudden outage.

Climate change is also one of the serious problems. After the earthquake, we have relied on fossil fuels which emit CO_2. It is difficult to reduce CO_2 emissions despite the promise of the 1997 Kyoto Protocol to other countries in the world. Japan agreed to reduce the emissions of greenhouse gases by 6% from 2008 to 2012, compared to a 1990 baseline.

Renewable energy such as solar and wind power should be promoted as an alternative energy in place of nuclear and fossil fuels to reduce CO_2 emissions. In July 2012, the Japanese government introduced a feed-in-tariff system to promote renewable energy. All companies which generate electricity by renewable energy can sell their electricity

[2] This study was aided by research funding from Osaka Gas Co. Ltd.

to nine major electric power companies[3]. These major electric power companies are required to purchase electricity from these companies. However, the bid prices are relatively high, particularly solar power tariffs. These high bid prices are then shifted to households via electricity bill. The bid price of solar power as an example is around 20 Japanese Yen (JPY) per 1kWh in 2018 fiscal year[4].

The Japanese government designs the energy plan about the desirable composition of energy sources that we call “best-mix” for the fiscal year 2030. The share of nuclear power will be raised to around 20-22% assuming nuclear power plants recommence operations. This share was only 1%[5] in the fiscal year 2013. The share was 30% in December 2010 before the earthquake. While the share of renewable energy such as solar and wind power will be raised to around 22–24%, from 11% in the fiscal year 2013. The share of fossil fuels such as coal, LNG, and oil will be reduced to 56%, from 87% in 2013.

The deregulation of electricity and gas retail sales is also an important topic. The deregulation started in 2000. In April 2016, the deregulation of electricity retail sales for general households started. In April 2017, the deregulation of gas retail sales for general households started. Now, all consumers can purchase electricity and gas from all suppliers including new entrants. Some suppliers provide electricity and gas by discounted prices if households purchase electricity and gas or telecommunication services at the same supplier.

The environment surrounding energy in Japan has been changing dramatically since the Fukushima disaster. We should discuss our future energy sources. I estimate Japanese households' preferences for energy sources by conjoint analysis. From the households' preferences in terms of willingness to pay (WTP), we discuss the most desirable energy sources and composition as a Japanese energy policy. Especially, I focus on the preferences for renewable energy sources such as solar and wind power and nuclear power. If their WTP for renewable energy sources is positive and substantially large, the policy to promote renewable energy is supported and this means that households accept a little higher priced electricity if it is generated by renewable energy sources. If their WTP for nuclear power is negative and substantially large, we should abolish nuclear power plants. After the deregulation, new suppliers with their

[3] In Japan there are nine major electric power companies; Hokkaido, Tohoku, Tokyo, Chubu, Hokuriku, Kansai, Chugoku, Shikoku and Kyushu electric power companies. These companies have monopoly power in their own operation area.

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

[5] These shares are from the Agency for Natural Resources and Energy in the Ministry of Economy, Trade and Industry.

own services and energy sources start their business. If households highly evaluate renewable energy, suppliers will start to provide electricity generated by renewable energy, and such households might purchase electricity from such suppliers. If households show negative evaluation for nuclear power, they won't purchase electricity from suppliers which use nuclear power for electricity generation, and suppliers will be forced to cease to use nuclear power. The questionnaire was surveyed in August 2014 when three years had passed and before the deregulation for general households. Accordingly, this study could provide useful suggestions for future energy policies from the viewpoint of consumer preferences.

This paper consists of the following sections. In section 2, related studies are introduced. In section 3, conjoint analysis is explained. In section 4, econometric methods are elaborated upon. In section 5, estimation results are delineated. Finally, in section 6, we conclude, with a focus on the policy implications emanating from this study.

2. Related literature

I estimate Japanese households' preferences for energy sources with some attributes by conjoint analysis. Especially, I focus on the preferences for renewable energy sources such as solar and wind power which are the promising future energy sources after the earthquake. In this section, I survey related studies about this topic. Firstly, I introduce studies after the earthquake in Japan.

Morita and Managi (2015) estimated the preferences for energy sources, particularly renewable energy sources, after the earthquake by conjoint analysis. They estimated WTP for each energy source and suggest policy implications vis-à-vis the energy mix of the Japanese government. They obtained negative WTP for nuclear power, while positive WTP for renewable energy which includes solar and wind power. Murakami et al. (2015) estimated the WTP for renewable and nuclear energy among US and Japanese consumers. They used conjoint analysis. They found that consumers in both countries showed negative WTP for nuclear power and positive WTP for renewable energy. They included solar, wind, biomass and geothermal as renewable energy sources and used the ratio of renewable energy. Ida, Takemura, and Sato (2015) found conflicts between nuclear power and electricity prices in Japan where a trade-off can occur between low prices with nuclear or high prices without it by conjoint analysis. However, these studies didn't mention the energy market after the deregulation.

Roe et al. (2001) is one of the first studies about preferences for renewable energy.

They estimated WTP for renewable energy sources such as solar and wind power among consumers in the US. They used hedonic analysis and the price premium as its dependent variable. They found that consumers were willing to pay for renewable energy and reduction of global greenhouse gases such as CO_2. Bordhers, Duke, and Parsons (2007) also estimated WTP for renewable energy among consumers. They adopted conjoint analysis and nested logit model for estimation. At the first stage consumers choose to join a green program or not. At the second stage consumers choose the best program among several green options. They also obtained positive WTP for renewable energy and consumers preferred solar power than other sources. Scarpa and Willis (2010) referred to appliances related with renewable energy. They estimated the preferences of UK households for renewable energy technologies using conjoint analysis. They found that households represented high WTP for micro generation technologies such as solar photovoltaic, micro-wind and so on. However, the value was not so large to cover the higher initial costs. Sundt and Rehdanz (2015) estimated the WTP for renewable energy and analyzed the factors which determined consumers' WTP for renewable energy by a meta-regression analysis where the WTP is the dependent variable. They found many factors which explained the differences in evaluation among each renewable energy. Yoo and Ready (2014) estimated variations in preferences for each renewable energy by using random parameter logit model. They found variations in preferences for solar power.

Sometimes electricity generated by renewable energy is unstable. For households the stability of electricity supply is necessary even though they prefer renewable energy. I mention the stability of electricity supply and also estimate the preferences for the stability. Some papers estimated the preferences for the stability and the cost of outages. Ozbafli and Jenkins (2015) estimated households' WTP for an improved electricity service by contingent valuation (CV) in North Cyprus. On the other hand, Ozbafli and Jenkins (2016) used conjoint analysis. Both papers found that households would accept higher monthly electricity bill to avoid the cost of outages. Kim, Nam, and Cho (2015) estimated households' WTP by contingent valuation (CV) in South Korea. They obtained positive cost of outages from both an unannounced and announced outages. However, they didn't mention the relation with renewable energy.

Compared with previous studies, I estimate households' preferences for energy sources in Japan after they have experienced an unprecedented disaster. As such, this study could provide useful insights vis-à-vis energy policies in countries which frequently experience massive natural disasters. Moreover, I focus on the deregulation of electricity and gas retail sales for general households. After the earthquake and deregulation, we Japanese should discuss our energy sources and its supply system.

3. Conjoint analysis

In this paper, Japanese households' preferences for energy sources are estimated by conjoint analysis[6]. 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, and we can evaluate each attribute by WTP. We present some alternatives and respondents choose one alternative of the hypothetical goods or services. In this paper, three alternatives are presented to households and they choose the most preferred one. Sometimes, the goods or services haven't yet prevailed, and this method is often used in marketing research. I analyze households' preferences for electricity or suppliers which have hypothetical attributes such as monthly electricity bill, and the levels of these attributes change. In conjoint analysis, profiles of goods or services which have several attributes are presented to respondents. The researcher decides the number of attributes and their levels to make profiles. A profile which has only few attributes may not be realistic, whereas a profile which has too many attributes makes it difficult for participants to choose among options. In general, five or six attributes are suitable. After attributes and their levels are selected, their profiles are completed. However, if all the combinations of attributes and levels are adopted, the patterns are too large and cause strong correlation between some attributes, what we call, 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 isn't 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.

Households choose one electricity provided by an electric power company. The

[6] Louviere, Hensher, and Swait (2000), Kuriyama and Shoji (2005), Tsuge, Kuriyama, and Mitani (2011), and Kuriyama, Tsuge, and Shoji (2013) are referred for conjoint analysis. Nakajima, Ida, and Kinoshita (2006) is one of the studies about energy market which use conjoint analysis. They estimate Japanese households' preferences for electricity and gas under their intense competition.

electricity has several attributes such as supply-stability and CO_2 emissions and is generated by some energy sources. Goett, Hudson, and Train (2000) examined customers' choice for retail energy suppliers by conjoint analysis. They included the ratio of renewable energy as an attribute of energy suppliers as well as other attributes such as a fixed price. The following three alternatives were presented to respondents.

Alternative 1: Electricity provided by an electric power company which has nuclear power plants. The electricity is generated by nuclear power and fossil fuels such as LNG, oil and coal.
Alternative 2: Electricity is generated by fossil fuels such as LNG, oil and coal and renewable energy through a feed-in-tariff system. The electric power companies don't use nuclear power because all nuclear power plants aren't operated. The electric power companies purchase electricity from other suppliers which generate electricity by renewable energy through a feed-in-tariff system and sell the electricity to households.
Alternative 3: Electricity provided by an electric power company including new entrants which doesn't have any nuclear power plants. The electricity is generated by renewable energy or fossil fuels.

Alternative 1 assumes that households purchased electricity from an electric power company before the earthquake in March 2011. This means that nuclear power plants resume operations and electricity generated by nuclear power and fossil fuels is provided. Alternative 2 assumes that households purchase electricity from a current[7] electric power companies after the earthquake. Nuclear power plants don't resume operations, and electricity generated by fossil fuels and renewable energy through a feed-in-tariff system is provided. Alternative 3 assumes that households purchase electricity from an electric power company in the future after the deregulation. Nuclear power plants don't resume operations, and electricity generated by fossil fuels and renewable energy is provided.

The attributes and the levels of each alternative are as follows.

1. Monthly electricity bill:

Monthly electricity bill will change compared with the current bill. The levels are −2000, −1500, −1000, −500, 0 (unchanged), +500, +1000, +1500, and +2000 JPY. The electricity bill might be cheaper when households purchase electricity from the nine

[7] The questionnaire was surveyed in August 2014.

major electric power companies since nuclear power plants resume operation. Sometimes the electricity bill might be higher when the electricity is generated by fossil fuels through rising fuel prices. The electricity bill might be higher when the electricity is generated by renewable energy due to the feed-in-tariff system. When households purchase electricity from a new coming supplier such as a telecommunications company, they might purchase electricity at discounted prices through simultaneous purchases with telephone, internet, or CATV.

2. CO_2 emissions:

CO_2 emissions will change in 2030 compared to 2014. The levels are −20%, −10%, 0% (unchanged), +10%, and +20%. When nuclear power plants resume operation, CO_2 emissions will decrease. When fossil fuels are used, CO_2 emissions usually increase. When renewable energy is used, CO_2 emissions will decrease.

3. Electricity-supply stability:

When nuclear power is used, electricity will be supplied constantly without interruptions and outages. When the electricity is generated by fossil fuels, the electricity might not be supplied constantly due to planned outages from electricity shortages. In that case, nuclear power plants don't operate. When renewable energy is used, sometimes electricity supply might not be stable due to weather conditions. When electricity is constantly supplied, outages will not happen in a year. When electricity is not constantly supplied, short-term outages may happen a few times a year or the lights in the houses become dimmer. A dummy variable is used. It equals 1 when electricity is constantly supplied, and 0 otherwise.

4. Energy sources:

When the electric power companies generate electricity, they use nuclear power, fossil fuels, solar power, or wind power as energy sources. Each energy source is just the main energy source which has the highest ratio in electricity generation. A dummy variable is used for each energy source where fossil fuels are the base category.

In Table 1, the levels of each attribute are summarized.

Table 1 The levels of each attribute

Attribute	Level
Monthly electricity bill (JPY)	−2000, −1500, −1000, −500, 0 (unchanged), +500, +1000, +1500, and +2000
CO_2 emissions	−20%, −10%, 0% (unchanged), +10%, and +20%
Stability	Yes (1), No (0)
Energy source	nuclear power, fossil fuels, solar power, and wind power

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 electricity bill is very cheap even though renewable energy is used.

Table 2 is an example of profile. Households answer with respect to eight choice questions like this profile where the levels change. Through a pretest, we identify problems with the questionnaire and correct profiles to maximize understanding and minimize ambiguity for respondents. In the questionnaire, I gave some information about energy problems for respondents to understand the purpose of the questionnaire. The information is about energy shortage after the earthquake, the global warming, the feed-in-tariff system and the deregulation of electricity retail sales.

Table 2 Example of profile

Attribute	Alternative 1	Alternative 2	Alternative 3
Monthly Electricity bill (JPY)	−2000	1000	−1000
CO_2 emissions	−10%	10%	−20%
Stability	Yes	No	No
Energy source	Nuclear power	Fossil fuels	Solar power

The sample was collected via a web-based questionnaire, utilizing the services of the Rakuten Research company. The sample size is 250 households in Kanto[8] and Kansai[9] area, thus 500 households in total. These two areas are the two biggest city areas in Japan. Households in Kanto area purchase electricity from Tokyo electric power company (TEPCO) which has some nuclear power plants. The Fukushima nuclear facility is one of them. They experienced planned outages after the earthquake. Households in Kansai area purchase electricity from Kansai electric power company (KEPCO) which has also some nuclear power plants. They didn’t experience planned outages but were requested to save electricity usage because the nuclear power plants stopped operation. Before the earthquake, TEPCO and KEPCO heavily depended on

8 Kanto area is in East Japan around Tokyo. It includes Saitama, Chiba, Tokyo and Kanagawa prefectures.

9 Kansai area is in West Japan around Osaka. It includes Shiga, Kyoto, Osaka, Nara, Hyogo and Wakayama prefectures.

nuclear power. The ratio of nuclear power was 27% in TEPCO and 44% in KEPCO in 2010. The perceptions of households in Kanto and Kansai area for energy sources might have changed after the earthquake. The sample was collected in August 2014. Table 3 presents the socio-demographic attributes of households in the sample. The percentages of unemployed in occupation and less than 2 million JPY in household income are larger, caused by housewives and retirees. In other attributes, the percentages are reasonable in urban area.

Table 3 Socio-demographic attributes

		Number	%
	Total	500	100
Occupation	Employed	243	63.2
	Unemployed （including housewives and retirees)	137	27.4
	other	47	9.4
Annual household income (million JPY)	Less than 2	159	31.8
	2–3.99	116	23.2
	4–5.99	87	17.4
	6–7.99	63	12.6
	8–9.99	36	7.2
	More than 10	39	7.8
Education	Junior high school and high school	122	24.4
	Technical school and junior college	119	23.8
	University and graduate school	255	51
Family composition	Single	91	18.2
	Couple	131	26.2
	Husband and wife (parents) and children	225	45
	Two households	26	5.2
Residential type	Detached house (including two household houses)	248	49.6
	Collective house (condominium, apartment, housing complex etc.)	241	48.2
	Company housing, dormitory housing etc.	11	2.2
Area	Kanto	250	50
	Kansai	250	50

Sex	Male	296	59.2
	Female	204	40.8
Age (years)	Average	47.45	
	Min	21	
	Max	69	

In the questionnaire, I surveyed households' opinions and perceptions of energy problems. 77.8% households feel that electricity bill has become higher after the earthquake. 74.6% save electricity usage after the earthquake. 78.4% think they should reduce global greenhouse gases and only 6% think they don't need to reduce these gases. 35.4% think nuclear power plants should be abolished. 33.6% think Japanese government should operate nuclear power plants. 18.2% allow current electric power companies to operate nuclear power plants. About the feed-in-tariff system for the promotion of renewable energy, 25.4% think the tariff is higher and 20.8% think it is fair. However, 44.4% don't have proper knowledge and information to evaluate the tariff. On the best future energy source, 34.4% think solar power is the best energy source. On the other hand, only 16.2% think nuclear power is the best energy source. 13.2% think LNG is the best energy source. I also surveyed households' opinions about the deregulation of electricity retail sales. 77.6% answered that they had a little information about the deregulation. They think lower electricity bill, the stability of electric power supply, and suppliers which don't have nuclear power plants are essential when they choose suppliers.

4. Econometric analysis

In a choice experiment the dependent variable is discrete. To estimate this choice model, we, thus, need to employ a discrete choice econometric model. The conditional logit model is a popular choice model in this context. However, this model assumes 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, we use a random parameter logit model (mixed logit model). This model allows the random variation of individual preferences, unrestricted substitution patterns and correlation in unobserved factors over time.

The random parameter logit model assumes that each parameter has a 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. α is a non-random parameter and β_n is a random parameter which represents the preference of each individual and varies over individuals. In this paper constant terms and the parameter of electricity bill which is a price parameter are non-random parameters. x_{nj} is a variable vector which includes monthly electricity bill. On the other hand, the parameters of CO_2 emissions, the stability of electricity supply and energy sources are random parameters. z_{nj} is a variable vector which includes CO_2 emissions, electricity-supply stability, 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

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

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

We should assume the distribution of β_n. Usually we assume normal, lognormal triangular distribution etc. In this paper, the normal distribution is assumed.

We use simulation methods for estimation. The simulated probability is

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

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

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

d_{nj} is an indicator. It equals 1 if individual n chooses alternative j, else 0. We maximize SSL to capture the maximum simulated likelihood estimator. We use 100 times Halton draws for simulation (Train, 2003, p138-154; Hensher, Rose, and Greene, 2005, p605-694). For estimation we use Limdep NLOGIT 5.

After estimation, the WTP for each attribute including each energy source is calculated. If the utility function is linear, it is expressed as:

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

V_{nj} is the deterministic term of the utility function. The total differentiation of the V_{nj} formula is:

$$dV_{nj} = \frac{\partial V_{nj}}{\partial x_{nj}} dx_{nj} + \frac{\partial V_{nj}}{\partial z_{nj}} dz_{nj}$$

Now we obtain the WTP of z_1 which is one of the attributes, such as solar power. If the utility level does not change ($dV_{nj} = 0$) and other variables, except z_1, are unchanged, we can obtain the marginal WTP (MWTP) as follows:

$$MWTP = -\left.\frac{\partial V_{nj}}{\partial z_{nj1}}\middle/\frac{\partial V_{nj}}{\partial x_{njm}}\right.$$

x_m is a monetary variable such as a price. We can also write MWTP by invoking parameters as follows:

$$MWTP = -\beta_i/\beta_m$$

β_i is the coefficient of each attribute and β_m denotes a monetary coefficient such as an electricity bill. We can obtain WTP by dividing the coefficient of each attribute by a monetary coefficient.

5. Estimation results

5.1 Estimation results of random parameter logit model

In this section, I analyze the estimation results of random parameter logit model. Table 4 shows the number of choices and the ratio of choices.

Table 4 Choice probability

	Number	Ratio
Alternative 1	1187	0.297
Alternative 2	1167	0.292
Alternative 3	1646	0.412

Alternative 3 is the most popular. Households prefer electricity provided by electric power companies which don't use nuclear power and generate electricity by renewable energy and fossil fuels.

Table 5 illustrates the estimation results of random parameter logit model.

Table 5 Estimation results

Variable	Coefficient	Standard Error	z value	p value
Random parameters (mean)				
CO_2	−0.03875	0.00569	−6.81	0
Stability	0.4898	0.13376	3.66	0.0003
Nuclear	−3.51017	0.30989	−11.33	0
Solar	0.94739	0.15276	6.2	0
Wind	0.40923	0.09601	4.26	0
Non-random parameters				
Electricity bill	−0.00067	4.87E-05	−13.78	0
Constant 1	0.85603	0.11824	7.24	0
Constant 2	0.03223	0.06465	0.5	0.6181
Standard deviation				
CO_2	0.05174	0.00587	8.81	0
Stability	1.84827	0.13921	13.28	0
Nuclear	4.878	0.36084	13.52	0
Solar	1.47681	0.13304	11.1	0
Wind	0.28513	0.18274	1.56	0.1187

Log likelihood −3297.20787
McFadden R^2 0.24969

The coefficient of electricity bill has a negative sign and is significant at the 1% level. If the electricity bill is lower, households choose the alternative. The coefficient of CO_2 emissions has a negative sign and is significant at the 1% level. If CO_2 emissions decrease, households choose the alternative. The coefficient associated with the electricity-supply stability has a positive sign and is significant at the 1% significance level. If electricity is constantly supplied without outages, households choose the alternative. Next, the estimation results of energy sources are explained. Dummy variables for each energy source have been used, where fossil fuels are the base category. The coefficient of nuclear power has a negative sign and is significant at the 1% level. If the electricity is generated by nuclear power in place of fossil fuels, households don't choose the alternative. On the other hand, the coefficient of renewable energy both solar and wind power has a positive sign and is significant at the 1% level. If the electricity is generated by renewable energy in place of fossil fuels, households choose the alternative. From the estimation results, households prefer the electricity which is lower monthly electricity bill, reduces CO_2 emissions, is constantly supplied, and is generated by renewable energy, not by nuclear power.

5.2 WTP

WTP for each attribute is calculated. WTP is obtained by dividing the parameter of each attribute by the parameter of monthly electricity bill which is a price parameter. Table 6 shows the WTP for each attribute.

Table 6 WTP

Variable	WTP (JPY)
CO_2	−57.84
Stability	731.04
Nuclear	−5239.06
Solar	1414.01
Wind	610.79

WTP for a stable electricity supply is 731.04. Thus, households will pay an additional 731.04 JPY per month for a stable electricity supply. Households highly evaluate a stable electricity supply. WTP for CO_2 emissions is −57.84. Thus, if the electricity bill is cheaper by 57.84 JPY, households will allow to increase CO_2 emissions. WTP for nuclear, solar and wind power is −5239.06, 1414.01 and 610.79 respectively. Households will, thus, pay an additional 1414.01 JPY per month for solar power and an additional 610.79 JPY per month for wind power. Households therefore highly evaluate renewable energy sources. On the other hand, households negatively evaluate nuclear power. Households will only satisfice with nuclear power if the electricity bill is cheaper by 5239.06 JPY per month.

5.3 Subsample analysis

I divide the sample into subsamples by households' socio-demographic attributes and their perceptions of energy problems. I compare their WTPs between the subsamples and test the differences of their preferences for electricity or suppliers by the test for parameter differences to quantify the extent to which preferences are heterogeneous. If preferences are indeed different, households in the two groups make contrasting preferences for electricity. We test the differences by the likelihood test and use the following test statistic.

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

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 likelihood which is obtained after estimation by each subsample. The null hypothesis is that preferences or parameters between two subsamples are equal. The alternative hypothesis is that preferences or parameters are not equal. The test statistic is chi-squared distributed with degrees of freedom equal to the number of parameters. The critical value for the 5% significance level is 22.362 and for 1% it is 27.688 for 13 degrees of freedom.

Table 7 is the list of subsamples. I divided the sample into two subsamples to balance the sample size in two subsamples.

Table 7 List of subsamples

Attributes	Subsamples	Definition	Sample size
Household income	Low income	Under 4 million JPY	275
	High income	More than 4 million JPY	225

Family composition	Small family	Single and couple family	222
	Big family	Married parents and unmarried children family, and more than two adult generations family	278
Residential type	Detached house	Detached house (two household houses are included)	248
	Collective house	Condominium, apartment, housing complex and a company and dormitory housing	252
Living area	Kanto	Households who live in Kanto area	250
	Kansai	Households who live in Kansai area	250
Age	Young age	Less than 46 years old (average)	255
	Old age	More than 47 years old	245
Perception of electricity bill	High bill	Households who think electricity bill is higher after the earthquake	389
	Low bill	Households who don't think electricity bill is higher after the earthquake	111
Perception of energy-saving	Save	Households who save electricity usage after the earthquake	373
	Not save	Households who don't save electricity usage after the earthquake	127
Knowledge of the deregulation	Knowledge	Households who have knowledge and interest of the deregulation	218
	No knowledge	Households who don't have knowledge and interest of the deregulation	282

Table 8 illustrates the WTP and the test statistics of the parameter differences test.

Table 8 WTP and the likelihood test

Variables	High income	Low income	Big family	Small family
CO_2	-51.71	-58.60	-44.32	-71.52
Stability	790.94	819.28	727.29	867.91
Nuclear	-5942.52	-4796.29	-4618.35	-5701.27
Solar	1310.06	1513.80	1656.24	1170.55
Wind	512.36	737.20	646.57	554.02

Test statistic	6.25	same	10.76	same
Variables	Detached house	Collective house	Kanto	Kansai
CO_2	-43.76	-73.88	-66.15	-48.49
Stability	920.31	608.18	663.18	928.51
Nuclear	-4414.05	-5643.20	-5135.20	-5306.70
Solar	1494.22	1433.49	1405.86	1272.80
Wind	759.33	486.02	640.46	595.51
Test statistic	16.38	same	0.40	same
Variables	Young age	Old age	High bill	Low bill
CO_2	-47.73	-71.89	-53.39	-88.76
Stability	613.13	939.95	807.64	1825.33
Nuclear	-4312.97	-7522.63	-4846.89	-7881.19
Solar	1336.69	1527.53	1136.15	4020.86
Wind	562.11	649.73	430.52	3346.86
Test statistic	49.43	different	110.83	different
Variables	Save	Not save	Knowledge	No knowledge
CO_2	-55.52	-56.73	-45.59	-62.60
Stability	766.89	1053.15	753.37	841.83
Nuclear	-4899.21	-4334.95	-5320.68	-5416.95
Solar	1701.07	599.35	1764.47	1095.84
Wind	645.29	636.18	711.08	539.44
Test statistic	40.02	different	34.17	different

Households of lower income, bigger family, detached house, Kanto, and older age more highly evaluate renewable energy. And, households who don't think electricity bill become higher after the earthquake, save more electricity usage, and have knowledge and interest of the deregulation also more highly evaluate renewable energy. In the future, renewable energy will become popular among them. Households of higher income, smaller family, collective house, Kansai, and older age more negatively evaluate nuclear power. Households who don't think electricity bill become higher after the earthquake, save more electricity usage, and don't have knowledge of the deregulation also more negatively evaluate nuclear power. In all subsamples, households show negative WTP, and it will be difficult to resume operations in the future.

From the test statistics, we don’t observe the differences of preferences for electricity or suppliers between two subsamples in household income, family composition, residential type, and living area. However, we observe the differences between younger and older generation. When households’ perception of electricity bill and electricity-saving and knowledge of the deregulation are different, the differences of preferences for electricity or suppliers are also different.

6. Conclusions and Policy Implications

I estimate preferences of Japanese households for energy sources by conjoint analysis and calculate WTP for each energy source and other attributes of electricity. Japanese households show negative WTP for nuclear power. On the other hand, their WTP for renewable energy sources such as solar and wind power is substantially positive. Further, their WTP for a stable electricity supply is positive. Japanese households positively evaluate renewable energy and electricity-supply stability but negatively evaluate nuclear power. From this study, we can support policy interventions to reduce the share of nuclear power and promote renewable energy. Households will pay higher electricity bill if the electricity is generated by renewable energy. Households will accept nuclear power if the electricity bill is much lower. This study may support the feed-in-tariff system to promote renewable energy because households accept higher priced electricity if the electricity is generated by renewable energy. If the stability of electricity supply associated with renewable energy is improved, renewable energy will become widely used. Households’ attributes and perception are also important for suppliers to sell electricity and for our future energy policy.

After the great East Japan earthquake in March 2011, nuclear power operations have been largely suspended. Fossil fuels are also difficult to be used because of climate change concerns and rising fuel costs. Renewable energy such as solar and wind power is expected to prevail as future energy sources.

Various suppliers have started to provide electricity after the deregulation in April 2016. Some suppliers don’t possess any nuclear power plants and will provide electricity generated by renewable energy as a main energy source. Some households who object to nuclear power will purchase electricity from such suppliers. This study provides some useful energy policies in Japan and countries where big earthquakes often happen.

Acknowledgments

This study was aided by research funding from Osaka Gas Co. Ltd. We presented an earlier version of this paper at the academic meeting of the Japanese Economic Association and the Japan Economic Policy Association in May 2015. We thank members of the workshop hosted by Osaka Gas Co. Ltd and the following discussants at the academic meeting: Prof. Takahiro Tsuge, Prof. Shinichi Hanada and Prof. Chiharu Kobayashi. The authors would like to thank Enago (www.enago.jp) for the English language review. All remaining errors are ours.

References

Borchers, Allison M., Joshua M. Duke, and George R. Parsons (2007), "Does willingness to pay for green energy differ by source?" *Energy Policy*, 35, p3327-3334.

Goett, Andrew, Kathleen Hudson, and Kenneth Train (2000), "Customers' choice among retail energy suppliers: The willingness-to-pay for service attributes," *The Energy Journal*, 21, p1-28.

Hensher, David A., John M. Rose, and William H. Greene (2005), *Applied Choice Analysis: A primer*, Cambridge University Press.

Ida, Takanori, Kousuke Takemura, and Masayuki Sato (2015), "Inner conflict between nuclear power generation and electricity rates: A Japanese case study," *Energy Economics*, 48, p61-69.

Kim, Kayoung, Heekoo Nam, and Youngsang Cho (2015), "Estimation of the inconvenience cost of a rolling blackout in the residential sector: The case of South Korea", *Energy Policy*, 76, p76-86

Kuriyama, Koichi and Yasushi Shoji edited (2005) *Economic evaluation of the environment and tourism*, (in Japanese), Keisou shobou.

Kuriyama, Koichi, Takahiro Tsuge, and Yasushi Shoji (2012) *Introduction to economic evaluation of the environment for beginners*, (in Japanese), Keisou shobou.

Louviere, Jordan J., David A. Hensher, and Joffre D. Swait (2000), *Stated Choice Methods Analysis and Application*, Cambridge University Press.

McFadden (1974), "Conditional logit analysis of qualitative choice behavior," in P. Zarembka, ed., *Frontiers in Econometrics, Academic Press*, New York, p.105-142.

Morita, Takamki and Shunsuke Managi (2015) "Consumers' willingness to pay for electricity after the Great East Japan Earthquake", *Economic Analysis and Policy,* 48,

p82-105
Murakami, Kayo, Takanori Ida, Makoto Tanaka, and Lee Friedman (2015), “Consumers' willingness to pay for renewable and nuclear energy: A comparative analysis between the US and Japan”, *Energy Economics*, 50, p178-189.
Nakajima, Miki, Takanori Ida, and Shin Kinoshita (2006) “The conjoint analysis for energy demand of households” *Journal of Public Utility Economics* (in Japanese) 58.2, p23-33.
Ozbafli, Aygul and Glenn P. Jenkins (2015) “The willingness to pay by households for improved reliability of electricity service in North Cyprus”, *Energy Policy*, 87, p359-369
Ozbafli, Aygul and Glenn P. Jenkins (2016) “Estimating the willingness to pay for reliable electricity supply: A choice experiment study”, *Energy Economics*, 56, p443-452
Roe Brian, Mario F. Teisl, Alan Levy, and Matthew Russel (2001), “US consumers' willingness to pay for green electricity,” *Energy Policy*, 29, p917-925.
Scarpa, Riccardo and Ken Willis (2010), “Willingness-to-pay for renewable energy: Primary and discretionary choice of British households' for micro-generation technologies,” *Energy Economics*, 32, p129-136.
Sundt, Swantje and Katrin Rehdanz (2015)"Consumer' willingness to pay for green electricity: a meta-analysis of the literature", *Energy Economics*, 51, p1-8
Takahiro, Tsuge, Koichi Kuriyama, and Yohei Mitani (2011), *New techniques of environmental evaluation*, (in Japanese), Keisou shobou.
Train, Kenneth E. (2002), *Discrete Choice Methods with Simulation*, Cambridge
Yoo, James and Richard C. Ready (2014) "Preference heterogeneity for renewable energy technology", *Energy Economics*, 42, p101-114