Willingness to pay for improvement of energy efficiency in residential buildings: A choice experiment study

Hyo-Yeon Choi* · Seung-Hoon Yoo** · Seung-Jun Kwak***

I. Introduction

Continuous increase in energy-use has caused security problems of energy resources, imbalance between demand and supply of energy, and environmental problems such as Global Climate Changes (GCC). Demand-side management can be a fundamental solution for those problems, while expanding energy supply have brought about the exhaustion of energy resources and environmental burden arisen from construction and operation of power plants, and have imposed huge investment and infrastructure costs. Demand-side management of energy could be two parts: reducing amount of energy-use itself and improving efficiency of energy-use. According to IEA (International Energy Agency, 2006), energy demand could be (at most) half of it, by the efficient energy-use. Thus, the improvement in energy efficiency is a cost-effective way to solve energy issues: reducing GHG emissions and ensuring a stable supply of energy without huge investment. Under this background, policy for the efficient energy-use named 'rational energy utilization act', have been implemented in Korea, and it has been applied in four sectors: industry, building, transportation and device.

Energy consumption in residential buildings is quite amount in Korea. Final energy consumption in the residential sector accounted for about 9.9 percentage of the total final energy consumption in Korea. Specifically, consumptions of electricity, natural gas and heat in the residential sector were about 13.5, 39.5 and 88.4 percentage of the each total consumption in 2013 in Korea, respectively (Korea Energy Economics Institute, 2014). Considering those high energy-consumption rates in residential sector, efforts for the efficient energy-use in residential buildings help to considerably release energy-issues. In this vein, Korea energy management cooperation (KEMCO) suggested some energy-saving measures in building such as insulation tools, a ventilation system, and a highly-efficient boiler, and implemented the house energy efficiency rating system to encourage the efficient energy-use in residential buildings.

Effective demand-side management of energy-use in residential buildings is based on the high participation of people and understand of their preferences on the energy-saving measures. Thus, it is important to analyze preferences of residential consumers when making investment decisions regarding heating system or a renovation that affects the efficiency of residential energy consumption.

Many studies on the energy efficiency in buildings have been widely conducted in various views:

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development of relevant technologies, education of energy-saving behaviors, and residential consumers' preferences of energy-saving measures. Most studies on assessment of residential consumers' preferences on energy-saving measures have conducted in foreign countries, and have applied to choice experiment (CE) technique (e.g., Sadler 2003; Banfi et al., 2008; Achtnicht, 2011). Kwak et al.(2010) is only one study that evaluated the economic values of energy-savings in residential buildings in Korea, and it focused on the some energy-saving measures, not the environmental effects of them like almost previous studies did. Therefore, the purpose of this study is to apply a CE in analyzing the consumer's preferences on some energy-saving measures suggested by KEMCO and environmental effects of them, specifically the reduction of CO2 emission. The CE approach provides respondents with choice sets which help to evaluate the trade-off among the evaluated attributes, in this study energy-saving measures, a monetary term (interior cost), and an environmental factor. Thus the results of this study can be presented as a monetary term, and so it will be helpful for evaluation of relevant policies.

The rest of this paper is organized as follows. Section 2 explains the CE approach and its methodological issues. Statistical model for analyzing CE survey data and analysis results of the study are presented in section 3 and section 4, respectively. In the final section, some concluding remarks are made.

II. Methodology

1. Choice experiment

The CE is one of the representative methods to evaluate the economic value of a non-market goods such as environmental goods. This methods helps to measure the economic values for various attributes, as it deals with choice sets that vary over a range of characteristics rather than with the estimation of the willingness-to-pay for one option. Moreover, it allows respondents to systematically evaluate trade-offs among multiple environmental attributes or among environmental and non-environmental attributes (Johnson and Desvousges, 1997).

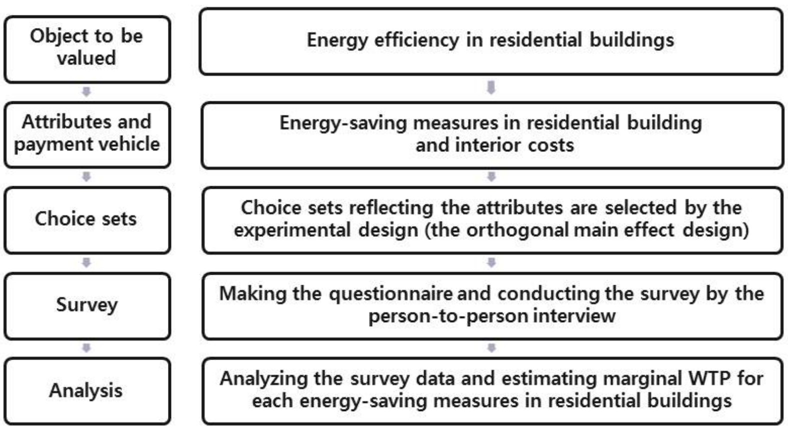

Figure 1. Process of an application of choice experiment to this study

General process of the CE is composed of five steps as presented in the left column of Figure 1: defining the object to be valued, selecting the attributes and payment vehicle, making choice sets, conducting CE survey, and analyzing the survey data. The right column of Figure 1 shows that application of the general process of the CE to this study.

2. Methodological issues

We identified the following four attributes: reduction of GHG emissions, A highly energy-efficient boiler, better insulations, ventilation system, and cost. Figure 2 describes these attributes, as well as the cost attribute, and how each level of attributes is defined.

<table>
<tr><th>Attributes</th><th>Explanations</th><th colspan="10">Status quo</th><th colspan="10">Improved Status</th></tr>
<tr><td>Reduction of GHG emissions</td><td>Energy-efficient measures in residential building reduce CO2 emissions.</td><td colspan="5">No change</td><td colspan="5">10% decrease</td><td colspan="5">25% decrease</td><td colspan="5">40% decrease</td></tr>
<tr><td>A highly energy-efficient boiler</td><td>Use a highly energy-efficient boiler.
This can reduce more than 8 % of heating energy used in buildings.</td><td colspan="10">No highly energy-efficient boiler</td><td colspan="10">Use a highly energy-efficient boiler</td></tr>
<tr><td>better insulations</td><td>The degree of the improvement in insulations of residential building through high-insulation windows, installation of façade, wall, balcony</td><td colspan="5">No change</td><td colspan="5">A little bit better than now</td><td colspan="5">Much better than now</td><td colspan="5">Quite much better than now</td></tr>
<tr><td>ventilation system</td><td>Installation of a ventilation system for saving cooling energy and circulating atmosphere</td><td colspan="10">No ventilation system</td><td colspan="10">Installation of ventilation system</td></tr>
<tr><td>Cost</td><td>Willingness to pay for energy-saving measures through additional costs of interior per 3.3m²</td><td colspan="4">0 won</td><td colspan="4">80,000 won</td><td colspan="4">150,000 won</td><td colspan="4">250,000 won</td><td colspan="4">400,000 won</td></tr>
</table>

Figure 2. Attribues and their levels

In the questions of the CE, there were three alternatives of which two represented the improved energy-saving measures and CO2 emissions, and the other represented the fixed status quo. Then, there were 320 ($=4^2*2^2*5$) possible combinations of attributes and levels to form the choice sets. It was impractical to ask respondents to choose from all the combinations. Thus, we employed the orthogonal main effects design that is effective in terms of isolating the effects of individual attributes on the choice (Hanley et al., 1998) to draw 16 cards, and then divided into two sets of eight choices each. Figure 3 shows an example of a choice set that was actually use. Each respondent was presented with four choice sets and was asked to choose among two alternatives and the status quo.

	Alternative A	Alternative B	Status quo
Reduction of GHGs emission based on now	10% decrease	10% decrease	No change (Current level)
A highly energy-efficient boiler	No a highly energy-efficient boiler	Use a highly energy-efficient boiler	No a highly energy-efficient boiler
Better insulations	**Quite much** better than now	**A little bit** better than now	No change (Current level)
Ventilation system	**No** ventilation system	Ventilation system is **Installed**	**No** ventilation system
Additional costs of interior for energy-efficient space per 3.3㎡	**USD 141.5** (KRW 150,000	**USD 75.5** (KRW 80,000)	**0**
	☐ **A**	☑ **B**	☐ **Status quo**

Figure 3. An example choice set used in this study

Sampling and field work were conducted by professional polling firm, Research Prime, Inc. in November 2013, and the survey was administered to 500 households lived in Seoul where is the capital of Korea. Considering the characteristics of object to be valued, the information about WTP per household is needed, and the interviewees are restricted to heads of household or housewives between 20 and 65 year of age who make a household spending decision. Stratified random sampling (based on district population and gender ratio) was used for selecting a representative sample of Seoul citizens. Furthermore, person-to-person interviews were performed to encourage higher responses and offer respondents more scope for detailed questions and answers, and visual-aid cards were shown to help respondents to understand the questionnaire contexts. By doing so, we souhgt to minimize the possibility of being biased and distorted.

Ⅲ. Model

1. Random parameter logit model

Data from choice experiments can be generally analysed with multinomial choice models, and multinomial logit model is the most common representative econometric model in multinomial choice analysis, and it has been applied in many empirical studies. However, this econometric model can be only applied when the independence of irrelevant alternatives (IIA) assumption is satisfied. Instead of employing the multinomial logit model, this study adopted random parameter logit (RPL) model with Baysian inference is employed to relax the IIA assumption that is required in multinomial logit analysis, and to allow heterogeneity across the respondents.

Based on the random utility theory proposed by McFadden (1974), the utility function U_{ij} can be expressed as sum of a deterministic component, V_{ij} and a error term, e_{ij} as follows

$$U_{ij} = V_{ij} + e_{ij} \tag{1}$$

where V_{ij} is typically specified as a function of the attributes, Z_{ij}, in alternative j chosen by the respondent i. Assuming consumers will maximize their utility, the probability of respondent i choosing alternative j conditional on β_i, a vector of coefficients to estimated, can be expressed as Equation (2) (McFadden, 1974; Train, 2003).

$$\begin{aligned} \Pr_i(y_{ij}|\beta_i) &= \Pr(U_{ij} > U_{ik},\ \forall j \neq k) \\ &= \Pr(V_{ij} + e_{ij} > V_{ik} + e_{ik},\ \forall j \neq k) \\ &= \frac{\exp(V_{ij})}{\sum_k \exp(V_{ik})} \end{aligned} \tag{2}$$

where y_{ij} is a binary variable whose value is one when respondent i chooses alternative j among the three alternatives and 0 otherwise.

In RPL model, a vector of coefficients β_i follows the normal or log-normal distribution, and therefore, the RPL probability of respondent i selecting alternative j can be written as (Train, 2003)

$$\Pr_i(y_{ij}) = \int \left(\exp(\beta_i' Z_{ij}) / \sum_k \exp(\beta_i' Z_{ik}) \right) f(\beta) d\beta \tag{3}$$

where $f(\beta)$ is a probability density function such as normal distribution function and log-normal distribution function. Then, assuming a particular distribution for each of the coefficients, the likelihood function of respondent i can be presented as follow

$$L = \prod_{i=1}^{N} \left(\exp(\beta_i' Z_{ij}) / \sum_{j=k}^{3} \exp(\beta_i' Z_{ik}) \right)^{y_{ij}} \tag{4}$$

2. The utility function and marginal willingness-to-pay

The utility function of the model, with the exception of the error term, can be expressed as a linear function of an attribute vector (Z_1, Z_2, Z_3, Z_4, Z_5) = (Reduction of GHG emissions, A highly energy-efficient boiler, Better insultation, Ventilation system, Cost), and individual parameter vectors corresponding to the attribute vector.

$$U_{ij} = \beta_i' Z_{ij} = \beta_1 Z_1 + \beta_2 Z_2 + \beta_3 Z_3 + \beta_4 Z_4 + \beta_5 Z_5,\ \beta_i \sim i.i.d.(b,\ W) \tag{5}$$

Here, β_i follows the normal or log-normal distribution with average vector b and variance-covariance W. The diagonal elements of W is a vector of standard deviation ($\sigma_{\beta_{il}}$) of β_{il}, and statistically significant $\sigma_{\beta_{il}}$ implies the existence of respondents' heterogeneous preferences on attribute l.

Economic value of each attributes can be analyzed by calculating marginal willingness-to-pay (MWTP) with the estimated coefficient value from RPL model.

$$MWTP_{Z_{il}} = ([\partial U_{ij}/\partial Z_{il}]/[\partial U_{ij}/\partial Z_{i,\cos t}]) = -\beta_{il}/\beta_{i,\cos t} \quad (6)$$

β_{il} and Z_{il} denote the coefficients and attributes respectively, excepting cost. $\beta_{i,\cos t}$ and $Z_{i,\cos t}$ represent the cost coefficient and attribute, respectively.

Ⅳ. Empirical results

A RPL model with Bayesian inference is used to estimate Seoul citizen's preference, which is expressed as the utility function seen in Equation (5). The parameters in Equation (5) are assumed to have a normal distribution except the coefficient for cost, since the parameter for cost certainly have one-side direction. The estimates can be assumed to have a log-normal distribution, so that they constantly have one-side sign (Train and Sonnier, 2005). Hence, the parameter for cost is assumed to follow a log-normal distribution.

Table 1 shows the estimation results of the RPL model, and the mean and variance of all estimated coefficient are statistically significant at the 1% level. The results from the RPL model show that the Korean public is willing to pay for the measures that can save energy in residential buildings: reduction of GHG emissions, a highly energy-efficient boiler, better insulations, and a ventilation system. Since the estimated for standard deviations of random parameters' distributions are different from zero in the statistically significant sense, IIA assumption can not be hold and RPL model is more appropriate than multinomial logit model for our data.

Table 1. Estimation results of the RPL model

Attributes	Assumed distribution	Mean of estimate	Standard deviation
Reduction of GHG emissions	Normal	0.161*	0.096*
A highly energy-efficient boiler	Normal	2.292*	7.892*
Better insulations	Normal	2.585*	8.037*
Ventilation system	Normal	1.940*	25.280*
Cost	Log-normal distribution	-1.520*	1.107*

Notes: The unit of interior costs is ten thousand won. * indicates significance at the 1 % level.

MWTPs is calculated based on 2,000 values drawn from the distribution of the estimated coefficients, and The median MWTP is presented Table 2. The MWTPs for a 1% of the reduction of GHG emissions, the highly energy-efficient boiler rather than current regular boiler, better insulations, than now, and the ventilation system are estimated to be KRW 4,450, KRW 73,593, KRW 78,409, and KRW 49,917, respectively.

Table 2. The estimated median marginal willingness-to-pay (MWTP) for each attributes

Attributes	Median MWTP
Reduction of GHG emissions (percentage)	4,450 Won
A highly energy-efficient boiler	73,593 Won
Better insulations	78,409 Won
Ventilation system	49,917 Won

Note: The MWTP is calculated based on 2,000 values drawn from the distribution of the estimated coefficients.

V. Concluding remarks

The demand-side management of energy can be a fundamental solution to some energy issues: security energy resource problem, GCC issues, and imbalance between supply and demand of energy. According EIA's 2014 energy outlook, efficiency gains for advanced technologies can reduce energy consumption growth. Considering the importance of energy-efficiency, this study attempted to apply CE in analyzing consumers' preference for not only energy-saving measures in residential buildings proposed by KEMCO but also their environmental effect, and eliciting MWTP of each of its attributes. The chosen attributes were the reduction of GHG emissions, the highly energy-efficient boiler rather than current regular boiler, better insulations, than now, the ventilation system and interior costs.

Findings in this study were based on random sample of 500 households in Seoul. The survey was relatively successful in eliciting MWTP for attributes of energy-saving measures and their environmental effect. In addition, a random parameter logit (RPL) model with Bayesian inference is employed to relax the independence of irrelevant alternatives (IIA) assumption that is required in multinomial logit analysis widely used in applied CE studies. The analysis results reveal that the IIA assumption is not satisfied and thus the RPL model is appropriate for our data. The results from the RPL model show that the Korean public is willing to pay for the measures that can save energy in residential buildings: reduction of GHG emissions, a highly energy-efficient boiler, better insulations, and a ventilation system. The marginal willingness to pay for a 1% of the reduction of GHG emissions, the highly energy-efficient boiler rather than current regular boiler, better insulations, than now, and the ventilation system are estimated to be KRW 4,450, KRW 73,593, KRW 78,409, and KRW 49,917, respectively.

The empirical analysis results shows that the Seoul citizen puts value on the energy-measures in residential buildings, and reduction of GHG emissions. The quantitative information can be utilized in decision-makings related to enhancement of energy efficiency.

References

Achtnicht Martin (2011), "Do Environmental Benefits Matter? Evidence from a Choice Experiment among

House Owners in Germany", *Ecological Economics*, 70: 2191-2200.

Banfi Silvia, Farsi Mehdi, Filippini Massimo, and Jakob Martin (2008), "Willingness to Pay for Energy-saving Measures in Residential Buildings", *Energy Economics*, 30: 503-516.

EIA (Energy Information Administration, USA) (2014), "Energy Outlook".

Hanely Nick, Wright Rovert E., and Adamowicz Vic (1008), "Using Choice Experiments to Value the Environment", *Environmental Resource Economics*, 11: 413-428.

IEA (International Energy Agency) (2006), "World Energy Outlook".

Johnson F. Reed, Desvousges William H. (1997), "Estimating Stated Preferences with Rated-Pare Data: Environmental, Health, and Employment Effects of Energy Programs", *Journal of Environmental Economics and Management*, 34: 79-99/

KEEI (Korea Energy Economics Institute, Korea) (2014), "2014 Yearbook of Energy Statistics".

Kwak So-Yoon, Yoo Seung-Hoon, and Kwak Seung-Jun (2010), "Valuing Energy-saving Measures in Residential Buildings: A Choice Experiment Study", *Energy Policy*, 38: 673-677.

McFadden Daniel (1974), "Conditional Logit Analysis of Qualitative Choice Behavior", in Zarembka, P.(Eds.), *Frontiers in Econometrics*, Academic Press, New York.

Sadler Margo (2003), "Home Energy Preferences and Policy: Appling Stated Choice Modeling to a Hybrid Energy Economic Model", *Report to Natural Resources Canada*, Simon Fraser University.

Train Kenneth (2003), "Discrete Choice Methods with Simulation", Cambridge University Press, Cambridge.

Train Kenneth, Sonnier Garrett (2005), "Mixed Logit sith Bounded Distributions of Correlated Partworths", 6: 117-134.