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Do Household Time, Risk, and Social Preferences Affect Home Energy Retrofit Decisions in Korea?

Jihyo Kim  and Suhyeon Nam *

Korea Energy Economics Institute, Ulsan 44543, Korea; jihyokim@keei.re.kr

* Correspondence: nam.suhyeon@keei.re.kr; Tel.: +82-52-714-2190

Abstract: Paying attention to impacts of behavioral factor on energy efficiency (EE) investments, this study attempts to identify preference characteristics affecting EE investments. We model households' EE investments with time, risk, and social preferences, conduct a survey, and empirically examine the effects of the preference characteristics on home energy retrofit decisions in Korea. We find that the research hypotheses for risk and social preferences that we are derived from the model are supported while those for time preference are partially supported. The results are summarized as follows. First, respondents who discount the future more heavily are less likely to plan a home energy retrofit. Second, very risk-averse respondents are less likely to have experienced a home energy retrofit and very risk-seeking ones are more likely to plan a home energy retrofit. Third, those seriously concerned about environmental issues or who strongly respond to moral norms are likely to have experienced or plan a home energy retrofit.

Keywords: home energy retrofit; time preference; risk preference; social preference; probit model



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1. Introduction

Energy efficiency (EE) improvements are considered to be necessary to cope with the increasing threat of climate change. EE is called the “first fuel” because it plays a crucial role in reducing energy consumption and is thus one of the most promising approaches to addressing climate change [1,2]. The first step toward EE improvements is to answer the following question: why do consumers fail to invest in EE technologies that appear to be economically superior? [3] Many scholarly works conducted to answer this question have found that underinvestment in EE technologies (i.e., the EE gap) is driven by (1) market imperfections such as price distortions and a lack of information and (2) behavioral issues related to the inherent characteristics of individuals' decision-making [4–6]. Even though many studies have been conducted on EE policies addressing market imperfections, the discussion of EE policies addressing behavioral issues has only recently begun. As a result, theoretical and empirical evidence for EE policies addressing behavioral issues is weak.

Understanding the effects of behavioral aspects on EE investment decisions is important because it can contribute to realizing “how to intervene, and with whom, where and when” [7]. In this context, we focus on the EE gap caused by behavioral issues (e.g., why, under the same conditions, some people invest in EE, whereas others do not). According to Kastner and Stern [8], a “human factor” is behind EE investment decisions. This human factor induces individual decisions to deviate from the ideal results, and this deviation results in behavioral issues [9]. In other words, behavioral issues help explain the individual heterogeneity of the EE gap and can offer insights into how to encourage people to change their behaviors in a more efficient and sustainable direction without increasing policy intensity [7].

According to Hausman [10], the EE investment decision can be converted into the trade-off between the capital cost and operating costs (i.e., energy costs). Heterogeneous preferences may influence this trade-off by making it more expensive or cheaper to invest

in EE. Hence, we raise the following research questions: which preference characteristics are related to the EE investment decision and how do they influence the decision? The first step to answer these questions is to examine the mechanism of EE investments by focusing on the trade-off. In most EE investments, the upfront capital cost is recovered by the energy cost savings in the long run [10]. However, the amount of energy cost savings is uncertain for various reasons [11]. Meanwhile, some people invest in EE improvements just to make the world better. In sum, even under the same conditions, people's EE investment decisions may differ by their time, risk, and social preference characteristics.

The aim of this study is to jointly investigate the effects of time, risk, and social preference characteristics on EE investment decisions. We focus on EE improvements to residential buildings' lighting, heating, ventilation, and air-conditioning (LHVAC) systems, termed the "home energy retrofit" herein. We first derive research hypotheses on the effects of time, risk, and social preference characteristics on home energy retrofit decisions by modifying the theoretical model of Allcott and Greenstone [12] explaining the source of the EE gap. Then, by analyzing the survey data that we gather, we examine whether the hypotheses are supported: we apply a probit estimation to the survey data of Korean people's home energy retrofit decisions with their time, risk, and social preference characteristics.

In Korea, there exists 18.8 million residential buildings, and more than half of them were built 15 years ago [13]. This figure indicates that there exists sufficient demand for home energy retrofit, by considering that the Korean government mandates boiler retrofits for apartments 15 years old. The 3rd Energy Master Plan [14], which determines the overall policy directions, admitted that existing buildings had been less concerned despite their importance in EE policy and that they were one of the most important targets for sustainable energy transitions. However, policy measures lacking considerations of residents' behavior aspects might be ineffective to enhance EE of existing buildings. By identifying the causes of EE gaps related to housing in terms of preference characteristics, this study contributes to the formulation of policies aimed at boosting home energy retrofit. Our results suggest that policies reducing the EE gap from high implicit discount rate and uncertainty and strategies strengthening environmental attitude or invigorating pro-social activities can contribute to induce home energy retrofit decisions. This study contributes to the literature on a behavioral approach regarding EE by bridging the gap in the literature. Many previous studies have focused one or two preference characteristics [10,11,15–18]. This study jointly investigates the effects of time, risk, and social preference characteristics and thus, provides more reliable results compared to the literature. It also derives meaningful insight into EE policy measures based on behavioral interventions.

The remainder of this paper proceeds as follows. In Section 2, we formulate the research hypotheses on the effects of time, risk, social preferences on the EE gap. We then describe the survey used to elicit Korean people's time, risk, and social preference characteristics and their self-reported home energy retrofit decisions in Section 3. Section 4 describes the data used. Section 5 introduces the econometric approach to obtain the quantities in which we are interested, demonstrates the estimation results, and discusses their policy implications. Finally, Section 6 presents the conclusions.

2. Research Hypotheses

We modify the intuition of the EE investment model of Allcott and Greenstone [12] to suggest research hypotheses explaining how time, risk, and social preference characteristics affect an agent's home energy retrofit decision. Allcott and Greenstone [12] proposed a simple but intuitive model in which an agent chooses between two types of energy-using durable goods.

In the setup of Allcott and Greenstone [12], pp.9–14, an agent is required to choose between two different goods, which are denoted option A, for the energy efficient version, and option B, for the energy inefficient baseline. The agent chooses and pays for capital investment in the period 0, whereas he/she uses the good and incurs energy cost. The energy intensities of two goods are e_A and e_B , respectively, with $e_A < e_B$. While option

A is more energy-efficient, it incurs the incremental upfront capital cost $c > 0$ and unobserved incremental opportunity cost ξ , which is understood as the difference between an engineering estimate of energy conservation cost and an empirical estimate of returns of investment. Then, the agent's choice depends on the cost comparison between two options, he/she will choose option A if:

$$\frac{\gamma p m_i (e_B - e_A)}{(1 + d)} - \xi > c. \quad (1)$$

d: risk-adjusted discount factor between two periods ($d > 0$)

ξ : unobserved incremental utility cost ($\xi > 0$) or benefit ($\xi < 0$)

p: private cost of energy in period 1

m_i : an agent's taste for usage of the durable good.

γ : implicit weight on energy cost savings in an agent's decision

Allcott and Greenstone [12] argued that the γ parameter is “the essence of EE gap” and is “conceptually related to implied discount rate that rationalizes the tradeoffs that agents make between upfront investment costs and future energy savings,” where $\gamma < 1$ indicates the existence of EE gap. They assumed that imperfect information and inattention are linked to this implied discount rate and eventually induce the EE gap. The arguments of Allcott and Greenstone [12] contributed to building a model that identifies the existence of EE gap. Meanwhile, in their approach [12], many behavioral factors which were supposed to influence the EE gap were not considered seriously, and merely summarized into imperfect information and inattention. The ignored behavioral factors are highly related to an agent's time, risk, and social preference characteristics, referring [15–17,19–22]. In this paper, starting from the perspective of the EE investment model shown in Equation (1), we hypothesize how time, risk, and social preference characteristics other than imperfect information and inattention affect home energy retrofit decisions.

First, present bias, which is considered as one of time preference characteristics, may cause the EE gap by increasing the implicit discount rate, d/γ in Equation (1). d/γ determines the balance of cost/benefit transactions occurring at different periods in the intertemporal choice. Implicit discount rates of EE investments are remarkably higher than money market rates, and higher implicit discount rates cause the EE gap [10,15,21]. DEFRA [19] pointed out present bias as one of the main factors increasing the implicit discount rate of EE investments. According to the simulation of Angeletos et al. [23], within the typical payback period of a home energy retrofit in Korea [24], a discount rate with quasi-hyperbolic schedules increases faster than that with exponential schedules [25].

We can check if an agent's time preference characteristics follow a quasi-hyperbolic discount schedule by using Equation (2), which is suggested by Laibson [26]:

$$D_i(t) = \frac{1}{d(t)/\gamma(t)} = \begin{cases} 1 & \text{if } t = 0 \\ \beta_i \delta_i^t & \text{if } t \geq 1 \end{cases}. \quad (2)$$

$D_i(t)$ has the inverse value of the implicit discount rate in period t for agent i and is decomposed into β_i and δ_i as $t \geq 1$. If $\beta_i < 1$, agent i 's time preference is present biased. If $\beta_i = 1$, his/her discount schedules are exponential. δ_i is defined as the adjusted discounting factor in which the effect of present bias on $D_i(t)$ is eliminated. Based on Equation (2), we formulate two hypotheses about the effects of the time preference characteristics on home energy retrofit decisions as follows:

Hypothesis 1 (H1a). *If an agent's time preference is present biased ($\beta_i < 1$), the possibility of investing in a home energy retrofit decreases.*

Hypothesis 1 (H1b). *The greater the adjusted discounting factor ($\delta_i \uparrow$), the greater is the possibility of investing in a home energy retrofit.*

Second, risk aversion, which is considered as one of risk preference characteristics, also contributes to extending the EE gap. Risk aversion is one of the sources causing present bias and thus, can increase the implicit discount rate by building up present bias [27]. Empirical studies supported the linkage between risk aversion and the EE gap. Greene [11] argued that when consumers decide to purchase a pro-environmental vehicle, the uncertainty about the net value of future fuel savings widens the EE gap. Farsi [16] provided empirical evidence that consumers are risk averse toward the benefits of EE systems and that this risk aversion significantly decreases the willingness to pay (WTP) for EE systems. By eliciting people's self-reported purchase history of EE technologies and their risk aversion, Qiu et al. [17] found that risk aversion negatively affects the likelihood of purchasing EE technologies. Fischbacher et al. [21] argued that homeowners more likely to take risks in general or in financial matters are more likely to invest in a home energy retrofit. Building on these discussions, we consider that an agent's risk aversion intensifies the EE gap by decreasing γ and thus formulate the following research hypothesis:

Hypothesis 2. *The more risk averse an agent is, the less likely he/she is to invest in a home energy retrofit.*

Finally, social preference characteristics including attitude toward environmental pollution and social norm may contribute to reducing the EE gap by increasing γ . Social preference helps explain why decision makers are concerned about not only their self-interest but also the payoffs of others because of altruism, fairness, reciprocity, and envy [28]. When looking into the EE investment decisions, one of the most frequently mentioned characteristics is attitude toward environmental pollution or climate change. In the theory of planned behavior, an agent's attitude toward behavior influences his/her actual behavior. Many empirical studies found that people seriously concerned about environmental pollution or climate change tend to be positive toward energy saving, EE investments, or green labeled residential buildings [18,22,29–31]. In particular, di Maria et al. [18] suggested that environmental attitude affects the implicit discount rate in the decision of energy efficient light bulb adoption. Another social preference characteristic that is expected to encourage EE investment is moral norms. Considering that energy saving is a type of pro-social behavior, the moral norms embodied in moral obligation and altruism are likely to encourage EE investment [32]. In addition, social comparisons stimulating social norms including injunctive norms and descriptive norms attract significant energy savings, and social comparisons may thus induce a home energy retrofit [20,33]. Based on these discussions, we formulate the following research hypotheses:

Hypothesis 3 (H3a). *The more seriously an agent is concerned about the influence of environmental pollution and climate change, the more likely he/she is to invest in a home energy retrofit.*

Hypothesis 3 (H3b). *The stronger an agent's moral norms are, the more likely he/she is to invest in a home energy retrofit.*

Hypothesis 3 (H3c). *The more sensitive toward social comparisons an agent is, the more likely he/she is to invest in a home energy retrofit.*

3. Survey Design

We conducted an online survey from 18–26 July 2016 to gather the data for analyzing the effects of the time, risk, and social preferences on home energy retrofit decisions. Before the survey, we made multiple improvements and adjustments to the questionnaire based on two pilot tests and suggestions from experts. The target population consists of household heads or their spouses aged from 20 to 65 living in 16 regions of Korea, who are likely to take the leading role in home energy retrofit decisions. Quota sampling by housing type, region, gender, and age is used here. [34], which is a national survey to understand the

size and characteristics of all people and houses in Korea and was the most up-to-date census at the time of the survey, provides the sampling frame for this survey. The target population includes both owner-occupiers and tenants. The questionnaire used in the survey is presented in a form of Supplementary Materials.

The survey consists of five blocks: (1) questions for eliciting the discounting factor and present bias, (2) questions for eliciting the risk aversion coefficient, (3) questions for inferring attitude toward environmental problems, moral obligation, and sensitivity toward social comparisons, (4) information about home energy retrofit decisions as well as housing conditions and energy use, and (5) information about socioeconomic factors. The questions contained in the first three blocks aiming to elicit the preference characteristics are designed by referring to the literature in the field of behavioral and experimental economics to exclude subjective judgments as much as possible. The detailed explanation of this design is presented in the subsequent sections. The questions on home energy retrofit decisions in the fourth block are designed by referring to Kim [35]. We ask respondents about their experiences and plans for a home energy retrofit. In particular, we present representative six activities of home energy retrofits as examples and ask survey participants to choose whether they have carried out any of these activities or plan to in the future. The remainder of the questions in the fourth block and the questions in the fifth block are designed by referring Frederiks et al. [30] that comprehensively reviewed previous research on the individual-level factors determining residential energy consumption. The responses to these questions are used to control for individual factors other than the preference characteristics.

3.1. Time Preference Characteristics

We assume that individuals' time preference characteristics are reflected in β_i and δ_i in Equation (2). To separately identify β_i and δ_i , we need to obtain information about $D_i(t)$ for at least two time periods. We thus provide a series of questions to infer a discounting factor of KRW (the South Korean Won) 0.5 million (approximately \$450) one year later, $D_i(1)$, and a discounting factor of KRW 0.5 million 10 years later, $D_i(10)$, by using the multiple price listing method [36–39]. Respondents are given the payoff tables in Table 1 with five almost symmetric intervals. Here, the first and second binary choices verify $D_i(1)$ and $D_i(10)$, respectively. The principle of the first binary choice question is simple: would you prefer KRW 0.5 million in one month or KRW 0.5 million + α (>0) in one year and one month? [36] Respondents are asked to choose between Choices A and B for each of the five payoff alternatives. We can infer the interval of $D_i(1)$ by observing when a respondent chooses A instead of B. Likewise, we can infer the interval of $D_i(10)$ by observing a respondent's choice between A and B in the second binary choices. Assuming that a respondent's discounting factor has a median value of the interval, substituting $D_i(1)$ and $D_i(10)$ into Equation (2) provides the approximate values of β_i and δ_i .

Table 1. Payoff tables for 1 year and 10 year time horizon in the questions eliciting time preference characteristics.

	Choice A ⁴	Choice B	Discounting Factor
First binary choice ^{1,3}			
(1–1)	KRW 0.5 million	KRW 0.52 million	0.962
(1–2)	KRW 0.5 million	KRW 0.54 million	0.926
(1–3)	KRW 0.5 million	KRW 0.56 million	0.893
(1–4)	KRW 0.5 million	KRW 0.58 million	0.862
(1–5)	KRW 0.5 million	KRW 0.60 million	0.833
Second binary choice ^{2,3}			
(2–1)	KRW 0.5 million	KRW 0.7 million	0.714
(2–2)	KRW 0.5 million	KRW 1.1 million	0.455
(2–3)	KRW 0.5 million	KRW 1.6 million	0.313
(2–4)	KRW 0.5 million	KRW 2.2 million	0.227
(2–5)	KRW 0.5 million	KRW 3.0 million	0.167

¹ In the first binary choice, Choice A is to accept the suggested amount below in 1 month and Choice B is to accept the suggested amount below in 1 year and 1 month. ² In the second binary choice, Choice A is to accept the proposed amount below in 1 month and Choice B is to accept the proposed amount below in 10 years and 1 month. ³ Choosing each delay as an acceptance after 1 month is intended to control for the front-end-delay effect [36]. ⁴ The suggested amount of KRW 0.5 million is set to close to the actual yearly benefit of home energy retrofits in Korea with reference to Park [24].

3.2. Risk Preference Characteristics

Under the assumption of constant relative aversion (CRRA) utility function $u_i(x) = x^{(1-r_i)} / (1 - r_i)$, a respondent's CRRA coefficient, r_i , shows the degree of his/her risk aversion. $r_i < 0$ implies risk seeking, $r_i = 0$ risk neutral, and $r_i > 0$ risk averse [17]. Based on the classification in Holt and Laury [40], we categorize respondents' risk aversion into five groups: very risk seeking, risk seeking, risk neutral, risk averse, and very risk averse. To derive the interval of r_i , we assess the WTP for a gamble of tossing a coin where a player is paid KRW 80,000 (approximately \$72) if the head is upside and KRW 40,000 (approximately \$36) otherwise [41]. The upper and lower rewards are determined by referring to the range of the actual monthly benefits of home energy retrofits in Korea [24].

The WTP for this gamble is elicited in the triple-bounded dichotomous choice format, which classifies the responses into six groups: Yes-Yes-Yes, Yes-Yes-No, Yes-No, No-Yes, No-No-Yes, and No-No-No [42]. We first determine the criteria of r_i following our risk aversion classification and then derive the WTP intervals that align with these criteria. Table 2 reveals how to infer respondents' risk aversion based on their responses to the WTP questions. As the expected value of this gamble is KRW 60,000 (approximately \$54), in the first question, a respondent is asked whether he/she is willing to pay KRW 60,000. If he/she responds "yes" to the initial bid, the respondent is asked the same question with a higher amount of money (KRW 60,500). If he/she responds "no" to the initial bid, a follow-up question with a lower amount is asked (KRW 59,500). This procedure is repeated to fix the third bid, and respondents do not face the third bid when their first two bid responses are different [42].

Our questionnaire design for eliciting r_i is contrary to that proposed by Qiu et al. [17], who framed the questions of eliciting risk preference characteristics in the context of EE improvements at home. Even though our purpose is to uncover the linkage of risk preference characteristics toward home energy retrofit decisions, the context of our survey questions is intentionally unrelated to a home energy retrofit for the following reasons. First, within the context of deciding on a home energy retrofit, a respondent may consider other uncertainties besides the payoffs presented in the questions, meaning that the derived risk aversion coefficient would be biased. Second, Qiu et al. [17] replicated the risk experiment of Holt and Laury [40] by simply replacing lotteries with options of lifetime energy cost savings. However, the actual payoff structure for home energy improvements differs from that of the lottery choice in Holt and Laury [40]. Thus, we derive respondents' risk aversion coefficients in a typical context widely applied in the literature on risk experiments.

Table 2. Risk aversion classification based on the responses to willingness to pay (WTP) questions.

Response	WTP Interval	CRRA Coefficient ¹	Classification
Yes-Yes-Yes	$WTP \geq \text{KRW } 61,500$	$r_i < -0.45$	Very risk seeking
Yes-Yes-No	$\text{KRW } 60,500 \leq WTP < \text{KRW } 61,500$	$-0.45 < r_i < -0.15$	Risk seeking
Yes-No; No-Yes	$\text{KRW } 59,500 \leq WTP < \text{KRW } 60,500$	$-0.15 < r_i < 0.15$	Risk neutral
No-No-Yes	$\text{KRW } 58,500 \leq WTP < \text{KRW } 59,500$	$0.15 < r_i < 0.44$	Risk averse
No-No-No	$WTP < \text{KRW } 58,500$	$r_i > 0.44$	Very risk averse

¹ Risk aversion is classified by the constant relative aversion (CRRA) coefficient given in Holt and Laury [40].

3.3. Social Preference Characteristics

In this study, social preference characteristics are represented by concerns about the influence of environmental pollution and climate change, strength of moral norms, and sensitivity toward social comparisons, as mentioned in Section 2. First, to figure out how seriously respondents are concerned about the influence of environmental pollution and climate change, we present the nine statements of Diekmann and Preisendörfer [43]. They developed questions to understand people's environmental attitudes from affective, cognitive, and conative aspects. These statements can be answered on a five-point Likert scale: strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree. The higher the level of their agreement to the statements, the more seriously they are concerned about the influence of environmental pollution and climate change.

Second, to understand how strong respondents' moral norms are, we ask about their experiences of charity activities including donation and volunteering activities. Referring the arguments of van der Linden [44] that moral norms play a significant role in the formation of charitable intention, we use respondents' experiences of donation and volunteering activities as the proxies for the measuring the strength of their moral norms. Using the questions provided in Kim et al. [45], we ask them if they have ever donated to religious organizations, politicians, or non-governmental organizations. We also ask them how much they have participated in volunteering activities such as fundraising, unpaid service, teaching or counseling, or collecting relief supplies in the past.

Finally, to find out how sensitive respondents are to comparing energy consumption with others, we ask the following question: "do you think that you are paying more energy costs than other similar households?" They can answer this question on the same five-point Likert scale. The insertion of this question is inspired by the Social Comparison Module of the OPOWER's Home Energy Report. The Home Energy Report compares a household's energy use to that of similar neighborhoods and provides energy conservation tips. Allcott [20] provided the evidence that the Home Energy Report reduces energy consumption by 2.0%. We assume that respondents thinking that they are paying more energy costs are more sensitive toward social comparisons.

4. Data Description

We sent 27,872 people selected from the target population e-mails asking them to participate in the survey and 1856 (6.7%) completed the survey. Among the responses of the 1856 people who completed the survey, we use the responses of 1609 people that guarantee consistency.

The survey results are processed to construct the dependent and explanatory variables for our empirical analysis (Table 3). We use two dependent variables: *EXP*, which indicates whether household *i* has experienced a home energy retrofit in her/his current house, and *PLAN*, which indicates whether household *i* plans to carry out a home energy retrofit in the next three years. *EXP* is a dummy variable being 1 if a respondent has experienced any of the six home energy retrofit activities. *PLAN* is defined in the same way. Approximately 75% of respondents have previously invested in a home energy retrofit and about 67% plan to invest in that in the future.

Table 3. Data description and sample statistics.

Variable	Description	Mean (S.D.) ²
<i>EXP</i>	1 if one has experienced home energy retrofit in the past, or 0 otherwise	0.749 (0.434)
<i>PLAN</i>	1 if one has a plan of home energy retrofit in 3 years, or 0 otherwise	0.672 (0.469)
<i>P.bias</i>	1 if $\beta_i < 1$ where $D_i(t) = \beta_i \delta_i^t, t \geq 1$ or 0 otherwise	0.659 (0.474)
<i>D.factor</i>	δ_i where $D_i(t) = \beta_i \delta_i^t, t \geq 1$	0.877 (0.069)
<i>Risk.1</i>	1 if one is very risk seeking, or 0 otherwise	0.149 (0.356)
<i>Risk.2</i>	1 if one is risk seeking, or 0 otherwise	0.028 (0.165)
<i>Risk.3</i>	1 if one is risk neutral, or 0 otherwise (base)	0.080 (0.272)
<i>Risk.4</i>	1 if one is risk averse, or 0 otherwise	0.009 (0.093)
<i>Risk.5</i>	1 if one is very risk averse, or 0 otherwise	0.735 (0.442)
<i>Attitude</i>	Attitudes toward environment issues (standardized) ¹	0.000 (3.047)
<i>Donation</i>	1 if one has ever donated, or 0 otherwise	0.622 (0.485)
<i>Volunteer</i>	Degree of participation in unpaid volunteer activities (standardized) ¹	0.000 (3.285)
<i>Comparison</i>	Sensitivity to energy expensed compared to similar households (standardized) ¹	0.000 (0.889)
<i>Edu</i>	1 if one entered or graduated a college, or 0 otherwise	0.843 (0.364)
<i>Child</i>	1 if there is any infant or toddler in his/her family, or 0 otherwise	0.204 (0.403)
<i>Senior</i>	1 if there is any senior in his/her family, or 0 otherwise	0.221 (0.415)
<i>Inc.1</i>	1 if the average monthly household income is below KRW 2 million, or 0 otherwise (base)	0.085 (0.279)
<i>Inc.2</i>	1 if the average monthly household income is KRW 2–4 million, or 0 otherwise	0.307 (0.461)
<i>Inc.3</i>	1 if the average monthly household income is KRW 4–6 million, or 0 otherwise	0.365 (0.482)
<i>Inc.4</i>	1 if the average monthly household income is KRW 6–8 million, or 0 otherwise	0.152 (0.359)
<i>Inc.5</i>	1 if the average monthly household income is over KRW 8 million, or 0 otherwise	0.091 (0.287)
<i>APT</i>	1 if living in an apartment, or 0 if living in other types of housing	0.643 (0.479)
<i>H.age1</i>	1 if living in a house built before 2000, or 0 otherwise	0.514 (0.500)
<i>H.age2</i>	1 if living in a house built between 2000 and 2010, or 0 otherwise (base)	0.318 (0.466)
<i>H.age3</i>	1 if living in a house built since 2011, or 0 otherwise	0.168 (0.374)
<i>Owner-occupier</i>	1 if one is owner-occupier, or tenants otherwise	0.468 (0.499)
<i>MP2</i>	1 if there is a possibility of moving within 2 years, or 0 otherwise	0.690 (0.463)
<i>Expense</i>	Level of expenses for heating and electricity (standardized) ¹	0.000 (1.114)
<i>Prospect</i>	Prospects for energy price changes in the future (standardized) ¹	0.000 (0.873)

¹ In case of standardized variables, only the variations provide valid information because they are standardized with zero means. ² S.D. is abbreviation for standard deviation.

Both *P.bias* and *D.factor* represent time preference characteristics. The survey results show that time preferences of more than 65% of the respondents are present biased. The sample mean of adjusted discounting factor is 0.877, which equals 14.0% at a discount rate. This discount rate is much higher than a typical money market rate. This result implies

that respondents attach lower discounted value to energy savings, and it is consistent with previous studies [10,15]. H1a is supported if the coefficient of *P.bias* has a statistically significant negative value, and a significant positive coefficient of *D.factor* supports H1b.

The variables reflecting the risk preference characteristics are *Risk.1*, *Risk.2*, *Risk.4*, and *Risk.5*; *Risk.3* is chosen as the base group. 17.7% of the respondents are (very) risk seeking, whereas 74.4% are (very) risk averse. H2 is supported if the coefficient of *Risk.1* or *Risk.2* is estimated to be significantly positive and/or if the coefficient of *Risk.4* or *Risk.5* is estimated to be significantly negative.

The variables *Attitude*, *Donation*, *Volunteer*, and *Comparison* represent the social preference characteristics. We derive a single indicator, *Attitude*, by calculating a standardized factor score based on the factor analysis using the responses to the nine statements of Diekmann and Preisendörfer [43]. We derive the variables *Volunteer* and *Comparison* in the same manner. The variable *Donation*, which is a dummy variable, reveals that 62.2% have ever donated. A coefficient of *Attitude* with a statistically significant positive value can be interpreted as supporting H3a. If the coefficient of *Donation* or *Volunteer* is significantly positive, it can be regarded as supporting H3b. Finally, a significant positive coefficient of *Comparison* supports H3c.

Table 3 also describes variables that might affect home energy retrofit decisions, such as socioeconomic characteristics, housing conditions, and perceptions of energy consumption. The variable *Edu*, *Child*, *Senior*, *Inc.1–Inc.5*, *APT*, *H.age1–H.age3*, and *Owner-occupier* are included by referring Frederiks et al. [7]. In particular, the variable *Owner-occupier* is included to see the difference between owner-occupiers and tenants in their home energy retrofit decisions.

We also include the variable *MP2* to check out whether the possibility of moving has a significant impact on home energy retrofit decisions. The variable *Expense*, which is a standardized factor score summarizing information of respondents' average heating bill in winter and average monthly electric bill, is included to control households' demands for energy consumption. The variable *Prospect* is included to check whether the arguments of Alberini et al. [46] that individuals who expect significant price increases are more likely to undertake EE investments are also valid in Korea. A standardized factor score combining respondents' expectations for gasoline price changes and electricity charge changes in the next ten years is used for this variable. Before a full-scale econometric analysis, we compare the sample means of the dependent variable *EXP* and *PLAN* by the status of the critical independent variables reflecting time, risk, and social preference characteristics to get an overview of whether the survey results support the research hypotheses presented in Section 2 (Table 4).

The sample means of *EXP* by the status of *P.bias* demonstrate that the proportion of the respondents experiencing a home energy retrofit is smaller in the group of those who are considered to be present biased than in the group of those who are not. The sample means of *PLAN* by the status of *P.bias* deliver a similar feature. Overall, these statistics are likely to be consistent with H1a. The sample means of *EXP* by the status of *D.factor* are calculated by the proportion of those who experienced home energy retrofit when their estimates of δ_i are smaller than the 25th percentile, between the 25th percentile and the 75th percentile, and higher than the 75th percentile, respectively. The sample mean of *EXP* increases from 72.0% to 78.3% as the percentile increases. The sample means of *PLAN* by the status of *D.factor* reveal the same tendency. Therefore, these statistics seem to support H1b.

The sample means of *EXP* and *PLAN* by the status of *Risk.1* through *Risk.5* are likely to be partially consistent with H2. The sample mean of *EXP* (83.3%) in the group of the very risk seeking respondents is higher than the sample mean of *EXP* (72.2%) in the group of the very risk averse respondents. Yet, the suggested relationship between risk aversion and *EXP* is not established for the group of the risk seeking respondents or the group of the risk averse respondents. Between risk aversion and *PLAN*, however, the suggested relationship seems to be validated. The sample mean of *PLAN* by the status of *Risk.1–Risk.5*

demonstrates that the proportion of those planning home energy retrofit decrease along with the increase in the degree of risk aversion.

Table 4. Sample mean of *EXP* and *PLAN* by the status of the preference variables.

Variables	Status ^{1,2}	Observations	<i>EXP</i> = 1	<i>PLAN</i> = 1
<i>P.bias</i>	<i>P.bias</i> = 1	1,061	0.739	0.657
	<i>P.bias</i> = 0	548	0.768	0.703
<i>D.factor</i>	<i>D.factor</i> < <i>p</i> (25)	393	0.720	0.595
	<i>p</i> (25) ≤ <i>D.factor</i> ≤ <i>p</i> (75)	825	0.747	0.688
	<i>D.factor</i> > <i>p</i> (75)	391	0.783	0.716
<i>Risk.1</i>	<i>Risk.1</i> = 1	239	0.833	0.787
<i>Risk.2</i>	<i>Risk.2</i> = 1	45	0.844	0.756
<i>Risk.3</i>	<i>Risk.3</i> = 1	129	0.798	0.636
<i>Risk.4</i>	<i>Risk.4</i> = 1	14	0.857	0.714
<i>Risk.5</i>	<i>Risk.5</i> = 1	1,182	0.722	0.650
<i>Attitude</i>	<i>Attitude</i> < <i>p</i> (25)	401	0.691	0.601
	<i>P</i> (25) ≤ <i>Attitude</i> ≤ <i>p</i> (75)	807	0.767	0.682
	<i>Attitude</i> > <i>p</i> (75)	401	0.771	0.726
<i>Donation</i>	<i>Donation</i> = 1	1,001	0.807	0.746
	<i>Donation</i> = 0	608	0.653	0.551
<i>Volunteer</i>	<i>Volunteer</i> < <i>p</i> (25)	399	0.674	0.579
	<i>P</i> (25) ≤ <i>Volunteer</i> ≤ <i>p</i> (75)	906	0.747	0.673
	<i>Volunteer</i> > <i>p</i> (75)	304	0.852	0.793
<i>Comparison</i>	<i>Comparison</i> < <i>p</i> (25)	346	0.731	0.630
	<i>P</i> (25) ≤ <i>Comparison</i> ≤ <i>p</i> (75)	915	0.726	0.654
	<i>Comparison</i> > <i>p</i> (75)	348	0.828	0.764

¹ For a dummy variable, the mean is provided by its status. ² For a continuous variable, the mean is provided depending on its the 25th percentile and the 75th percentile.

The sample means of *EXP* by the status of *Attitude* demonstrate variations in the proportion of the respondents who experienced home energy retrofit by their attitudes toward environmental pollution and climate change. The proportion increases from 69.1% up to 77.1% as the percentile increases. The sample means of *PLAN* by the status of *Attitude* illustrate the same tendency. Based on these sample statistics, H3a is likely to be valid. The sample statistics of *EXP* and *PLAN* by the status of *Donation* and by the status of *Volunteer* are likely to support H3b. The sample mean of *EXP* in the group of the respondents who have ever donated is 80.7%, which is higher than the sample mean (65.3%) of *EXP* in the others. The sample mean of *PLAN* also increases from 55.1% to 74.6% depending on their donation experiences. Likewise, the sample means of *EXP* and *PLAN* increase depending on the degree of participating in volunteer activities. For example, the sample mean of *EXP* in the group of the respondents whose degrees of participating in volunteer activities are smaller than the 25th percentile is 67.4%. It increases up to 85.2% with the percentile increase. The sample means of *EXP* and *PLAN* by the status of *Comparison* are in line with H3c. The sample mean of *EXP* is 73.1% for the respondents whose sensitivities toward relative energy costs are below the 25th percentile. It increases up to 82.8% for the respondents whose sensitivities are over the 75th percentile.

Consequently, we can infer that our survey data may support all the research hypotheses for now. We need a rigorous analysis to confirm it by controlling for other variables.

5. Estimation Model and Empirical Results

5.1. Model Specification

The purpose of this study is to investigate the impact of time, risk, and social preference characteristics on home energy retrofit decisions. Following the arguments of Qiu et al. [17], Fischbacher et al. [21], and Ramos et al. [22], we begin with the linear model of utility function y^* :

$$y^* = X\theta + u, \quad (3)$$

where X includes the time, risk, and social preferences as well as the other individual characteristics that may affect y^* . The list of individual characteristics is presented in Table 3. The error term u is assumed to be independent of X and has a standard normal distribution.

Even though we cannot observe y^* , we can observe the response function y , defined based on y^* :

$$y = \begin{cases} 1 & \text{if } y^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

y is *EXP* or *PLAN*. We then can apply the probit model as follows:

$$\Pr(y = 1|X) = \Pr(X\theta + u > 0|X) = \Phi(X\theta) \quad (5)$$

where $\Phi(\cdot)$ is the standard normal cumulative distribution function.

Using the estimation results of the probit model, we further derive the average partial effects (APEs), which allow us the quantitative effects of each explanatory variable on the possibility of dependent variables [47]. The partial effect of an explanatory variable in probit model differs by where it is evaluated. Therefore, in order to summarize them into a single number, we use APEs. Each APE shows a change in the response probability resulted from a unit change in an explanatory variable.

5.2. Empirical Results

5.2.1. Dependent Variable: *EXP*

Table 5 presents the coefficient and APE estimates for *EXP*. When it comes to the impacts of the time preference characteristics, neither *P.bias* nor *D.factor* is significant at the 10% level, although their directions are consistent with our expectations. Among the variables reflecting the risk preference characteristics, only *Risk.5* is negatively significant at the 5% level. In particular, the APE estimate of *Risk.5* indicates that very risk-averse respondents are about 8%p less likely to have experienced a home energy retrofit than risk-neutral respondents. Among the variables reflecting the social preference characteristics, *Attitude*, *Donation*, and *Volunteer* are positively significant, whereas *Comparison* is not significant. This finding reveals that respondents seriously concerned about environmental pollution and climate change issues, who have ever donated, or who have been highly involved with volunteering are likely to have experienced a home energy retrofit. In particular, the APE estimate of *Donation* indicates those who have donated over the past year have a 10.9%p higher chance of having experienced a home energy retrofit than those who have not. In sum, H2, H3a, and H3b are supported by our survey data.

Table 5 also provides the effects of the socioeconomic factors on the probability of a home energy retrofit experience. The APE estimate of *Edu* shows that respondents who have entered or graduated college are 5.1%p less likely to have experienced a home energy retrofit than those who have not. This result is in contrast to Frederiks et al. [30], suggesting that education level is positively related to understanding new technologies (e.g., EE technologies) and thus yields EE improvements. On the contrary, it is in accord with studies analyzing Korean cases [48,49]. There are two plausible explanations for this contradiction. First, the definition of *Edu* in this study is unsuitable for reflecting a variety of education levels. Second, there might be a negative correlation between education level and an awareness of energy saving in Korea [48,49].

Table 5. Estimation results for $y = EXP$.

Variable	Coefficient ^{1,2}	APE ^{1,3}
<i>P.bias</i>	−0.073 (0.140)	−0.023 (0.036)
<i>D.factor</i>	0.129 (0.991)	0.040 (0.221)
<i>Risk.1</i>	−0.041 (0.172)	−0.010 (0.040)
<i>Risk.2</i>	0.019 (0.273)	0.005 (0.067)
<i>Risk.4</i>	−0.063 (0.478)	−0.015 (0.085)
<i>Risk.5</i>	−0.307 ** (0.144)	−0.080 ** (0.034)
<i>Attitude</i>	0.021 * (0.012)	0.006 * (0.003)
<i>Donation</i>	0.385 *** (0.077)	0.109 *** (0.022)
<i>Volunteer</i>	0.040 *** (0.012)	0.011 *** (0.003)
<i>Comparison</i>	0.035 (0.051)	0.010 (0.014)
<i>Edu</i>	−0.193 * (0.108)	−0.051 * (0.027)
<i>Child</i>	−0.003 (0.093)	−0.001 (0.026)
<i>Senior</i>	0.236 ** (0.098)	0.062 ** (0.025)
<i>Inc.2</i>	0.193 (0.139)	0.060 (0.044)
<i>Inc.3</i>	0.424 *** (0.144)	0.124 *** (0.044)
<i>Inc.4</i>	0.371 ** (0.168)	0.110 ** (0.049)
<i>Inc.5</i>	0.512 *** (0.190)	0.146 *** (0.054)
<i>APT</i>	−0.132 (0.083)	−0.036 * (0.022)
<i>H.age1</i>	0.272 *** (0.085)	0.072 *** (0.023)
<i>H.age3</i>	−0.487 *** (0.104)	−0.157 *** (0.033)
<i>MP2</i>	−0.020 (0.077)	−0.006 (0.021)
<i>Owner-occupier</i>	0.443 *** (0.084)	0.129 *** (0.025)
<i>Expense</i>	0.072 * (0.044)	0.020 (0.012)
<i>Prospect</i>	0.099 ** (0.042)	0.027 ** (0.011)
<i>Constant</i>	0.314 (0.884)	−
Scale factor		0.273
Observations		1609
Log-likelihood		−781.680

¹ * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. ² The standard errors of the coefficient estimates are provided in parentheses. ³ The standard errors of APE estimates are calculated using 1000 bootstrap replications and provided in parentheses.

The APE estimate of *Senior* demonstrates that households living with the elderly are 6.2%p more likely to have experienced a home energy retrofit than the others. The elderly are likely to consider thermal comfort or energy saving to be important because they tend to spend more time at home. The APE estimates of *Inc.3*, *Inc.4*, and *Inc.5* show that the effect of income is significant but not linear. For instance, the APE estimate of *Inc.3* shows that respondents with an average monthly household income of KRW 4–6 million have a 12.4%p higher chance of having experienced a home energy retrofit than those with an income of less than KRW 2 million. On the contrary, the APE estimate of *Inc.4* indicates that respondents with an average monthly household income of KRW 6–8 million have a 11%p higher chance of having experienced a home energy retrofit than those with an income of less than KRW 2 million. Thus, it is hard to conclude that the higher the income level, the greater is the likelihood of having experienced a home energy retrofit.

Among the variables reflecting housing conditions and energy use, the effects of *H.age1*, *H.age3*, *Owner-occupier*, and *Prospect* on the probability of a home energy retrofit experience are statistically significant. The APE estimates of *H.age1* and *H.age3* demonstrate that compared with those living in a house built between 2000 and 2010, the probability of having experienced a home energy retrofit is 7.2%p higher for those living in a house built before 2000 and 15.7%p lower for those living in a house built after 2010. This finding implies that the more recently a house is built, the less likely its energy performance is retrofitted. Since a house built after 2010 should meet the reinforced building code including energy performance, the APE estimate of *H.age3* is sensible. The APE estimate of *Owner-occupier* reveals that with our survey data, owner-occupiers are 12.9%p more likely to have experienced a home energy retrofit than tenants. The APE estimate of *Prospect*

implies that those expecting energy prices to increase in the future are more likely to experience a home energy retrofit; this implication is in line with Alberini et al. [46].

5.2.2. Dependent Variable: *PLAN*

In Table 6, the coefficient and APE estimation results for *PLAN* are demonstrated. Concerning the effects of the time preference characteristics first, both the estimates of *P.bias* and *D.factor* are statistically insignificant, although their directions are consistent with our expectations. Meanwhile, the APE estimate of *D.factor* is positively significant at the 10% level, and partially supports H1b. Second, among the four variables reflecting the risk preference characteristics, only *Risk.1* is statistically significant at the 1% level, which partially supports H2. Its APE estimate suggests that compared with risk-neutral respondents, the probability of planning a home energy retrofit is 12.6%p higher for very risk-seeking respondents. Finally, we examine the effects of the social preference characteristics. H3a and H3b are supported since the estimates of *Attitude*, *Donation*, and *Volunteer* are positive and statistically significant. The APE estimate of *Donation* implies that respondents who have donated are 10.8%p more likely to plan a home energy retrofit in the future than those who have not.

Table 6. Estimation results for $y = PLAN$.

Variable	Coefficient ^{1,2}	APE ^{1,3}
<i>P.bias</i>	−0.212 (0.133)	−0.052 (0.032)
<i>D.factor</i>	1.482 (0.934)	0.368 * (0.194)
<i>Risk.1</i>	0.430 *** (0.160)	0.126 *** (0.047)
<i>Risk.2</i>	0.250 (0.245)	0.076 (0.080)
<i>Risk.4</i>	0.063 (0.392)	0.020 (0.132)
<i>Risk.5</i>	0.171 (0.130)	0.053 (0.041)
<i>Attitude</i>	0.031 *** (0.012)	0.009 ** (0.004)
<i>Donation</i>	0.353 *** (0.076)	0.108 *** (0.024)
<i>Volunteer</i>	0.020 * (0.012)	0.006 * (0.003)
<i>Comparison</i>	0.074 (0.049)	0.022 (0.014)
<i>Edu</i>	0.063 (0.102)	0.019 (0.031)
<i>Child</i>	0.013 (0.092)	0.004 (0.028)
<i>Senior</i>	0.198 ** (0.092)	0.057 ** (0.026)
<i>Inc.2</i>	0.228 * (0.138)	0.069 (0.044)
<i>Inc.3</i>	0.268 * (0.141)	0.081 * (0.043)
<i>Inc.4</i>	0.111 (0.163)	0.035 (0.052)
<i>Inc.5</i>	−0.005 (0.179)	−0.001 (0.055)
<i>APT</i>	0.049 (0.078)	0.015 (0.023)
<i>H.age1</i>	−0.242 *** (0.083)	−0.070 *** (0.024)
<i>H.age3</i>	−0.265 ** (0.107)	−0.077 ** (0.032)
<i>MP2</i>	0.268 *** (0.075)	0.079 *** (0.022)
<i>Owner-occupier</i>	0.246 *** (0.083)	0.075 *** (0.027)
<i>Expense</i>	0.056 (0.042)	0.017 (0.013)
<i>Prospect</i>	0.020 (0.042)	0.006 (0.012)
<i>EXP</i>	0.919 *** (0.083)	0.315 *** (0.030)
<i>Constant</i>	−2.175 *** (0.835)	
Scale factor		0.296
Observations		1609
Log-likelihood		−844.344

¹ * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. ² The standard errors of the coefficients are provided in parentheses. ³ The standard errors of APEs are calculated using 1000 bootstrap replications and provided in parentheses.

In terms of the socioeconomic factors, the APE estimate of *Senior* shows that households living with the elderly have a 5.7%p higher chance of planning a home energy retrofit than the others. The APE estimate of *Inc.3* indicates that compared with those with an average monthly household income of less than KRW 2 million, the probability of planning a home energy retrofit is 8.1%p higher for those with an income of KRW 2–4 million. When considering the APE estimates of *Inc.2*, *Inc.3*, *Inc.4*, and *Inc.5* altogether, the effects of

income level on *PLAN* are non-linear like those on *EXP*. The effects of *H.age1*, *H.age3*, *MP2*, and *Owner-occupier* are significant. Compared with those living in a house built between 2000 and 2010, the probability of planning a home energy retrofit is lower for those living in a house built before 2000 and is also lower for those living in a house built after 2010. Considering that the estimated APE of *H.age1* on *EXP* is 0.072, respondents living in a house built before 2000 are less likely to plan a home energy retrofit in the next three years because they have already experienced a home energy retrofit. Based on this result, we can infer that houses built between 2000 and 2010 are the main targets of a home energy retrofit in the near future. In addition, the APE estimate of *MP2* reveals that those planning to move within two years are 7.9%p more likely to plan a home energy retrofit than the others. This result makes sense since Korean people usually plan a home energy retrofit when they move to a new house. Furthermore, the APE estimate of *Owner-occupier* implies that owner-occupiers have a 7.5%p higher chance of planning a home energy retrofit than those who do not.

When it comes to explaining the possibility of planning a home energy retrofit, we include the variable *EXP* as an explanatory variable. The reason to include the variable *EXP* is to figure out the impact of past experiences of a home energy retrofit on future plans. The APE estimate of *EXP* is significantly positive at the 1% level and indicates that those experiencing a home energy retrofit have a 31.5%p higher chance of planning a home energy retrofit than those who do not. The result means that the accumulation of experiences in a home energy retrofit is likely to have a positive impact on future decisions of a home energy retrofit.

5.3. Implications

Overall, our results show that the impacts of time, risk, and social preference characteristics on the home energy retrofit decisions are in line with the research hypotheses. First, the time preference characteristics partially affect respondents' future plans to conduct a home energy retrofit. Our survey results indicate that on average, their time schedules are present biased and their discounting factors, which are inversely proportional to the implicit discount rate, are lower than market standards. The estimation result reveals that the respondents whose discounting factors are lower are less likely to plan to invest in home energy retrofits. However, the heterogeneity in discount schedules has no significant impact on their past home energy retrofit decisions. Together, these findings show that H1b is partially supported. Since our survey data represent discounting schedules for the future, we infer that the impacts of the time preference characteristics are only valid in individuals' future decisions. Given that the implicit interest rates for EE investments are quite higher than money market rates, this finding implies that subsidies rather than loans help to lower the barrier to a home energy retrofit by compensating the EE gap from high implicit discount rates.

Second, we find that the risk preference characteristics play a significant role in respondents' home energy retrofit decisions. The results show that very risk-averse respondents are less likely to have experienced a home energy retrofit and that very risk-seeking ones are more likely to plan a home energy retrofit than risk-neutral ones. This result supports H2: the more risk averse an agent is, the less likely he/she is to invest in a home energy retrofit. Our finding confirms those of previous studies suggesting that uncertainty raises the EE gap [11]. The result suggests that contract methods or government guarantees that reduce uncertainty might be effective at encouraging EE investments such as home energy retrofits.

Third, when it comes to the social preference characteristics, both environmental attitude and moral norms significantly affect not only the possibility of experiencing but also that of planning a home energy retrofit. Respondents seriously concerned about environmental pollution and climate change issues, who have ever donated, or who have been highly involved with volunteering are likely to have experienced or plan a home energy retrofit. However, evidence that sensitivity toward social comparisons affects the

two types of home energy retrofit decisions is lacking. Thus, we conclude that H3a and H3b are accepted, but H3c is not. Our results corroborate the effect of environmental attitude discussed by the previous studies [18,22,30,31]. However, to the best of our knowledge, this is the first study to provide empirical evidence suggesting the positive effect of moral norms on EE investment decisions. This finding implies that either strategies to inspire an environmental attitude or pro-social activities connected with EE programs might contribute to accelerating EE investment.

Furthermore, our results identify significant factors other than the preference characteristics that affect home energy retrofit decisions. We find that people with an average monthly household income below KRW 2 million are less likely to invest in home EE compared with the others. In particular, while low-income households living with the elderly are supposed to need a home energy retrofit, they seem to be incapable of achieving this in general; thus, policy support for EE needs to focus on them. We also show that owner-occupiers are more likely to invest in EE than tenants, resulting in the EE gap between these groups. This result makes sense because (i) if tenants want to retrofit their rental properties, generally they must negotiate with their property owners and (ii) in Korea, a rental contract is usually renewed every two years, which is too short to recoup the benefits of some kinds of EE investments. Thus, this result suggests that it is necessary to develop a policy focusing on improving the EE of tenants. Reinforcing information provision on home EE and EE regulations on property owners may be effective in dealing with this issue. In addition, we identify that houses built between 2000 and 2010 could be the main target for a policy regarding a home energy retrofit. It suggests that it is necessary to develop EE programs targeting the property owners of these houses. Finally, we notice that experiences of a home energy retrofit have a positive impact on plans for a home energy retrofit. The result implies that policy supports to encourage home energy retrofit can contribute to periodically generating new demands.

6. Conclusions

This study ponders the impacts of preference characteristics on home energy retrofit decisions. By categorizing preference characteristics into time, risk, and social, we formulate a series of research hypotheses based on the modification of the EE investment model of Allcott and Greenstone [12]. We then conduct a survey which is designed to elicit the experiences and plans of a home energy retrofit, the preference characteristics, and the socioeconomic characteristics of Korean households. On the responses of 1609 households, we run a probit model with an interest in the effects of the preference characteristics on the possibilities of having experienced a home energy retrofit and on those of planning a home energy retrofit in the future. The results show that respondents who discount the future more heavily are less likely to plan a home energy retrofit. Very risk-averse respondents are less likely to have experienced a home energy retrofit and very risk-seeking ones are more likely to plan a home energy retrofit. Those seriously concerned about environmental pollution and climate change issues or who strongly respond to moral norms are likely to have experienced or plan a home energy retrofit.

This study makes the following contributions to the literature. First, we investigate the joint effects of the time, risk, and social preference characteristics based on the modified intuition of the EE investment model of Allcott and Greenstone [12]. Except Fischbacher et al. [21], most studies mentioned in this section lack a theoretical explanation or focus on only one or two of the three preference characteristics, consequently yielding unreliable results that the effects of the preference characteristics may be exaggerated. Second, we design our survey by borrowing the methods in the previous studies regarding behavioral and experimental economics and thus, try to provide more reliable results. When conducting a survey eliciting time and risk preference characteristics, it is important to pay particular attention to satisfying incentive compatibility and to exclude respondents' subjective judgment. Previous studies such as Fischbacher et al. [21], however, elicited the risk preference characteristics based on subjective judgment; thus, their results are somewhat

doubtful since the risk preference characteristics they elicit vary by context. Even though the survey in this study was conducted five years ago, the results and their implications are valid because the effects of the time, risk, and social preference characteristics on home energy retrofit decisions in this study are in line with previous studies [10,11,15–18]. Furthermore, our results are meaningful because current academic literature provides limited understanding on behavioral aspects of EE investments of Korean people.

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