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The role of risk preferences and loss aversion in farmers' energy-efficient appliance use behavior

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ABSTRACT

Improving rural household energy efficiency is an important policy issue for climate change mitigation in China. A better understanding of the factors affecting farmers' energy-efficient appliance use behavior can help policymakers design more effective policies. This paper explores the effect of farmers' risk preferences and loss aversion on their energy-efficient appliance use behavior in rural China. Using unique data from a survey and a paired lottery experiment completed by 235 rural household heads in the Dazu District of China, this study finds that the farmers' risk preferences and loss aversion have significant effects on their energy-efficient appliance use behavior. The more risk-averse farmers are less likely to buy or use energy-efficient appliances. The farmers who are more loss averse are more willing to purchase and more likely to use durable energy-efficient appliances. In addition, the farmers' demographic factors (age, gender, education, and family location), their perceptions of climate change adaptation and their trust attitudes have significant effects on their energy-efficient appliance use behavior. This paper contributes to the emerging literature that relates risk preferences and loss aversion in experiments to farmers' energy-efficient appliance use behavior.

1. Introduction

Total energy consumption has increased rapidly in the past decades all over the world. Fossil fuels play an important role in the world's energy consumption. However, with fast depletion and many issues surrounding the use of fossil fuels (Dhinesh et al., 2016; Parthasarathy et al., 2016), improving energy efficiency is considered an important option for meeting energy and climate targets in many countries (Matsumoto and Omata, 2017; Craig, 2018). In China, almost one half of the population lives in rural areas (Liu et al., 2013). Therefore, improving the energy efficiency of rural households is considered an important strategy for climate change mitigation in China (Fei and Lin, 2017).

There are a number of factors affecting residents' energy use behavior, such as household composition and income, education and information, and regulations and policies (Wang and Jiang, 2017). In recent years, studies have aimed to incorporate insights from economics, psychology and sociology to overcome the oft-criticized disciplinary lock-in of energy studies (Volland, 2017). Some scholars argue that investments in energy-efficient consumption behavior generate uncertain benefits and can be considered risky (Qiu et al., 2014). Therefore, risk preferences are expected to affect energy efficiency adoption (Just and Zilberman, 1983; Liu and Huang, 2013). Farsi (2010) conducted a choice experiment study in Switzerland and found that risk attitudes were important determinants for consumers to choose energy-efficient home improvements. Fischbacher et al. (2015) suggested that more risk-averse households were less likely to adopt energy-efficient ventilation and insulation systems in Switzerland. In a sample of homeowners from California and Arizona in the US, Qiu et al. (2014) found that individuals who were more risk averse were less likely to have adopted various energy-efficient measures and appliances (but not air conditioners). However, in the context of developing countries, very few empirical studies have considered the influence of risk preferences on energy use behavior.

The common model to characterize an individual's risk preference in the literature is the expected utility theory, where risk aversion is the sole parameter for determining the curvature of the utility function (Holt and Laury, 2002). However, research in the field of behavioral economics has found that individuals presented

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with risky choices perceive the losses more seriously than the equivalent gains. In their seminal paper regarding Prospect Theory and Cumulative Prospect Theory (CPT), Kahneman and Tversky (1979) and Tversky and Kahneman (1992) argue that economic agents behave differently in the loss domain and in the domain of gains. More recently, Pope and Schweitzer (2011) provided evidence that economic agents are indeed loss averse. Thus, loss aversion may affect the adoption of energy-efficient technologies. If decision makers evaluate energy bills as a loss, they may be more willing to use energy-efficient appliances. Therefore, in addition to risk preference, attention should also be given to loss aversion when considering individuals' energy use behavior. However, to the best of our knowledge, only a few studies have empirically examined the extent to which loss aversion plays a role in residents' energy use behavior (Schleich et al., 2017). This study aims to fill this gap by applying a paired lottery experiment to elicit farmers' risk preferences and degree of loss aversion and to explore the effect of farmers' risk preferences and loss aversion on their energy-efficient appliance use behavior in rural China.

This paper first provides the study area, the survey and experimental design, and the sample and data collection. These sections are followed by the empirical results and discussions, a summary of the findings of the study and suggested policy implications.

2. Materials and methods

2.1. Study area

This study uses Dazu District as the study area. It is located in the western suburbs of the Chongqing municipality (see Fig. 1), which is one of the four municipalities directly controlled by the central government of China. Dazu covers a total area of 1436 square kilometers. It has a total population of 1.06 million, with the agricultural population accounting for 55.17 percent. Therefore, rural areas are expected to play an important role in improving energy efficiency in this area. In 2016, the total GDP of the region was 5.73 billion USD (National Bureau of Statistics, 2017). Dazu District is the national commodity grain base and is strongly representative of agricultural production and rural development in China.

2.2. Survey design

The research framework of this study is shown in Fig. 2. The first step is the survey instrument design used in the field, which was developed based on a series of focus-group discussions and pilot tests on people in the general public. Some energy experts, government officials on rural energy policy and local farmers were invited to attend the focus group discussions to collect more detailed information on rural energy use behaviors and to obtain their opinions on the research design. Questionnaires were further pilot tested on local farmers to ensure that all questions in the survey and experiments were understandable. Based on the feedback of the pilot testing surveys, some clarifications and modifications were made.

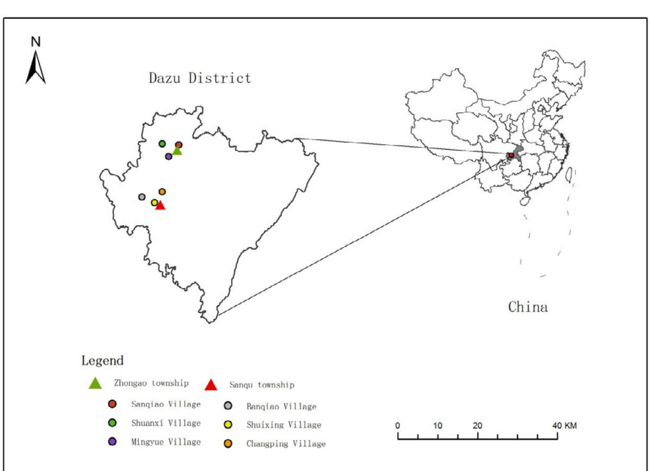

Fig. 1. The location of the study area.

The final questionnaire used in the survey consisted of three main sections. The first section contained questions about farmers' knowledge and perceptions of climate change and its adaptation. Each respondent was asked whether they knew about climate change and whether their individual energy use behavior would affect climate change. Several statements, that climate change had severely affected their daily life, that the public cannot mitigate the effects of climate change by taking any measures and that the costs of climate change adaptation measures were high, were presented where respondents were asked to express the extent of their agreement on a five-point Likert scale rating from “totally agree” to “totally disagree”. The second section investigated a wide range of farmers' use behavior of household appliances and energy consumption patterns. As Raaij and Verhallen (1983) and Ding et al. (2017) reported, rural households' energy-saving behavior was divided into two dimensions: daily use behavior and buying choice behavior. Six kinds of household energy-efficient appliances that use less energy were investigated, including lamps, air conditioners, refrigerators, washing machines, showers and small farming vehicles. To understand the status of farmers' use behavior of all appliances, the respondents were first asked about whether they owned energy-efficient versions of these six kinds of appliances. If they did, they were asked how many of each appliance they had. The respondents were further asked that if they needed to buy home appliances, whether they would buy the energy-efficient or the ordinary models. Then, they were asked to indicate the reasons for why they would or would not buy the energy-efficient appliance. The last section of the survey collected the demographic information of the respondents and their households (e.g., gender, age, level of education, residence location and agricultural activities).

2.3. Experimental design

To capture the risk preferences and loss aversion, an experiment referring to the method of Liu et al. (2014) was designed. This design is among the most commonly used experimental risk preference elicitation methods (Bartczak et al., 2017). The experiment included a series of choices to measure farmers' risk preferences and another series to elicit farmers' loss aversion.

2.3.1. Risk aversion lottery choice task

This experiment was based on the widely used Holt-Laury design, modeled after Brick et al. (2012). This design has been applied in the developing world, showing that even respondents with low education levels are able to understand the experimental design (Liu and Huang, 2013).

The respondents were asked to make their own decisions in a series of eight binary choice questions between a risky option and a safe option (Table 1). The token of the safe option (option A) from Task 1 to Task 8 is reduced sequentially from 200 to 150, 120, 100, 80, 60, 40 and finally 20, with a win probability of 100% certainty. Under the risky option (option B), respondents have a 50% chance of receiving 200 and a 50% chance of receiving zero. Moving down the list of eight lotteries, the payoffs in option B remain the same, while

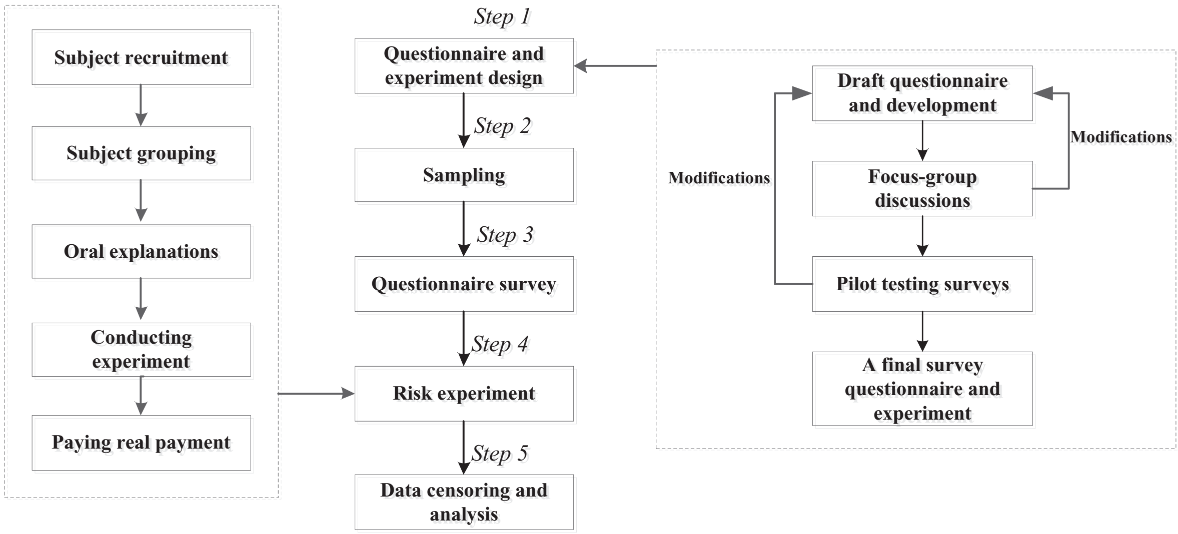

Fig. 2. The research framework of this study.

Table 1
Risk aversion experimental design.

Task	Option A		Option B			EV_A- EV_B
	Tokens	Win probability	Tokens (1)	Tokens (2)	Win probability	
1	200	100%	200	0	50%	100
2	150	100%	200	0	50%	50
3	120	100%	200	0	50%	20
4	100	100%	200	0	50%	0
5	80	100%	200	0	50%	−20
6	60	100%	200	0	50%	−40
7	40	100%	200	0	50%	−60
8	20	100%	200	0	50%	−80

Note: EV_A and EV_B are the expected value of option A and option B, respectively.

the payoffs associated with option A decline systematically. The difference in the expected values between the two options is presented in a fourth column, which was not shown to the respondents. A risk-neutral participant should choose the option with the higher expected value (Brick et al., 2012), option A for the first three or four tasks, and then option B thereafter. On the other hand, a risk-averse respondent would choose the safe option more than four times, while a risk-seeking respondent may choose the safe option less than three times (Holt and Laury, 2002).

2.3.2. Loss aversion lottery choice task

To elicit respondents' attitudes toward loss, an experiment that was built upon the method of Liu et al. (2014) was designed. Respondents were asked to make a choice between two options that involved the possibility of losing money. Table 2 presents the choice tasks and the differences in the expected payoff between the two options. For each of seven choice tasks, options A and B have a 50% chance of receiving tokens and a 50% chance of losing tokens. The possible loss amount in option A (loss of 35 tokens) is always lower than that in option B (loss of 40–65 tokens). In the first choice task, the expected payoff associated with option A is greater than the expected payoff of option B. As one moves down the series, the expected payoff of option B increases so that option B becomes increasingly more appealing than option A. A respondent who is risk neutral and not loss averse would choose option A for the first three tasks, would be indifferent between options A and B in the fourth task, and would choose the option B thereafter. Someone who is loss averse and risk neutral would not be indifferent

Table 2
Loss aversion experiment design.

Task	Option A			Option B			EV_A- EV_B
	Tokens (1)	Tokens (2)	Win probability	Tokens (1)	Tokens (2)	Win probability	
1	60	−35	50%	75	−65	50%	7.5
2	55	−35	50%	75	−65	50%	5
3	50	−35	50%	75	−65	50%	2.5
4	45	−35	50%	75	−65	50%	0
5	40	−35	50%	75	−50	50%	−10
6	40	−35	50%	75	−45	50%	−12.5
7	35	−35	50%	75	−40	50%	−17.5

Note: EV_A and EV_B are the expected values of option A and option B, respectively.

between choices A and B in Task 4 since choice B incurs a larger loss than choice A. All other things being equal, someone who is more loss averse, would choose option A (a low loss option) more often than a less loss-averse individual (Liu et al., 2014).

2.4. Sample and data collection

In July 2017, the field survey and risk experiments were carried out in Dazu District. The process of data collection is shown in Fig. 2. Based on the township scale, population and geographical location, the research team randomly selected two townships (Zhongao and Sanqu). Then, in each township, three villages were randomly selected. Finally, 30–50 households were randomly drawn in each village, depending on the population size of the village. In this study, only the household heads or decision makers of the family participated in the survey and experiments. The respondents were interviewed face-to-face by well-trained enumerators. The risk experiment was conducted immediately after the questionnaire survey. To ensure incentive compatibility, the respondents were told that they would receive a real cash payment after the experiments but that the amount would depend on the answers that they made in the two experiments.

The research team compensated each respondent 1.5 USD for completing the survey plus a real cash reward for the risk experiments. Ultimately, a total of 235 responses were collected, of which 218 were found to be valid for further analysis after censoring for missing and inconsistent answers.

2.5. Description of explanatory variables

Based on the empirical findings in the existing literature, some variables were included to identify the factors that may influence rural households' energy-efficient appliance use behavior. The following issues are of particular interest.

First, farmers' risk preferences and loss aversion may affect farmers' energy use behavior in risky or uncertain situations (Qiu et al., 2014). The higher a household's risk coefficient (i.e., greater risk aversion), the less likely the household is to use energy-efficient appliances. A higher loss aversion coefficient is associated with a higher likelihood of adopting an energy-efficient appliance. Second, an individual's knowledge or perception is an important factor affecting an individual's behavior. Mills (2010) argues that perception is an important factor that influences the behavior of energy consumption. Third, social capital, such as social trust and networks, has been found to influence individuals' environmental behaviors (Jones, 2010). Consequently, it is important to understand the influence of an individual's social capital on his or her decisions of energy use. Finally, the interviewees' socioeconomic and demographic factors, such as gender, age, education, household size and income degree, may influence their energy-efficient appliance use behaviors.

3. Results

3.1. Descriptive statistics

The descriptive sociodemographic profile of our respondents is reported in Table 3. Approximately 56% of our sample was represented by male household heads. The typical respondent was 57 years old, ranging from 18 to 84 years. One reason for the absence of young household heads is that many young farmers leave their villages to work in large cities. The education level of our respondents was low. On average, the respondents had attained approximately six years of education (primary school). Specifically, approximately 25% of the respondents reported they had no school education at all, and the majority of the remaining respondents (42% of the total) had completed their primary education. Only 22% and 11% of the respondents had attained junior high school and higher education, respectively. The overall average household size of the sampled respondents was approximately four persons. Only 6% of the sample had experience with bank loans. The average household income was approximately 724 USD/month. Our sample was representative of the province as a whole, which was verified with data from the Chongqing Statistical Yearbook 2017 (National Bureau of Statistics, 2017).

3.2. Farmers' energy-efficient appliance use behavior

Fig. 3 presents the rural residents' use situation of energy-efficient appliances. The results show that a typical household had 2.66 different types of the six energy-efficient appliances included in the survey. Lamps are a must-have item for a rural household, and all the households in the study area had lamps. Approximately 89% of the respondents reported that their households used energy-efficient lamps, with an average of 7.64 per household. Approximately 92% of the respondents declared that their households had refrigerators. Among them, more than half of the respondents (58%) stated that they used energy-efficient refrigerators. On average, a rural household had 0.65 energy-efficient refrigerators. Approximately 93% of the respondents had washing machines. However, only half of them (51%) owned energy-efficient washing machines, with an average of 0.52 per household. Energy-efficient showers were not very popular. Only one-third of the rural households had energy-efficient showers. Less than one-fourth of the rural families used energy-efficient air conditioners. Only 11% of the households owned energy-efficient farming vehicles, with an average of 0.11 per household.

The respondents' buying choice behavior of energy-efficient appliances was also investigated. Our results show that 88.9% of the respondents would prefer to buy energy-efficient lamps when they purchase lamps. Sixty-seven percent of the rural households stated that they would buy energy-efficient models rather than the ordinary model when buying air conditioners. More than half of the respondents (63%) reported that they would like to buy energy-efficient models when they buy refrigerators. Approximately half of our respondents (54%) would choose to buy energy-efficient washing machines. With regard to showers, 72% of the families would choose to buy energy-efficient showers. Approximately one-third of the farmers (36%) stated that they would choose energy-efficient farming vehicles.

The respondents were asked to indicate their reasons for why they would buy energy-efficient appliances. The results in Table 4 show that the most important reason for buying energy-efficient appliances was that the respondents believed that energy-efficient appliances could lower their future energy bills. The second most important reason was that the respondents learned that others, such as relatives or friends, bought energy-efficient appliances, and they responded similarly. Approximately 25.38% of the respondents declared that their reason for buying energy-efficient appliances was that local governments provided subsidies or incentives for using these appliances. Only a smaller percentage of the respondents (19.80%) believed that using energy-efficient appliances could have a positive impact on climate change, indicating that rural residents' environmental consciousness is relatively weak.

Table 5 presents the responses to a question asking the respondents to select all of the reasons why they would not buy energy-efficient appliances. The most common reason given for not purchasing efficient appliances was the cost. All the respondents stated that the energy-efficient appliance was more expensive than

Table 3
Demographics of the survey sample and census population statistics.

Variable	Description	Mean	Std. Dev.	Provincial average
Gender	Male = 1, female = 0	0.56	0.50	0.51
Age	Age of the respondent	57	12	n/a
Farmyears	Years engaged in farming activities	35	16	n/a
Education	Years of education	5.88	4.05	n/a
Hhsize	Household size	3.69	1.72	3.03
Landowned	Farm size(mu)	3.36	6.90	n/a
Bank_loan	Access to bank loans (yes = 1; no = 0)	0.06	0.23	n/a
Income	Total household income (USD/month)	724	604	653.60

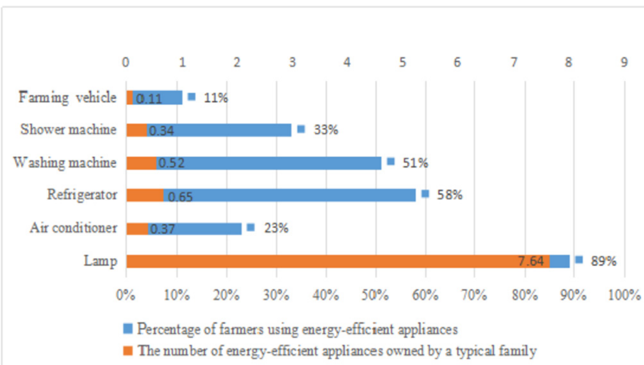

Fig. 3. Farmers' energy-efficient appliance use situation.

the ordinary model. Other important reasons for not buying energy-efficient appliances were the uncertainties in the energy savings and economic returns of the energy-efficient appliances. Approximately 11% of those who would not buy the energy-efficient appliances declared that they did not care whether the appliances were energy-efficient or not.

3.3. Farmers' risk preferences and loss aversion

A descriptive analysis of the respondents' decision switching points in the experiments was first carried out. The results are shown in Table 6. In previous studies reported in the literature, respondents tended to switch back and forth between lotteries as they moved down the decision rows (Andersen et al., 2006). Multiple switching behavior has been reported in a number of studies (Brick et al., 2012). Our results show that there was only a small proportion of crossover choices in the risk aversion experiment (4.68%) and the loss aversion experiment (5.53%), indicating that our respondents had a good understanding of our experimental design. To obtain more robust results, these crossover choices were excluded from further analysis.

Approximately 27.23% of the respondents always chose option A in the risk aversion experiment, showing that they were completely risk averse. In the loss aversion experiment, 21.62% of the respondents exhibited complete loss aversion behaviors. Regarding risk, 20.98% of the respondents were risk neutral, while only 17.41% of the respondents were risk loving, and most of the respondents (61.61%) were risk averse. Turning to the results of our loss aversion experiment, only 30.63% of the respondents were loss neutral, and 29.28% of the respondents were less loss averse. Approximately 40.09% of the respondents were seriously loss averse.

Table 7 presents the statistical coefficients of the risk preferences and loss aversion across the sample. The mean risk aversion coefficient was 0.16, indicating that the typical respondent in the study area was risk averse. The average estimated value of the loss aversion parameter was 2.68, indicating that the individuals weighted losses more heavily than the equivalent gains (Bartczak et al., 2017).

3.4. Determinants of farmers' use behavior

In this section, respondents' energy-efficient appliance use behavior was divided into two categories: daily use behavior and buying choice behavior. A series of binary probit models were used to investigate the determinants of farmers' use behavior of energy-efficient appliances. Lamps are must-have and relatively cheap home appliances for each household. Other appliances, including

Table 4
Reasons for buying energy-efficient appliances.

Reasons	%
Energy-efficient appliances can lower my energy bills.	99.49
Somebody around me bought energy-efficient appliances and I follow them.	28.93
Governments provide subsidies for using energy-efficient appliances.	25.38
Using energy-efficient appliances can have a good impact on climate change.	19.80
Energy price will rise in the future.	18.27

Note: The percentages do not add up to 100% because respondents were asked to select all that apply.

Table 5
Reasons for not buying energy-efficient appliances.

Reasons	%
The energy-efficient appliance is more expensive than the general one.	100
I am not sure how much energy the energy-efficient one can save.	47.37
I am not sure the money that the energy-efficient appliance saved in the coming months can cover the balance of the price.	34.21
I don't care if the appliance can save energy or not.	10.53
It takes too long to recover the price differences between the two appliances.	7.89

Table 6
Distribution of farmers' switching points in the experiment.

Series I Risk aversion experiment			Series II Loss aversion experiment		
Switching point	Frequency	Percentage(%)	Switching point	Frequency	Percentage(%)
2	17	7.59	Always B	34	15.32
3	22	9.82	2	8	3.60
4	27	12.05	3	23	10.36
5	20	8.93	4	26	11.71
6	37	16.52	5	42	18.92
7	28	12.50	6	25	11.26
8	12	5.36	7	16	7.21
Always A	61	27.23	Always A	48	21.62

Table 7
Estimates of risk aversion and loss aversion coefficient.

	Risk aversion coefficient	Loss aversion coefficient
Mean	0.16	2.68
Std. Dev.	0.74	2.69

air conditioners, washing machines, refrigerators, showers and farming vehicles, are relatively more expensive and durable. These five appliances were grouped as "others".

The definitions of the dependent variables and explanatory variables used as well as their major statistical values are reported in Table 8. The explanatory variables included the farmers' risk aversion coefficient, the loss aversion coefficient, the perceptions of climate change adaptation, the social trust attitudes and some sociodemographic factors. The correlations among the independent variables are presented in Table 9. The results show that the majority of the variables were correlated with a correlation coefficient of $r < \pm 0.35$. It can be confirmed that multicollinearity among the explanatory variables is not a problem (Bhandari et al., 2018).

Table 10 presents the results of a set of probit estimations for respondents' daily energy-efficient appliance use behavior. Models (1) and (3) give the results for the models that only included respondents' risk aversion and loss aversion. The results show that the rural household heads who are more risk averse are less likely to use energy-efficient lamps and other appliances. Loss aversion has no significant effect on rural residents' use behavior of energy-efficient lamps, but it has a significantly positive impact on their use behavior of other energy-efficient appliances. With respect to the controlled variables included in model (2) and model (4), the estimation results are largely consistent with previous economic findings on the determinants of residential energy consumption (Volland, 2017). The parameter estimates on the farmers' cognition are consistently positive and significant at the 1% level, suggesting that rural household heads' perceptions regarding the ability of human actions to mitigate climate change have a positive effect on their use behavior of energy-efficient appliances. The coefficient estimates on trust are positive and significant, indicating that trust attitudes are positively associated with rural residential energy-efficient appliance use behavior. The coefficients and marginal effects for education and assets are positive and significant in each equation.

The relationship of the rural household heads' risk preferences and their buying choice behavior for energy-efficient appliances was assessed by using four probit models. The dependent variables are whether the respondents would purchase energy-efficient appliances. The regression results are shown in Table 11. The standard measures of goodness-of-fit at the bottom of the table suggest that the explanatory variables chosen have significant importance in explaining the rural household heads' buying choice behavior for energy-efficient appliances.

Turning to the main objectives of our analysis, both risk aversion and loss aversion are found to be statistically significant. The results show that the risk aversion coefficient in model (1) is negative and significant, suggesting that respondents who are more risk averse are less willing to purchase energy-efficient appliances. The loss aversion coefficients are positive and significant in each model,

Table 8
List of variables and their descriptive statistics.

Variable	Description	Mean	Std. Dev.
Dependent variable			
Use_lamp	Use energy-efficient lamp (yes = 1, no = 0)	0.89	0.32
Use_others	Use other energy-efficient appliances except for lamps (yes = 1, no = 0)	0.71	0.45
Buying_choice	Buying choice behavior of energy-efficient appliances (yes = 1, no = 0)	0.84	0.37
Independent variable			
Risk	Risk aversion coefficient	0.16	0.74
Loss	Loss aversion coefficient	2.68	2.69
Controlled variable			
Cognition	Agreement with the statement that the public cannot mitigate the effects of climate change by taking any measures (1 = strongly agree; 2 = agree; 3 = neutral; 4 = disagree; 5 = strongly disagree)	3.27	0.83
Trust	Trust in friends, relatives, neighbors and most people in society (1 = strongly distrust; 2 = distrust; 3 = neutral; 4 = trust; 5 = strongly trust)	3.58	0.42
Gender	Male = 1, female = 0	0.56	0.50
Age	Age of the respondents	57.05	12.72
Education	Below junior high school = 0, junior high school and above = 1	0.32	0.47
Farming_time	Daily farming hours	6.02	2.45
Location	Residence location (town perimeter = 1, otherwise = 0)	0.43	0.50
NNFR	Number of non-farm relatives and friends (1 = 1–4; 2 = 5–7; 3 = 7–10; 4 = 10–14; 5 = More than 15 people)	3.8	1.40
Bank_loan	Access to bank loans (yes = 1, no = 0)	0.06	0.23
Asset	Fixed Asset (million USD)	23.88	20.89

Table 9
Correlations among independent variables.

Variable	Risk	Loss	Cognition	Trust	Gender	Age	Farming_time	Location	NNFR
Loss	0.10								
Cognition	0.11	−0.03							
Trust	−0.13	0.06	0.03						
Gender	−0.08	0.15	−0.07	0.11					
Age	0.13	0.10	−0.09	0.00	0.14				
Farming_time	0.09	0.08	−0.15	0.06	−0.08	−0.03			
Location	−0.20	−0.17	−0.11	−0.04	−0.06	−0.21	0.06		
NNFR	0.14	0.17	−0.11	−0.16	0.10	0.03	0.03	−0.02	
Bank_loan	0.09	0.06	0.03	0.08	0.02	−0.13	0.28	0.00	0.06

Table 10
Probit models for farmers' daily use decisions on energy-efficient appliances.

Variable	Lamp				Others			
	Model(1)		Model(2)		Model(3)		Model(4)	
	Coef.	M.E.	Coef.	M.E.	Coef.	M.E.	Coef.	M.E.
Risk	−0.23* (0.15)	−0.05* (0.03)	−0.16* (0.17)	−0.03* (0.03)	−0.24** (0.12)	−0.08** (0.04)	−0.21* (0.14)	−0.07* (0.04)
Loss	0.01 (0.04)	0.002 (0.007)	0.01 (0.05)	0.002 (0.008)	0.07** (0.04)	0.03** (0.01)	0.08** (0.04)	0.03** (0.01)
Cognition			0.44*** (0.15)	0.08*** (0.03)			0.30*** (0.12)	0.01*** (0.04)
Trust			0.87*** (0.35)	0.15*** (0.06)			0.49** (0.25)	0.16** (0.08)
Education			0.92** (0.37)	0.16** (0.06)			0.33* (0.22)	0.11* (0.07)
Asset			1.38** (1.08)	0.24** (0.19)			1.24** (0.76)	0.40** (0.24)
Constant	1.21* (0.16)		−0.75 (1.25)		0.37* (0.13)		−0.69 (0.95)	
Log likelihood	−78.83		−68.02		−132.16		−121.71	
LR *chi*^{2} statistic	2.79**		21.58***		6.94**		16.61***	
# of observations	219		218		219		218	

Note: M.E. stands for marginal effect; Standard errors are in parentheses; $^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 11
Probit models for farmers' decisions to buy energy-efficient appliances.

Variable	Model(1)		Model(2)		Model(3)		Model(4)	
	Coef.	M.E.	Coef.	M.E.	Coef.	M.E.	Coef.	M.E.
Risk	−0.13* (0.14)	−0.03* (0.03)	−0.06 (0.15)	−0.01 (0.03)	−0.12 (0.16)	−0.02 (0.03)	−0.12 (0.16)	−0.02 (0.03)
Loss	0.15*** (0.05)	0.04*** (0.01)	0.15*** (0.05)	0.03*** (0.01)	0.14*** (0.06)	0.03*** (0.01)	0.13*** (0.06)	0.03*** (0.01)
Cognition			0.30** (0.15)	0.07** (0.03)	0.22* (0.15)	0.04* (0.03)	0.22* (0.15)	0.04* (0.03)
Trust			0.50** (0.26)	0.11** (0.06)	0.65** (0.29)	0.13** (0.06)	0.64* (0.29)	0.13** (0.06)
Gender			0.37* (0.22)	0.08* (0.05)	0.36* (0.23)	0.07* (0.05)	0.35* (0.23)	0.07* (0.05)
Age			−0.02*** (0.01)	−0.01*** (0.002)	−0.03*** (0.01)	−0.01*** (0.002)	−0.03*** (0.01)	−0.01*** (0.002)
Farming_time					−0.01*** (0.004)	−0.002*** (0.001)	−0.02*** (0.004)	−0.01*** (0.001)
Location					−0.70*** (0.24)	−0.14*** (0.05)	−0.69** (0.24)	−0.14** (0.05)
NNFR					0.14* (0.09)	0.03* (0.02)	0.15* (0.09)	0.03** (0.02)
Bank_loan							1.08*** (0.43)	0.22** (0.09)
Constant	0.63* (0.15)		1.09 (1.15)		0.62 (1.32)		0.65 (1.30)	
Log likelihood	−95.20		−86.23		−78.79		−78.33	
LR *chi*^{2} statistic	9.66***		21.26***		37.45***		43.24***	
# of observations	218		218		218		218	

Note: M.E. stands for marginal effect; Standard errors are in parentheses.
$^{*}p < 0.1$.
$^{**}p < 0.05$.
$^{***}p < 0.01$.

suggesting that a respondent with high loss aversion is more willing to purchase energy-efficient appliances.

With respect to perception and the socioeconomic variables included in the models, the results are in agreement with earlier findings (Volland, 2017). The coefficients and corresponding marginal effects for the cognition variable are significantly positive, indicating that household heads who had a better perception of climate change adaptation would be more likely to buy energy-efficient appliances. The coefficient estimates for gender are positive and statistically significant, implying that men are more willing than women to buy energy-efficient appliances. The coefficients of age and farming time are negative and statistically significant in model (2) to model (4). This finding implies that older people and farmers with longer farming hours are more reluctant to buy energy-efficient appliances. The coefficients of residence location are negative and significant, indicating that farmers who live far away from towns are more likely to purchase energy-efficient appliances.

Some social capital variables are also found to have significant effects on rural household heads' willingness to purchase energy-efficient appliances. The number of non-farm relatives and friends is significant and positive at the 10% level or lower, implying that farmers with more non-farm relatives and friends are more willing to buy energy-efficient appliances. The coefficients associated with trust are statistically positive, implying that respondents' trust attitudes have a positive effect on their willingness to purchase energy-efficient appliances. The estimation results show that farmers who had access to bank loans are more likely to purchase energy-efficient appliances.

4. Discussion

It is becoming increasingly important to promote rural household energy efficiency for the sustainable development of China (Zhang et al., 2017). A better understanding of the determinants of rural residents' use behavior of energy-efficient appliances can help decision makers design more effective policies. Individuals' risk preferences and loss aversion have been identified as factors affecting people's investment decisions (Kairies-Schwarz et al., 2017). However, there is little empirical evidence of the effects of farmers' risk preferences and loss aversion on their energy-efficient appliance use behavior. This study used a paired lottery experiment to elicit farmers' risk preferences and loss aversion. Then, the elicited risk preferences and loss aversion were used to explain farmers' use behavior of energy-efficient appliances in rural China.

Our survey results indicate that energy-efficient lamps were the most popular energy-efficient appliances in the study area, followed by energy-efficient refrigerators and washing machines. Less than one-third of the respondents used energy-efficient showers, air conditioners and farming vehicles. Given their low adoption, there is a need for the promotion of these energy-efficient appliances.

Most of the respondents reported that they would prefer to buy energy-efficient lamps, air conditioners, showers and refrigerators. However, not many farmers stated that they would choose energy-efficient farming vehicles. The lower interest in the last category is probably due to the fact that energy-efficient farming vehicles are relatively less powerful than fossil-fuel powered vehicles, and our study area is a mountain city where the terrain is rather rugged. Another possible reason is that energy-efficient farming vehicles are usually more expensive.

The results of the experiment showed that most of the farmers were risk averse. This result is consistent with most previous studies that found farmers in developing countries to be consistently risk averse (Brick et al., 2012; Liu et al., 2013). The average loss aversion parameter was 2.68, indicating that the typical farmer perceived the losses more seriously than the equivalent gains (Bartczak et al., 2017). This estimation result is very close to the findings in the literature: 2.63 in Tanaka et al. (2010) and 2.25 in Tversky and Kahneman (1992).

Our estimation results indicated that the rural household heads who were more risk averse were less willing to purchase or use energy-efficient lamps and other appliances. One possible reason for this is that more risk-averse household heads are more reluctant to accept new technologies, and therefore, they are less likely to purchase or use energy-efficient appliances. This finding is consistent with Liu and Huang (2013), who found that farmers who are more risk averse adopted *Bacillus thuringiensis* (Bt) cotton (a genetically modified cotton that is insect resistant) later in China. Jin et al. (2015) also provided evidence that more risk-averse farmers are less willing to adopt newer adaptation technologies. Qiu et al. (2014) noted that homeowners who are more risk averse are less likely to have either purchased energy-efficient appliances or conducted energy-efficient retrofits to their homes.

The results indicated that a more loss-averse respondent was more willing to purchase and more likely to use energy-efficient appliances. One reason for this finding might be that loss-averse households are more concerned about energy cost savings and therefore invest more effort in energy-efficient appliances. Nguyen (2016) also found that loss aversion plays a key role in driving a respondent's decision about whether to purchase the desired goods.

Our findings showed that a respondent with a better perception of climate change was more likely to purchase and use energy-efficient appliances. The education and assets of farmers were positively related to their energy-efficient appliance use behavior. As expected, the more highly educated household heads had better energy-saving consciousness and were more likely to have used energy-efficient appliances. Similarly, Sun and Jiang (2013) found that the degree of education plays a positive role in residents' energy-saving behavior. Assets were a proxy of household income, which was positively associated with the use behavior of energy-efficient appliances. This finding is expected, as household income has proven to be a key factor affecting household energy consumption and the major driver behind the uptake of modern fuels (Wang and Jiang, 2017).

Moreover, farmers who had farmed longer were less willing to purchase energy-efficient appliances. One possible reason for this is that farmers will spend less time at home if they work longer hours on their farm. As a consequence, the benefits of using energy-efficient appliances may be less extensive. The farmers who lived far away from towns were more likely to purchase energy-efficient appliances. This result is in line with the findings in the literature, where suburban homes were less likely to have conducted energy efficiency measures compared with similar rural homes (Qiu et al., 2014).

The estimation results show that a respondent with more non-farm relatives and friends was more willing to buy energy-efficient appliances. This could indicate that families with better social networks would have more information on energy-saving and other resources; thus, they may be more willing to accept new technologies and buy energy-efficient appliances. Our results also show that trust attitudes were positively associated with rural residential energy-efficient appliance use behavior. This finding is congruent with the literature, which indicates that more trusting individuals are more willing to exhibit environmentally conscious behaviors, such as using public transportation (Lange et al., 1998), recycling (Sonderskov, 2011) and conserving water (Vugt and Samuelson, 1999). Carattini et al. (2015) also demonstrated that countries with higher shares of trusting individuals show lower per capita energy consumption and greenhouse gas emissions. This result confirms the importance of trust in solving collective action problems, as has been identified in institutional economics (Ostrom, 2009; Volland, 2017). Farmers who had access to bank loans were more willing to purchase energy-efficient appliances. One likely explanation for this is that access to bank loans can increase rural household heads' financial resources, resulting in a higher willingness (Hassan and Nhemachena, 2008; Obayelu et al., 2014).

Finally, although several issues were investigated and some useful findings were obtained in this study, it has some limitations. First, the experimental economics literature stresses the importance of using incentives (paying respondents as a function of their responses) to guarantee valid results (Liu et al., 2014; Fischbacher et al., 2015). However, monetary rewards can sometimes encourage poor performance if the experiment is not conducted properly (Ola et al., 2013). Second, although small sample sizes have often been used in previous studies (Pitfield and Castillo, 2002; Ding et al., 2017), there is a need to acknowledge that our results are based on a relatively small sample and that a larger sample size could potentially generate more robust results. Third, our survey showed that 72% of the respondents intended to buy energy-efficient showers, but only 33% had actually used. Some literature also argues that there is a gap between farmers' stated intentions and their actual behavior (Väre et al., 2010; Viira et al., 2014). Väre et al. (2010) studied the planned and actual succession in Finnish farms and found that 63% of the farmers acted according to their stated intentions. Viira et al. (2014) investigated farm operators' intentions about continuation or exiting from farming and found that 28.5% of the farmers behaved consistently with their intentions. Therefore, there is a need to study the discrepancies between farmers' stated intentions and their actual behavior as well as their possible reasons. Finally, our findings indicated that the rates of energy-efficient appliances varied depending on what the appliance was. This result suggests that there is more to this decision that risk preferences and loss aversion, which can be a future research topic. Despite the above limitations, this paper contributes to the nascent stream of literature investigating the relationship between farmers' risk preferences, loss aversion and household use behavior of energy-efficient appliances in rural China.

5. Conclusions

Using unique data from a survey and a paired lottery experiment completed in the Dazu District of China, this study finds that farmers' risk preferences and loss aversion have significant effects on their energy-efficient appliance use behavior. The more risk-averse farmers are less likely to use energy-efficient appliances, while the more risk-seeking households are more likely to invest in energy-efficient appliances. The farmers who are more loss averse are more likely to adopt energy-efficient appliances. In addition, the farmers' sociodemographic factors (age, gender, education, family location) and perceptions of climate change adaptation have significant effects on their energy-efficient appliance use behavior. Finally, our results also indicate that some social capital variables are associated with a variety of use behaviors regarding energy-efficient appliances. The more trusting households are more likely to use and more willing to buy energy-efficient appliances compared to their less trusting counterparts. This paper provides a more comprehensive understanding of the factors affecting farmers' use behavior of energy-efficient appliances in rural China.

The findings of this study provide some important policy implications for China and similar localities in other parts of the developing world. First, lowering the uncertainty or increasing the reliability of energy-efficient technology may have a positive impact on rural households' adoption of energy-efficient appliances. More information on the benefits of using energy-efficient technologies, such as energy cost savings, may increase the adoption of energy-efficient appliances. Second, when promoting policies concerning energy efficiency, policy-makers should fully consider individuals' socioeconomic characteristics, such as income, age and educational level. Energy-saving education or information on energy efficiency can provide positive guidance for farmers' low-carbon energy consumption practices. Third, social capital such as trust is crucial for promoting economic growth, improving project performance and protecting the environment. To increase the adoption of energy-efficient appliances, there is a need to enhance the trust level among participants. Raising public awareness of average policy compliance on national or regional levels may help improving trust levels. The goal of energy-saving may be achieved by providing regular information on average energy savings or energy-efficient appliance use of households in a community.

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References

Andersen, S., Harrison, G.W., Lau, M.I., Rutström, E.E., 2006. Elicitation using multiple price list formats. Exp. Econ. 9 (6), 675–682. https://doi.org/10.1007/s10683-006-7055-6.

Bartczak, A., Chilton, S., Czajkowski, M., Meyerhoff, J., 2017. Gain and loss of money in a choice experiment. The impact of financial loss aversion and risk preferences on willingness to pay to avoid renewable energy externalities. Energy Econ. 65, 326–334. https://doi.org/10.1016/j.eneco.2017.04.020.

Bhandari, G., Atreya, K., Yang, X., Fan, L., Geissen, V., 2018. Factors affecting pesticide safety behaviour: the perceptions of Nepalese farmers and retailers. Sci. Total Environ. 631–632 (468), 1560–1571. https://doi.org/10.1016/j.scitotenv.2018.03.144.

Brick, K., Visser, M., Burns, J., 2012. Risk aversion: experimental evidence from South African fishing communities. Am. J. Agric. Econ. 94 (1), 133–152. https://doi.org/10.1093/ajae/aar120.

Carattini, S., Baranzini, A., Roca, J., 2015. Unconventional determinants of greenhouse gas emissions: the role of trust. Environ. Policy Gov. 25 (4), 243–257. https://doi.org/10.1002/eet.1685.

Craig, C.A., 2018. Residential support for energy efficiency by utility organizations in the Southeast US. J. Clean. Prod. 177, 89–100. https://doi.org/10.1016/j.jclepro.2017.12.189.

Dhinesh, B., Isaac JoshuaRamesh Lalvani, J., Parthasarathy, M., Annamalai, K., 2016. An assessment on performance, emission and combustion characteristics of single cylinder diesel engine powered by Cymbopogon flexuosus biofuel. Energy Convers. Manag. 117, 466–474. https://doi.org/10.1016/j.enconman.2016.03.049.

Ding, Z., Wang, G., Liu, Z., Long, R., 2017. Research on differences in the factors influencing the energy-saving behavior of urban and rural residents in China—A case study of Jiangsu Province. Energy Policy 100, 252–259. https://doi.org/10.1016/j.enpol.2016.10.013.

Farsi, M., 2010. Risk aversion and willingness to pay for energy efficient systems in rental apartments. Energy Policy 38 (6), 3078–3088. https://doi.org/10.1016/j.enpol.2010.01.048.

Fei, R., Lin, B., 2017. Estimates of energy demand and energy saving potential in China's agricultural sector. Energy 135, 865–875. https://doi.org/10.1016/j.energy.2017.06.173.

Fischbacher, U., Schudy, S., Teyssier, S., 2015. Heterogeneous Preferences and Investments in Energy Savings Measures. Munich Discussion Paper No. 2015-11. Department of Economics, University of Munich. http://nbn-resolving.de/urn:nbn:de:bsz:352-0-322031.

Hassan, R., Nhemachena, C., 2008. Determinants of African farmers' strategies for adapting to climate changes: multinomial choice analysis. AFJARE 2 (1), 85–104. http://agris.fao.org/agris-search/search.do?recordID=GB2013203150.

Holt, C.A., Laury, S.K., 2002. Risk aversion and incentive effects. Am. Econ. Rev. 92 (5), 1644–1655. http://doi.org/10.1257/000282802762024700.

Jin, J., Gao, Y., Wang, X., Pham, K.N., 2015. Farmers' risk preferences and their adaptations to climate change in the Yongqiao District, China. Land Use Pol. 47, 365–372. https://doi.org/10.1016/j.landusepol.2015.04.028.

Jones, N., Evangelinos, K., Iosifides, T., Halvadakis, C.P., Sophoulis, C.M., 2010. Social factors influencing perceptions and willingness to pay for a market-based policy aiming on solid waste management. Resour. Conserv. Recycl. 54, 533–540. https://doi.org/10.1016/j.resconrec.2009.10.010.

Just, R.E., Zilberman, D., 1983. Estimation of multicrop production functions. Am. J. Agric. Econ. 65 (4), 770–780. https://doi.org/10.2307/1240465.

Kahneman, D., Tversky, A., 1979. Prospect theory: an analysis of decision under risk. Econometrica 47 (2), 263–291. https://doi.org/10.2307/1914185.

Kairies-Schwarz, N., Kokot, J., Vomhof, M., Jens, Weßling, 2017. Health insurance choice and risk preferences under cumulative prospect theory-an experiment. J. Econ. Behav. Organ. 137, 374–397. https://doi.org/10.1016/j.jebo.2017.03.012.

Lange van Lange, P.A.M., van Vugt, M., Meertens, R.M., Ruiter, R.A.C., 1998. A social dilemma analysis of commuting preferences: the roles of social value orientation and trust. J. Appl. Soc. Psychol. 28 (9), 796–820. https://doi.org/10.1111/j.1559-1816.1998.tb01732.x.

Liu, E.M., Huang, J., 2013. Risk preferences and pesticide use by cotton farmers in China. J. Dev. Econ. 103, 202–215. https://doi.org/10.1016/j.jdeveco.2012.12.005.

Liu, E.M., Meng, J., Wang, T.Y., 2014. Confucianism and preferences: evidence from lab experiments in Taiwan and China. J. Econ. Behav. Organ. 104, 106–122. https://doi.org/10.1016/j.jebo.2013.09.008.

Liu, W., Spaargaren, G., Heerink, N., Mol, A.P.J., Wang, C., 2013. Energy consumption practices of rural households in north China: basic characteristics and potential for low carbon development. Energy Policy 55 (4), 128–138. https://doi.org/10.1016/j.enpol.2012.11.031.

Matsumoto, S., Omata, Y., 2017. Consumer valuations of energy efficiency investments: the case of Vietnam's Air Conditioner market. J. Clean. Prod. 142, 4001–4010. https://doi.org/10.1016/j.jclepro.2016.10.055.

Mills, B., Schleich, J., 2010. What's driving energy efficient appliance label awareness and purchase propensity? Energy Policy 38 (2), 814–825. https://doi.org/10.1016/j.enpol.2009.10.028.

National Bureau of Statistics (NBS), 2017. Chongqing Statistical Yearbook. China Statistics Press, Beijing.

Nguyen, Q., 2016. Linking loss aversion and present bias with overspending behavior of tourists: insights from a lab-in-the-field experiment. Tourism Manag. 54 (36), 152–159. https://doi.org/10.1016/j.tourman.2015.09.019.

Obayelu, O.A., Adepoju, A.O., Idowu, T., 2014. Factors influencing farmers/choices of adaptation to climate change in Ekiti State, Nigeria. J. Agric. Environ. Int. Dev. 108 (1), 3–16. https://doi.org/10.12895/jaeid.20141.140.

Ola, K., Petra, N., Anja, S., 2015. Hidden benefits of reward: a field experiment on motivation and monetary incentives. Eur. Econ. Rev. 76, 188–199. https://doi.org/10.1016/j.euroecorev.2015.03.003.

Ostrom, E., 2009. A Polycentric Approach for Coping with Climate Change. Policy Research Working Papers. The World Bank. https://doi.org/10.1596/1813-9450-5095.

Parthasarathy, M., Isaac JoshuaRamesh Lalvani, J., Dhinesh, B., Annamalai, K., 2016. Effect of hydrogen on ethanol-biodiesel blend on performance and emission characteristics of a direct injection diesel engine. Ecotoxicol. Environ. Saf. 134, 433–439. https://doi.org/10.1016/j.ecoenv.2015.11.005.

Pitfield, D.E., Castillo, N.H., 2002. Factors affecting the adoption of natural gas vehicles by UK road freight operators. Munic. Eng. 151 (1), 83–89. https://doi.org/10.1680/muen.2002.151.1.83.

Pope, D.G., Schweitzer, M.E., 2011. Is tiger woods loss averse? Persistent bias in the face of experience, competition, and high stakes. Am. Econ. Rev. 101 (1), 129–157. https://doi.org/10.2139/ssrn.1419027.

Qiu, Y., Colson, G., Grebitus, C., 2014. Risk preferences and purchase of energy-efficient technologies in the residential sector. Ecol. Econ. 107, 216–229. https://doi.org/10.1016/j.ecolecon.2014.09.002.

Raaij, W.F.V., Verhallen, T.M.M., 1983. A behavioral model of residential energy use. J. Econ. Psychol. 3, 39–63. https://doi.org/10.1016/0167-4870(83)90057-0.

Schleich, J., Gassmanna, X., Meissnerc, T., Faurea, C., 2017. The Impact of Preferences over Risk, Time, and Losses on Household Adoption of Energy Efficiency Technologies in Europe. Briskee Project Presentation at FAERE 2017 on 12-13 September 2017. http://faere.fr/pub/Conf2017/FAERE2017_Schleich.pdf.

Sonderskov, M.K., 2011. Explaining large-N cooperation: generalized social trust and the social exchange heuristic. Ration. Soc. 23 (1), 51–74. https://doi.org/10.1177/1043463110396058.

Sun, Y., Jiang, L., 2013. Review of research on energy consumption behavior of residents. Resour. Sci. 2013, 697–703 (In Chinese).

Tanaka, T., Camerer, C.F., Nguyen, Q., 2010. Risk and time preferences: linking experimental and household survey data from vietnam. Am. Econ. Rev. 100 (1), 557–571. https://doi.org/10.1257/aer.100.1.557.

Tversky, A., Kahneman, D., 1992. Advances in prospect theory: cumulative representation of uncertainty. J. Risk Uncertain. 5, 29–323. https://doi.org/10.1007/BF00122574.

Väre, M., Pietola, K., Weiss, C.R., 2010. The irrelevance of stated plans in predicting farm successions in Finland. Agric. Food Sci. 19 (1), 81–95. https://doi.org/10.2137/145960610791015041.

Viira, A.H., Põder, A., Värnik, R., 2014. Discrepancies between the intentions and behavior of farm operators in the contexts of farm growth, decline, continuation and exit: evidence from Estonia. GJAE 63, 46–62. http://www.gjae-online.de/news/pdfstamps/freeoutputs/GJAE-755_2014.pdf.

Volland, B., 2017. The role of risk and trust attitudes in explaining residential energy demand: evidence from the United Kingdom. Ecol. Econ. 132, 14–30. https://doi.org/10.1016/j.ecolecon.2016.10.002.

Vugt, van V., Vugt, M., Samuelson, C.D., 1999. The impact of personal metering in the management of a natural resource crisis: a social dilemma analysis. Pers. Soc. Psychol. Bull. 25 (6), 735–750. https://doi.org/10.1177/0146167299025006008.

Wang, R., Jiang, Z., 2017. Energy consumption in China's rural areas: a study based on the village energy survey. J. Clean. Prod. 143, 452–461. https://doi.org/10.1016/j.jclepro.2016.12.090.

Zhang, Y., Bian, X., Tan, W., Song, J., 2017. The indirect energy consumption and CO_2 emission caused by household consumption in China: an analysis based on the input–output method. J. Clean. Prod. 163, 69–83. https://doi.org/10.1016/j.jclepro.2015.08.044.