Household Energy Transition and Social Preference in China

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ABSTRACT

China has long suffered from severe haze pollution due to coal consumption, especially household low-quality coal use for winter space heating in rural areas. To combat this problem, a switch in household energy sources from low-quality coal to high-quality coal and electricity is advocated in rural areas recent years. Regarding household electricity use for winter space heating, one possible solution is the promotion of a new electric heating system, low temperature air source heat pump (LTHP) technology. Subsidy policies on high-quality coal consumption and the adoption of new-type coal stoves have also been implemented. While these policies are still in an early stage of implementation, little is known about the possibility that the public will accept LTHPs for electric heating, as well as the determinants of household coal consumption and switching behavior between low-quality and high-quality coals.

There is also an increasing concern of nonpecuniary interventions on changing people's energy consumption behaviors in policy making and research recent years. Social value orientation (SVO) refers to people's social preferences on the allocation of resources (e.g., money) between oneself and another and can categorize people's social values into cooperative, competitive or individualistic type. This research considers SVO an important factor of people's energy transition behavior, since selfishness is assumed to be an obstacle in public acceptance of environmentally friendly energy sources. At the same time, prosocial value orientation is claimed to be essential to address various social problems (e.g., environmental degradation) via individual voluntary efforts in modern societies. Hence, understanding the determinants of SVOs becomes a basic step to obtain insights from human societies for future sustainability.

Using household survey data in Beijing, in Chapter 2, we first assess people's willingness to adopt (WTA) and willingness to pay (WTP) for LTHP technology. The analysis reveals that income, science

literacy and local environmental concern positively affect WTA and WTP, whereas global environmental concern does not. Contrary to our initial expectation, people in mountainous areas express the highest WTA and WTP, followed by those in hilly and plains areas. These findings suggest that efforts to promote this technology could begin in mountainous areas and move to hilly and then to plains areas, thereby advancing public education on local environmental concerns and science literacy.

In Chapter 3, we analyze the determinants of coal consumption and switching behavior between low-quality and high-quality coals, considering the evaluation of subsidy policies in the analysis. Results reveal that prosociality and local environmental concern play crucial roles in household choices and consumption behaviors between two types of coals. The promotion of new-type coal stoves significantly facilitates the transition from low-quality to high-quality coal, while price subsidies on high-quality coal do not influence market acceptance of high-quality coal. These results demonstrate the importance of cognitive and psychological factors and promotion policies on coal consumption behavior.

In Chapter 4, we mainly examine a topographical differences in people's SVOs and its policy implications for future sustainability. Topography is hypothesized to directly and indirectly influence individual SVOs via physical environment and urbanization. we observe that social preferences tend to transition from prosocial to proself as the living environment changes from mountainous to hilly and plains areas, while urbanization does not show a significant effect. The results imply that a new social mechanism is necessary to direct individual social preferences toward prosociality when more people live in plains and hilly areas.

In conclusion, this dissertation focuses on the factors influencing household energy transition from low-quality coal to high-quality coal and electricity. We empirically analyze possibility and public acceptance of an electric heating system (LTHP) and high-quality coal, respectively, taking perception variables, cognitive and psychological factors as a part of main concerns. We also observe topographical differences in people's living environment such as mountainous, hilly and plains areas in energy technological acceptance and people's social preference, respectively. These studies not only provide crucial insights on how to promote household energy transition in rural China to address haze pollution

problems, but also observe a necessity of social mechanism in human societies to induce more prosocial values and behaviors for future sustainability.

Key Words: energy transition, low-quality coal, high-quality coal, electricity, public acceptance, SVO, topography.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

China has experienced extremely severe smog and haze pollution recent years, especially in Beijing-Tianjin-Hebei (B-T-H) region. As one of the key pollution indicators, high concentration of $\mathrm{PM}_{2.5}$ has attracted considerably attention in China and other countries such as South Korea and Japan (Li and Liu, 2014; Wu et al., 2016; Sun et al., 2016a).[1] China is the leading coal consumer in the world, representing 48.0 % of global coal consumption in 2015 (Enerdata, 2016). As reported, coal consumption is responsible for 22.4 % of the $\mathrm{PM}_{2.5}$ concentrtion in Beijing (Beijing Municipal Environmental Protection Bureau, 2014). In northern part of China, households in rural areas heavily rely on coal as the main energy source for winter space heating. For instance, Jingchao and Kotani (2012) reveal that coal consumption accounts for 73 % of total energy consumption in rural households of Beijing in 2008. More recently, coal consumption in rural Beijing has found to reach 4 million tons of coal equivalent (TCE) per year, of which 92 % is used for space heating, with considerable pollution being generated from residential sectors due to incomplete coal combustion (Wu et al., 2016).

In addition to huge amount of coal use in rural households of China, poor coal quality is a major cause of severe air pollution in China (Litvinenko, 2016) and that raw coal burning by rural households is responsible for even higher emissions than those of the industrial sector (Zhi et al., 2015; Chai et al., 2016). Moreover, Cheng et al. (2016) prove that high concentrations of CO and $PM_{2.5}$ emissions result from incomplete combustion of household coal use due to the primitive and inefficient equipments for coal combustion. Coal combustion was also found to be connected to 366 000 deaths in China in 2013 alone (GBD MAPS Working Group, 2016). To combat these problems, it is salient to find out the effective solutions to replace and reduce low-quality coal use in rural households. In this process, Beijing takes the lead in the promotion of cleaner energy through policies, strategies and demo projects.

[1] PM (particulate matter) is the sum of all solid and liquid particles suspended in the air. Particles with a diameter of 2.5 micrometers and smaller, denoted by $PM_{2.5}$, pose the greatest health risk.

1.1 Overview of cleaner energy policies

Since the enaction of renewable Energy Law of China in 2006, the promotion of cleaner energy use in rural households has been implemented in Beijing, for instance, the Three Energy Strategies (2006-2009) in Beijing (Jingchao and Kotani, 2012). For "warming the peasants' house" in this strategy, solar heating systems and energy-efficiency retrofit have been mainly promoted and encouraged in households to replace low-quality coal use for winter space heating in villages. At this time, a switch of household energy source from coal to electricity was mainly promoted in core city area of Beijing (since 2001). Since the January in 2013, people in northern part of China have been seriously suffered from haze and fog pollution, and household coal use for winter heating was found to be an important contributor to air pollution (Beijing Municipal Environmental Protection Bureau, 2014). Accordingly, in 2013, a switch of energy source from low-quality coal to electricity and high-quality coal have been advocated in rural areas of Beijing (General Office of Beijing Municipal People's Government, 2013b, 2014).

Beijing also has a topographical variation of mountainous, hilly and plains areas based on the difference in geography and socio-economic development (Jingchao and Kotani, 2012). In 2016, a target was announced that by 2020, the plains areas will entirely use cleaner energy for winter space heating to replace the coal use (General Office of Beijing Municipal People's Government, 2016), and consequently, clean energy technologies (i.e., electricity and natural gas) have been widely promoted in the rural villages located in Beijing's plains areas. Based on the review of these energy policies in China and the urgency of addressing the air pollution problems, little is still known about the public acceptance of electric heating systems based on a market perspective (e.g., where to start and how to successfully promote the electricity use to avoid the market failure of government investment) as well as the factors that influence people's energy choices and consumption between low-quality coal and high-quality coal. Another important issue is the effectiveness of these newly implemented policies such as the subsidy policies in people's energy switching behavior in a timely manner. It is also crucial to understand and focus on the potentials of energy switch in mountainous and hilly areas in the future.

1.2 The importance of behaviorial factors in energy research

Recent years, in academic world of policy-related research, there is an rising concern of nonpecuniary interventions on changing people's energy choice and consumption behaviors (Allcott and Mullainathan, 2010; Pollitt and Shaorshadze, 2013). Frederiks et al. (2015) summarize that behaviorial and psychological factors are important in understanding people's energy consumption behavior in response to the government policy. Public perception of environmental issues, such as environmental concern has also been widely found to be a fundamental determinant of people's willingness to pay (WTP) for environmentally friendly technologies (see e.g., Erdem et al., 2010; Ward et al., 2011; Daziano and Bolduc, 2013; Michelsen and Madlener, 2016).

Although few studies have analyzed the relationship between science literacy and public attitudes toward science and technology, there is a debate on whether this relationship is positive or insignificant (Lee et al., 2005; Snow and Dibner, 2016). Social value orientation (SVO) refers to people's preferences on the allocation of resources (e.g., money) between oneself and another and categorizes people's social values into either cooperative, competitive or individualistic types (Van Lange et al., 1997, 2007b). Social values are assumed to be important determinants of people's attitude toward environmentally friendly energy sources. For instance, Sovacool (2009) reveal that selfishness can be an obstacle in public acceptance of renewable energy. Thus, to avoid the market failure of public investment, it is beneficial to understand the role of these cognitive and psychological factors in people's choices and consumption behavior regarding energy sources and technologies.

1.3 Social value orientations (SVOs) and proenvironmental behavior

As the second largest economy in the world, China has been recognized as an important economic contributor to world development in the 21st century (Fang et al., 2015). From 1985 to 2015, China's population ratio in rural areas declined from 76.29 % to 43.90 % in contrast to the high population growth in urban areas (National Bureau of Statistics of China, 2016). Along with this urban expansion, China faces a series of challenges such as environmental deterioration and air pollution (Chan and Yao, 2008; Chen et al., 2017). Many scholars suggest that individual voluntary contributions and efforts are essential to address such environmental and sustainability problems facing today (See, e.g., Van Vugt et al., 1995; Van Lange et al., 2007a). Hence, proenvironmental and cooperative behaviors must be promoted at individual level for solutions of various social problems that arise in the progress of urbanization (Ostrom et al., 2002; Dawkins, 2006; Wilson et al., 2009; Shahrier et al., 2016).

In social dilemma, social value orientation (SVO) is frequently used to measure stable preferences between interest of self and others (Messick and McClintock, 1968; Van Lange et al., 1997, 2007a). A SVO game can categorize people into four types of social preference: prosocial, competitive, individualistic and unidentified. Prosocial value orientation has been claimed to induce people's proenvironmental behaviors (Van Vugt et al., 1995; Garling et al., 2003; Van Lange et al., 2007a; Balliet et al., 2009). Regarding energy transition behaviors, for instance, Sovacool (2009) reports that an individualistic or selfish orientation in people's social preferences becomes an obstacle for public acceptance of renewable energy. Moreover, in Chapter 3, we have also observed that prosocial value orientation is a key determinant of household energy transition from low-quality coal to high-quality coal in Beijing. Thus, it is necessary to examine the determinants of SVOs in the progress of urbanization for future sustainability in China.

Chapter 2

Public acceptance of environmentally friendly heating in Beijing: A case of a low temperature air source heat pump

2.1 Introduction

China has suffered from severe smog and haze pollution since 2012, and the high concentration of $\mathrm{PM}_{2.5}$ has attracted considerable attention in China (Li and Liu, 2014; Wu et al., 2016).[1] Coal consumption is responsible for 22.4 % of the $\mathrm{PM}_{2.5}$ concentration in Beijing (Beijing Municipal Environmental Protection Bureau, 2014). Wu et al. (2016) find that coal consumption in rural Beijing has reached 4 million tons of coal equivalent (TCE) per year, of which 92 % is used for space heating, with considerable pollution being generated from residential sectors due to incomplete coal combustion. To combat this problem, a switch in household energy sources from coal to electricity is advocated in rural Beijing (General Office of Beijing Municipal People's Government, 2014), and the government plans to broadly promote and subsidize electric heating using LTHP technology, which has been scientifically demonstrated to be effective in many aspects of rural life (General Office of Beijing Municipal People's Government, 2014; Chai et al., 2016).[2]

Beijing has promoted the switch of household energy source from coal to electricity in the core city area since 2001 and expanded this promotion to rural areas in 2013 (General Office of Beijing Municipal People's Government, 2013b, 2014). A peak-valley time price policy was also introduced

[1]PM (particulate matter) is the sum of all solid and liquid particles suspended in the air. Particles 2.5 micrometers and smaller in diameter, denoted $\mathrm{PM}_{2.5}$, pose the greatest health risks.

[2]LTHP technology is an environmentally friendly technology comprising an air-to-air source heat pump. The remarkable advantage of this technology is its good performance in cold climates with relatively lower investment and running cost, comfort and ease of use and no pollution emission. The steady-state coefficient of performance (COP) will not be lower than 2.0 on average throughout a winter season when the temperature is above or equal to $-20\,^{\circ}\mathrm{C}$. More detailed information is provided in the appendix.

to subsidize the electricity price in rural households in 2015.[3] In 2016, a target was announced that by 2020, the plains areas will entirely use cleaner energy for heating instead of coal (General Office of Beijing Municipal People's Government, 2016). Consequently, clean energy technologies (i.e., electricity and natural gas) have been widely promoted in plains areas. As a new technology, LTHP technology has been mostly promoted in demo projects without fixed subsidies of the adoption cost.

Many governmental policies intended to promote certain technologies among the public have been unsuccessful and led to significant social costs (Hallsworth et al., 2011). Thus, it is argued that policies used to promote technologies should be designed in advance and, crucially, on the basis of scientific evidence regarding public acceptance and needs (Sutcliffe and Court, 2005; Hallsworth et al., 2011). Moreover, there has been an important policy debate over how to promote LTHP technology in rural areas of China to ensure a cleaner environment (Lu, 2016). Many scholars suggest that LTHP technology should be promoted on a large scale based on its technological advantages, affordable investment and environmental friendliness (Jiang et al., 2016; Chai et al., 2016). In addition, the promotion of LTHP technology should consider topographical differences and prioritize colder areas (Ministry of environmental protection of the people's republic of China, 2016). Another concern is the financial burden associated with promoting clean energy and whether the mode of promotion use in Beijing is applicable in other parts of China (Cui, 2017). Thus, a sustainable promotion policy for LTHPs should be designed based on public acceptance of and satisfaction with the technology before wider promotion (Lu, 2016). Given this state of affairs, this paper addresses public acceptance of LTHP technology.

Several papers have studied the factors that influence the selection of sustainable or environmentally friendly residential heating systems in developed countries (see, e.g., Mahapatra and Gustavsson, 2008; Braun, 2010; Sopha et al., 2010; Lillemo et al., 2013; Karytsas and Theodoropoulou, 2014; Michelsen and Madlener, 2012, 2013, 2016). For instance, Sopha et al. (2010) compare the choice among electric heating systems, heat pumps and wood pellet stoves and argue that sociodemographic factors, interaction among households, the perceived importance of heating system attributes and the decision strategy influence Norwegian homeowners' decisions. Lillemo et al. (2013) find that household and demo-

[3]The details of the peak-valley time price policy are provided in the appendix.

graphic factors, environmental attitudes and people's motives affect households' investment in heating and the choice among four types of heating equipment in Norway. Similarly, Karytsas and Theodoropoulou (2014) show that age, income, education and the presence of a person in a household that has an occupation or interest in the environment, technology or engineering or an awareness of renewable energy resources and alternative technologies affect people's willingness to adopt ground source heat pumps in Greece.

These studies address the adoption or selection among several sustainable heating systems in developed countries, where these sustainable heating systems are available and traded on the market. By contrast, few studies have focused on the determinants of public acceptance of environmentally friendly electric heating systems when the heating system in question is not traded on the market and will instead be promoted through government policies. Moreover, the public acceptance of environmentally friendly technologies has not yet been analyzed in the context of emerging and developing economies, where air pollution is more serious than in developed countries and modes of thinking are likely different (Gupta et al., 2011). Among developing countries, China suffers from particularly heavy air pollution and, as a primary contributor to haze and smog pollution, has attracted considerable attention from the media and other countries such as South Korea and Japan (Sun et al., 2016a). LTHP technology has been scientifically demonstrated to be effective in coping with air pollution in rural China. This paper empirically characterizes the determinants of public acceptance to evaluate the potential for public acceptance and contributing to promotion policies for LTHP technology.

To this end, we collect data through face-to-face surveys in rural Beijing regarding people's willingness to adopt (WTA) and willingness to pay (WTP) for LTHP technology to measure public acceptance, socioeconomic characteristics, such as income and education, and perception variables such as science literacy and environmental concerns. LTHPs are a private good of environmentally friendly electric heating technology. Given the technological advantages of LTHPs shown in the appendix, we ask respondents whether they are willing to adopt LTHP technology and how much they are willing to pay to purchase one LTHP unit. We employ WTA and WTP in our analysis because the end users' WTA and WTP represent the market capacity, size or potential for LTHPs, thus providing an important reference point for policy makers to design appropriate promotion strategies and subsidy schemes for LTHP. Only the successful promotion of LTHP can improve environmental sustainability. In other words, identifying the determinants of WTA and WTP will facilitate the promotion of LTHP technology to reduce air pollution in Beijing.

In addition to socioeconomic factors, our analysis focuses on the perception variables of environmental concerns, science literacy and spatial differences. Environmental concern is a fundamental determinant of people's WTP for environmentally friendly technologies (see e.g., Erdem et al., 2010; Ward et al., 2011; Daziano and Bolduc, 2013; Michelsen and Madlener, 2016). Based on these studies, we examine the impact of environmental concern on public acceptance of LTHP technology by adopting two levels of environmental concern (global and local levels). In addition, few studies have analyzed the relationship between science literacy and public attitudes toward science and technology. There is a debate on whether this relationship is positive or insignificant, and thus it is particularly valuable to further understand the role of science literacy in public acceptance of emerging technologies (Lee et al., 2005; Snow and Dibner, 2016). Another focus of our analysis is spatial differences in public acceptance of space heating systems (see, e.g., Braun, 2010; Michelsen and Madlener, 2012, 2016). We seek to clarify area-specific effects on public acceptance of LTHP technology because the question of where to start the LTHP promotion project (in plains, hilly or mountainous areas) is an important point in the policy debate.

2.2 Literature review

In the field of household choices on space heating systems, revealed preference (i.e., households that have adopted the technologies) or real adoption data are widely employed in past studies (Michelsen and Madlener, 2013; Ruokamo, 2016). Some studies mainly examine the influence of household-specific characteristics on people's choices (see, e.g., Dubin and McFadden, 1984; Vaage, 2000; Braun, 2010). For example, Braun (2010) analyzes the determinants of household choices among seven heating technologies and proves the importance of building types and regional differences in household heating choices in Germany. Other studies focus on the role of behavioral elements (i.e., system attributes and advantages, environmental consideration) in household heating choices (see, e.g., Mahapatra and Gustavsson, 2008; Nyrud et al., 2008; Sopha et al., 2010; Lillemo et al., 2013; Karytsas and Theodoropoulou, 2014; Michelsen and Madlener, 2012, 2013, 2016).

Nyrud et al. (2008) investigate adopter attitudes toward a new wood stove in Norway and find that economic benefits, comfort of use, heating and environmental performance mainly motivate them to continue using it. Michelsen and Madlener (2012, 2013, 2016) document the drivers or barriers of household motivation to adopt sustainable heating systems in Germany. Michelsen and Madlener (2012) demonstrate that for existing houses, socioeconomic, spatial factors and home environments are the main determinants, whereas technological attributes are people's main concerns for newly built houses. Michelsen and Madlener (2013) reveal that the home characteristics of "energy standard," "dwelling size" and type of house influence the adoption motivation. Michelsen and Madlener (2016) find that the degree of dependence on fossil fuels and knowledge of technologies influence the adoption of renewable energy resources, with habits and perceived difficulty of operation as the main obstacles.

Another group of studies focus on household stated preference or WTP for residential heating systems using contingent valuation (CV) or choice experiment (CE) methods under hypothetical scenarios (see, e.g., Byrnes et al., 1999; Scarpa and Willis, 2010; Claudy et al., 2011; Rouvinen and Matero, 2013; Ruokamo, 2016). Rouvinen and Matero (2013) study household heating choices regarding attributes of 6 heating systems via a CE method in Finland and find that installation cost is the main influencing factor, although the technological advantages of emission (i.e., CO_2 and fine particles) also play an important role. Ruokamo (2016) shows that sociodemographic factors, environmental friendliness and comfort of use are important determinants of household heating choices based on a CE study in Finland. By adopting the CV method, Claudy et al. (2011) document that the variation in Irish households' WTP among four types of micro-generation technologies is explained by their different perceptions and beliefs about technological characteristics.

The CV method is employed to value public goods or environmentally friendly technologies (see, e.g., Mitchell and Carson, 1989; Yoo and Kwak, 2009; Zografakis et al., 2010; Mozumder et al., 2011;

Adaman et al., 2011; Reynolds et al., 2015; Sun et al., 2016a,b; Baharoon et al., 2016). The bidding game, payment card, dichotomous choice and open-ended questions are the four main elicitation methods to estimate WTP values (Mitchell and Carson, 1989; Green et al., 1998; Haab and McConnell, 2002; Champ et al., 2003; Hanley et al., 2007). The bidding game is the traditional technique and less recommended because of the potential starting-point bias. The payment card method allocates actual ranges of monetary values for respondents to state their maximum WTP, which is not applicable in this research due to the high cost of each LTHP unit.

Dichotomous choice (DC) and open-ended question methods are frequently used in previous studies. Yoo and Kwak (2009) and Zografakis et al. (2010) apply DC to estimate public acceptance of green electricity. Adaman et al. (2011) investigate people's WTP for CO_2 reduction by adopting DC surveys in Turkey. Similarly, Claudy et al. (2011) apply a DC method to analyze household WTP for different residential heating systems. The DC method is popular because it does not require much knowledge or experience of people about the goods or the technology under valuation. Its potential weakness is overestimation of WTPs caused by more yea-saying or starting-point bias (Mitchell and Carson, 1989; Haab and McConnell, 2002). Open-ended question methods provide observations of continuous variables that can be used to generate the most efficient estimates compared with any other method (Carlsson and Stenman, 2000; Haab and McConnell, 2002; Wang and Zhang, 2009). Open-ended methods are reliable once the respondents have sufficient knowledge or experience about the goods and technologies under valuation (see, e.g., Mozumder et al., 2011; Reynolds et al., 2015; Sun et al., 2016a; Baharoon et al., 2016).

Based on this review of the literature, we select the open-ended question format to elicit people's WTP for adoption of LTHP technology in our surveys. Beijing is now taking the lead in advertising and promoting clean energy to reduce coal consumption. Therefore, people in Beijing realize the necessity of an energy switch from coal to electricity to some extent and are interested in adopting better heating technologies as well as understanding the economic performance and convenience of these technologies. Given this state of affairs, people in Beijing have sufficient knowledge, interest and experience to judge and state their maximum WTP for LTHP technology considering its financial attributes (i.e., annual running cost) and nonfinancial attributes (i.e., zero pollution emission) given the LTHP information provided in the surveys. Based on these arguments, the open-ended question format is the most appropriate to fulfill our goal. In this paper, one of our goals is to clarify the public acceptance and potential adoption decisions for an environmentally friendly technology, LTHP, by applying the CV method of open-ended questions.

2.3 Data description and methodology

2.3.1 Survey areas and data

Beijing is the capital city of China and is also the country's political, economic and cultural center. It is located in northeastern China and is surrounded by Tianjin Municipality and Hebei Province. Beijing consists of 16 administrative county-level districts, including 6 urban and 10 suburban and rural districts. While Beijing has a total area of 16 410.5 km^2, only 1368.3 km^2 is an urban area, while the rest is broadly suburban and rural areas (Beijing Municipal Government, 2012b). In this study, we focus primarily on analyzing rural Beijing for several reasons. First, Beijing's energy consumption structure is dominated by coal, and the city has suffered from smog and haze in recent years. Second, Beijing has taken the leading role in China with respect to replacing coal with cleaner substitutes. Third, there are substantial variations in geographical status, sociodemographic characteristics and economic levels across the rural areas in Beijing. The survey areas in our research comprise the following five suburban and rural districts (figure 3.1): Yanqing, Miyun, Pinggu, Fangshan and Daxing. Regarding geographical and socioeconomic differences, we categorize these five districts into three groups: mountainous districts (Yanqing and Miyun), hilly districts (Pinggu and Fangshan) and plains districts (Daxing).

Beijing has 10 rural districts that consist of 3 plains, 3 hilly and 4 mountainous districts. The plains areas have been the focus of promotion policies for clean energy to reach the zero coal target, whereas the hilly and mountainous areas have not been well studied. Therefore, we considered mountainous and hilly areas for the purpose of comparison with plains areas. Accordingly, we selected 2 districts from the mountainous and hilly areas, respectively, and 1 district from the plains areas. This selec-

Figure 2.1: Administrative divisions of Beijing

Table 2.1: Description of the variables

Variable	Description
Area dummy variables (Base group = Plains areas)	
Mountainous dummy	This variable takes a value of 1 when a respondent lives in a mountainous area and 0 otherwise.
Hilly dummy	This variable take a value of 1 when a respondent lives in a hilly area and 0 otherwise.
Environmental concern and perception factors	
Global environmental concern	This is a score on 12 global environmental issues, ranging from 12 to 60.
Local environmental concern	This is a score on 6 local (Beijing) environmental concerns ranging from 6 to 29.
Science literacy scale	This is a score of the answers to 10 questions related to general science ranging from 0 to 10.
Household variable	
Age	Age of the respondent
Gender	This is a dummy variable that takes a value of 1 when the respondent is male and 0 otherwise.
Education	This variable represents the respondent's years of schooling.
Household size	The number of household or family members.
Heating area	Area in square meters that needs to be heated in winter.
Income	Annual household income for the year 2015 in 10 000 RMB

tion was made partly due to time, budget and resource limitations; this set of districts represented the maximum of our capacity to cover all three topographical areas in our survey. In the second step, we randomly selected IDs from the residential list in the selected districts, and 605 respondents were selected based on the population in the three areas. The total populations of the mountainous (Miyun and Yanqing), hilly (Fangshan and Pinggu) and plains (Daxing) areas are 710, 1200 and 660 thousand people, respectively (Beijing Municipal Bureau of Statistics, 2016a). The distribution of our sample size for the mountainous, hilly and plains areas was 150, 300 and 155, respectively, with a sample ratio of 0.211, 0.250 and 0.235 per thousand people respectively.[4] Although the sample ratios were not exactly identical across the three areas due to rejections from some respondents, they were sufficiently close to ensure the randomness and representativeness of our data.

For this research, we conducted a field survey in rural Beijing of people's WTA and WTP for LTHP technology in March 2016. We organized a pilot survey with 30 rural respondents to ensure the reliability and validity of the questionnaire. Based on that, the content of the questionnaire was finalized in the local language. Overall, a total of 605 households were randomly selected and interviewed face-to-face. In the end, our data set consisted of 579 samples due to some missing observations in 26 questionnaires. Because the respondents' decision of whether to adopt LTHP and state their maximum WTP value is a hypothetical scenario, information about the LTHP was provided and explained individually during the survey.[5] In addition to WTA and WTP for the LTHP, the survey data include socioeconomic and perception information about the households. The socioeconomic information included age, gender, house size, education, household income, heating area and house location (plains, hilly or mountainous areas). The perception information included science literacy and local and global environmental concerns. We hypothesize that the variables used in this paper are important determinants of WTA and WTP for LTHP. Table 3.1 summarizes the definition of each variable used in our analysis.

The subjects in our survey were not aware of the promotion policy for the LTHP. During the interviews, we first introduced the technological information, advantages of the LTHP and its good per-

[4]The sample ratio is the sample size divided by the total population in each area.

[5]The LTHP information distributed to the respondents is provided in the appendix.

formance in cold climates. We also explained the electricity pricing scheme of the peak-valley time policy to the respondents. Following this, the economic benefits and costs of the LTHP (i.e., investment and running cost) and its potential environmental benefits were explained individually. Next, we asked whether the respondents had questions to confirm their understanding of the LTHP. Then, we began our survey by collecting the respondents' socioeconomic information, local and global environmental concerns and science literacy level. Finally, we asked the respondents' WTA and WTP for LTHP using open-ended questions. Since we implemented the face-to-face interviews individually, the respondents did not know other people's WTA and WTP during the CV survey, and biases caused by interactions among the respondents were avoided.

2.3.2 Two dependent variables: WTA and WTP

This paper uses two dependent variables for analysis: people's WTA and WTP for the environmentally friendly LTHP technology. The respondents were asked to answer two questions: (1) whether they would be willing to adopt the LTHP and (2) what their maximum WTP for the technology would be if they answered "yes" to the first question. Table 2.2 provides a brief description of people's WTA and WTP for the LTHP. Among the 579 respondents in rural Beijing, 53 % of them reported being willing to adopt the LTHP, while the remaining 47 % were not. Figure 2.2 clearly reveals significant differences in people's WTA for the LTHP among the overall area and the plains, hilly and mountainous areas. In particular, only 7 % of people in the plains areas reported being willing to adopt the LTHP. This is the lowest acceptance rate among the three area types. By contrast, 74 % of people in mountainous areas reported being willing to adopt the LTHP. Figure 2.3 summarizes the distribution of WTP for the LTHP in the general case. It clearly shows that 1000 RMB and 2000 RMB represent the highest nonzero mode of the WTP value. To capture more detailed results, figure 2.4 describes the distribution of WTP for the LTHP in the three areas. The two outstanding nonzero WTP values are 1000 RMB and 2000 RMB in the mountainous and hilly areas, whereas WTP is only 1000 RMB in the plains area. Table 2.2 also shows that people in the plains area expressed the lowest WTP, at 71.05 RMB on average, whereas

Table 2.2: Summary statistics for the dependent variables

Dependent variable	Areas			Overall
	Plains area	Hilly area	Mountainous area	
WTA (Yes $= 1$, No $= 0$)				
Average (Median)[1]	0.07 (0)	0.66 (1)	0.74 (1)	0.53 (1)
SD[2]	0.26	0.47	0.44	0.5
Min	0	0	0	0
Max	1	1	1	1
WTP (RMB)				
Average (Median)	71.05 (0)	1001.36 (1000)	992.48 (1000)	755.10 (500)
SD	256.73	954.09	783.31	886.37
Min	0	0	0	0
Max	1200	3000	3000	3000
Sample size	152	294	133	579

[1] Median in parentheses.

[2] SD refers to standard deviation.

people in the hilly and mountainous areas had higher WTP values of 1001.36 RMB and 992.48 RMB, respectively. Overall, people in plains areas are the least likely to adopt the LTHP and have the lowest WTP for the technology compared with their counterparts in hilly and mountainous areas, and this result can be considered unexpected or in contrast to our initial expectation.

Basic socioeconomic and demographic characteristics

Table 2.3 provides an overview of the socioeconomic and demographic characteristics of our respondents. There is substantial variation among the survey respondents in the variables of age, household size and household heating area. Overall, the ranges of age, household size and household heating

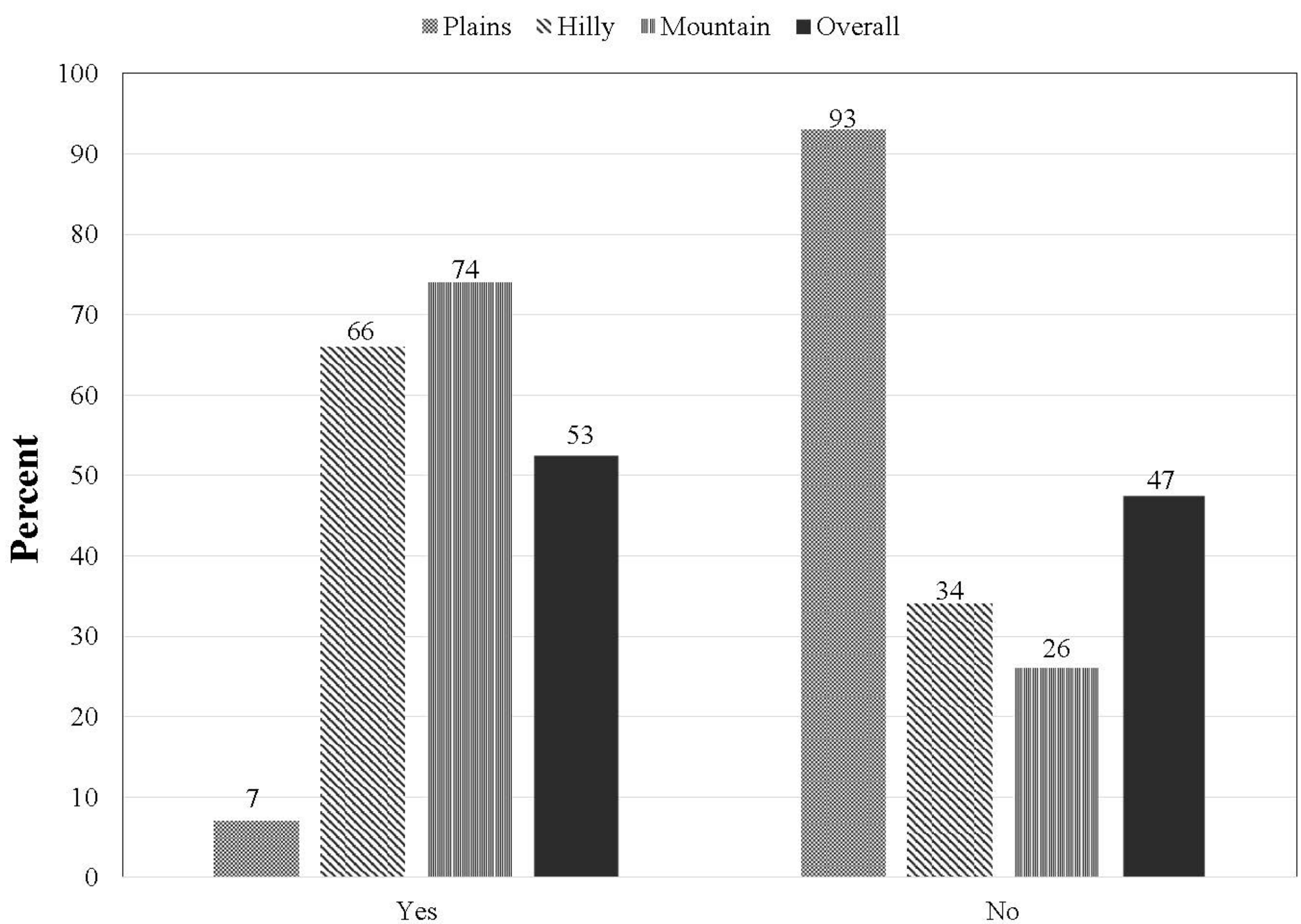

Figure 2.2: Distribution of WTA in rural Beijing

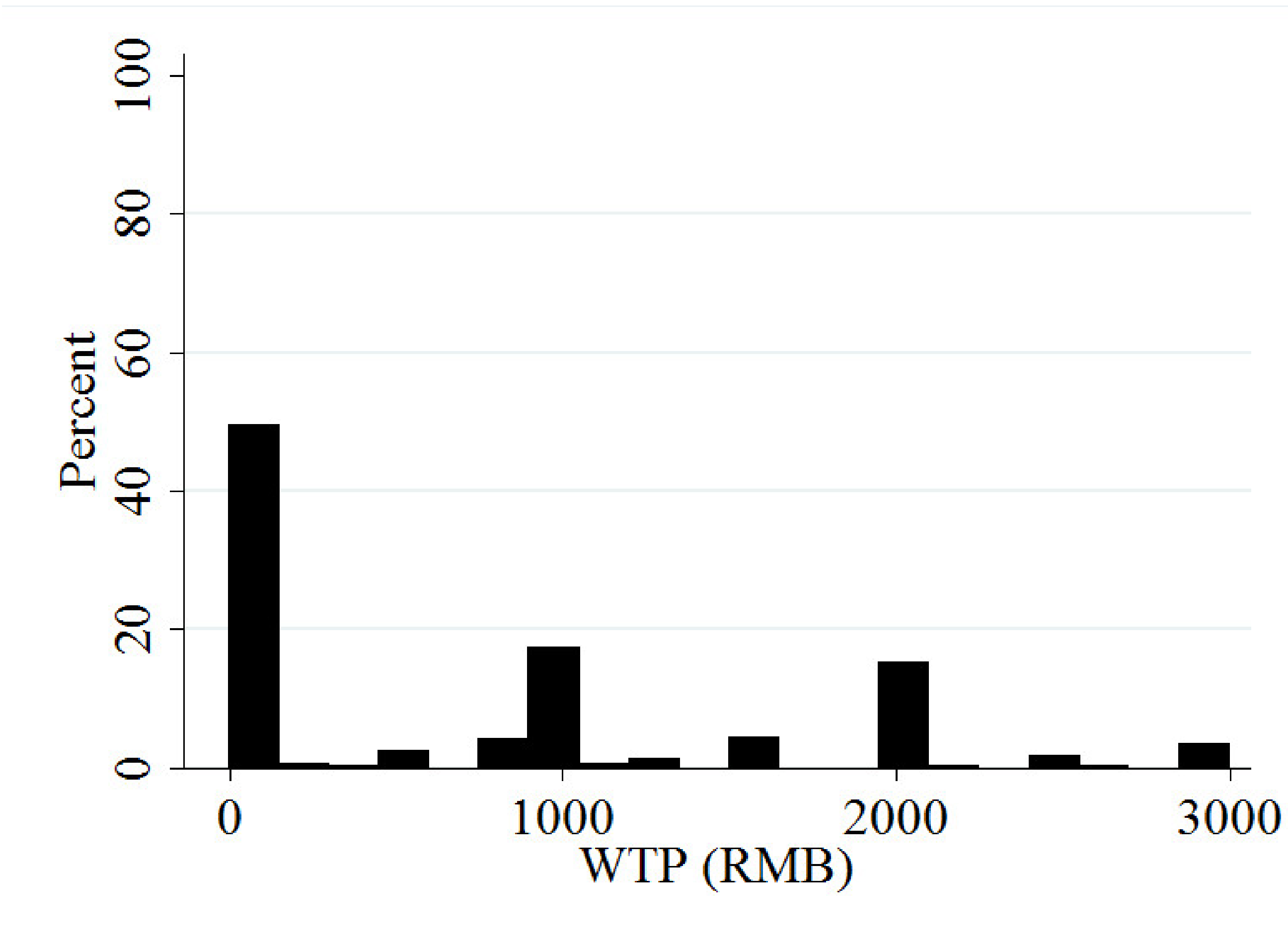

Figure 2.3: Distribution of WTP for LTHP in rural Beijing (N=579)

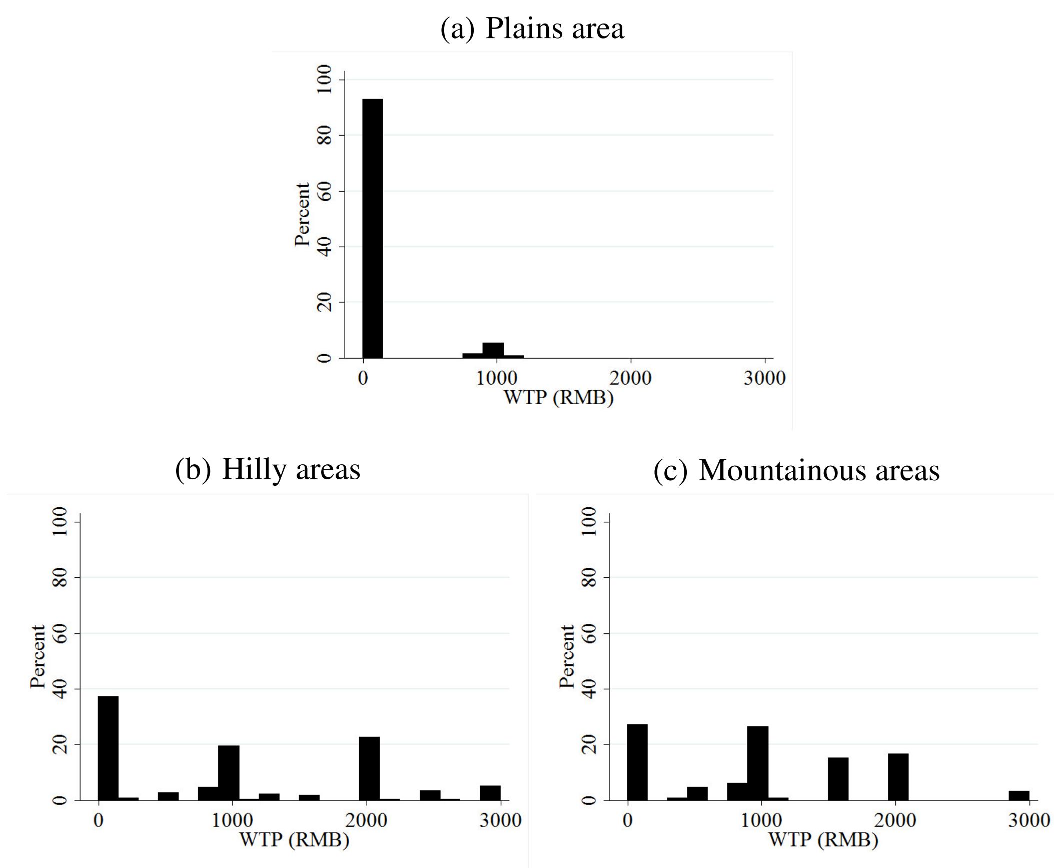

Figure 2.4: Distribution of WTP for LTHP in three areas

area are 20 to 91, 1 to 11, and 12 to 500, respectively. The same tendency can be also observed with respect to these variables within each of the three area types. On average, the annual household income is highest in the plains area and lowest in the mountainous areas. People in the hilly areas have the highest household income gap, ranging from 2000 RMB to 120 000 RMB per year. The respondents' education status is lower in the mountainous areas than in the plains and hilly areas.

Perception variables

We collect two types of perception variables: (1) environmental concern and (2) science literacy. Environmental concern is categorized into two levels: global environmental concern and local environmental concern. Global environmental concern comprises 12 questions, basically following Nakagawa (2017) (see table 2.4). In addition to the 11 questions used in Nakagawa (2017), one item on global warming is added to the measurement as we are also interested in studying individual technological adoption behaviors to reduce haze pollution and coal consumption. Each question is assessed on a 5-point scale: $1 =$ strongly disagree, $2 =$ disagree, $3 =$ neutral, $4 =$ agree, $5 =$ strongly agree. The global environmental concern score ranges from 12 to 60. Local environmental concern focuses more on the specific environmental issues in Beijing (table 3.3). Except for the 4-point score used for question 6, all other questions are rated as $1 =$ strongly disagree, $2 =$ disagree, $3 =$ neutral, $4 =$ agree, $5 =$ strongly agree. The local environmental concern score ranges from 6 to 29. Table 2.3 provides the summary statistics separately for global and local environmental concerns. On average, people in plains areas express the lowest concern regarding both local and global environmental issues, relative to those in hilly and mountainous areas.

Science literacy is measured by 10 questions listed in table 3.4 (Miller, 1998). The respondents answer "true," "false" or "no idea" for each question. The option "no idea" is scored zero to avoid accidental correct answers. Science literacy is scored from 0 to 10 by summing up all the correct answers. As indicated by table 2.3, the respondents' science literacy ranges from 0 to 9. On average, people in mountainous areas exhibit the least science literacy but the largest standard deviation thereof, indicating broad variation in scientific knowledge, whereas the highest science literacy is shown by

Table 2.3: Summary statistics for the independent variables

Independent variable	Areas			Overall
	Plains area	Hilly area	Mountainous area	
Age (Years)				
Average (Median)[1]	53.88 (54)	54.28 (55.5)	56.48 (55)	54.68 (55)
SD[2]	10.64	13.88	11.39	12.56
Min	21	20	20	20
Max	86	88	91	91
Gender (Female = 0)				
Average (Median)	0.8 (1)	0.56 (1)	0.65 (1)	0.64 (1)
SD	0.4	0.5	0.48	0.48
Min	0	0	0	0
Max	1	1	1	1
Household size (persons)				
Average (Median)	4.25 (4)	3.86 (4)	3.21 (3)	3.81 (4)
SD	1.59	1.57	1.4	1.58
Min	1	1	1	1
Max	8	11	7	11
Education (years)				
Average (Median)	8.34 (9)	8.91 (9)	7.90 (9)	8.53 (9)
SD	2.26	2.61	1.86	2.40
Min	6	6	6	6
Max	16	16	12	16
Income (10 000 RMB per year)				
Average (Median)	2.95 (3)	2.84 (3)	1.44 (1)	2.55 (2)
SD	1.78	1.98	0.98	1.84
Min	0.2	0.2	0.2	0.2
Max	8	12	5	12
Heating area (m^2)				
Average (Median)	123.82 (100)	109.09 (100)	82.06 (80)	106.74 (100)
SD	61.56	61.86	33.35	58.34
Min	30	12	20	12
Max	300	500	200	500
Science literacy (The theoretical range is 0-10)				
Average (Median)	4.24 (4)	4.78 (5)	3.52 (3)	4.35 (4)
SD	1.78	2.06	2.58	2.18
Min	0	0	0	0
Max	8	9	9	9
Local environmental concern (The theoretical range is 6-29)				
Average (Median)	18.26 (18)	21.80 (23)	19.56 (18)	20.36 (20)
SD	3.31	3.81	4.05	4.04
Min	9	7	10	7
Max	27	29	29	29
Global environmental concern (The theoretical range is 12-60)				
Average (Median)	41.32 (42)	45.19 (45)	44.04 (46)	43.91 (44)
SD	5.73	7.72	7.06	7.26
Min	33	29	24	24
Max	56	60	60	60
Sample size	152	294	133	579

[1] Median in parentheses.

[2] SD refers to standard deviation.

Table 2.4: Measures of global environmental concern

Questions	Description
1	I am concerned about global warming.
2	I am concerned about the relationship between energy and the environment.
3	I am concerned about environmental protection.
4	I like reading books about environmental problems.
5	I want to consider environmental problems proactively.
6	I would like to learn more about environmental problems.
7	I watch TV programs or read articles on the environment with interest.
8	I am interested in the biosphere.
9	I am interested in natural energy such as solar energy.
10	I would like to be actively engaged in environmental problems.
11	I am concerned about energy problems.
12	I am interested in the protection of species in danger of extinction.

Table 2.5: Measures for local environmental concern

Questions	Description
1	I am concerned about air quality in Beijing.
2	I am concerned about water/soil pollution problems in Beijing.
3	I am concerned about news or knowledge about air pollution control in Beijing
4	I am concerned about the harmful effect of air pollution on health in Beijing.
5	I am concerned about the daily air quality index forecast.
6	I am concerned about the trade-off between life convenience and energy conservation:
	a. Life convenience always has higher priority.
	b. Energy should be conserved without sacrificing life convenience.
	c. The environment should be conserved even if life convenience is sacrificed to some extent.
	d. Environmental conservation is always more important.

Table 2.6: Measures of science literacy

Questions	Description
1	The temperature of the core of the earth is extremely high.
2	All radioactive materials are artificial.
3	The sex of a baby is determined by his/her father's genes.
4	Laser beams can be generated by collecting sonic waves together.
5	Electrons are smaller than atoms.
6	Antibiotics kill viruses like bacteria.
7	The universe was born in a huge explosion.
8	The continents have been moving over the millennia, and they will continue moving.
9	Human beings evolved from primitive animals.
10	The earth is moving around the sun.

people in hilly areas.

2.3.3 Methodology

The government plans to widely promote LTHP technology, but LTHPs remain a new product that has not been introduced in markets. It is an environmentally friendly technology to reduce coal consumption and mitigate air pollution. Hence, this paper employs the contingent valuation (CV) method to examine the population's WTA and WTP for the LTHP product. The CV questions in this analysis are divided into two steps. In the first step, we ask whether each respondent is willing to adopt the product, given the information provided about LTHP technology. Therefore, WTA is a dummy variable that takes a value of 1 when a respondent wants to adopt LTHP and 0 otherwise. If the respondent answers "yes," the second step follows, and we ask the respondent her maximum WTP value for LTHP technology.

To empirically characterize public acceptance of LTHP technology, we run two types of regression models: (1) a probit model in which the dummy variable of WTA is taken as the dependent variable and (2) a Tobit model in which the continuous variable of WTP is taken as the dependent variable. In both models, the same set of independent variables is included. The baseline specification for the two models can be expressed as

$$y_i = f(D_i, E_i, S_i, H_i) \tag{2.1}$$

where subscript i represents the subject's ID from 1 to 579, y_i is the dependent variable of WTA_i or WTP_i, D_i is a vector of area dummy variables corresponding to whether each respondent lives in mountainous areas (Yanqing and Miyun) and hilly areas (Pinggu and Fangshan), with the plains area (Daxing) treated as the reference group. E_i is a vector of two variables: global environmental concern and local environmental concern. S_i is the science literacy scale, H_i is a vector of variables at the individual and household levels such as age, gender, education, household size, housing area and annual household income in the year 2015.

In the probit regression, each respondent's qualitative decision of whether to adopt LTHP technology is modeled by the dummy variable $y_i = \text{WTA}_i$, that takes a value of 1 when the respondent i is willing to adopt LTHP technology and $\text{WTA}_i = 0$ otherwise. In this case, the probability that the respondent i is willing to adopt, $\text{Prob}(\text{WTA}_i = 1)$, is expressed by the standard normal cumulative distribution function G:

$$\text{Prob}(\text{WTA}_i = 1) = G(\alpha_0 + D_i\alpha_1 + E_i\alpha_2 + S_i\alpha_3 + H_i\alpha_4) \tag{2.2}$$

where α_0 is an intercept, and α_js for $j = 1, \ldots, 4$ are the vectors of unknown parameters associated with D_i, E_i, S_i, H_i to be estimated. The probit regression identifies the estimates of $\alpha_0, \alpha_1, \alpha_2, \alpha_3, \alpha_4$ via maximum likelihood methods, enabling us to compute the marginal probability of LTHP technology adoption (See, e.g., Wooldridge, 2008, 2010, for the details of mathematical derivations). Specifically, the marginal probability represents a change in $\text{Prob}(\text{WTA}_i = 1)$ when one independent variable increases by one unit, holding other variables constant. Thus, the key qualitative determinants and the marginal probability of LTHP adoption are characterized by the probit regression as a first step.

In the Tobit regression, our focus is on the "quantitative" decision of the maximum WTP expressed by respondents. When respondent i is willing to adopt the LTHP, i.e., $\text{WTA}_i = 1$, she is asked to express a maximum WTP, i.e., $\text{WTP}_i > 0$ for the LTHP adoption. When the respondent is NOT willing to adopt the technology, i.e., $\text{WTA}_i = 0$, implying $\text{WTP}_i = 0$. Therefore, WTP_i is considered left-censored at zero or a nonnegative continuous variable. Tobit regression is most appropriate when the dependent variable is left-censored at zero and a considerable portion of WTP_is are found to be zero in the sample (Wooldridge, 2008, 2010). The Tobit regression is specified as

$$\text{WTP}_i^* = \beta_0 + D_i\beta_1 + E_i\beta_2 + S_i\beta_3 + H_i\beta_4 + \epsilon_i \tag{2.3}$$

where WTP_i^* is the latent variable satisfying the relation of $\text{WTP}_i = \max(0, \text{WTP}_i^*)$, β_0 is an intercept, β_js for $j = 1, \ldots, 4$ are the vectors of unknown parameters associated with D_i, E_i, S_i, H_i to be estimated, and ϵ_i is a normally distributed error term.

While the latent variable WTP_i^* follows the ordinary linear regression assumptions with a normal distribution, the observed WTP_i does not follow the same assumptions in the sense that WTP_i is equal to WTP_i^* when $\text{WTP}_i^* \geq 0$, otherwise $\text{WTP}_i = 0$. Specifically, WTP_i follows the normal distributions over strictly positive values, otherwise $\text{Prob}(\text{WTP}_i = 0) = \text{Prob}(\text{WTP}_i^* < 0)$ on the basis of the fact that WTP_i^* is normally distributed. With these assumptions of probability distributions for the WTP_i, the Tobit regression identifies the estimates of $\beta_0, \beta_1, \beta_2, \beta_3, \beta_4$ via maximum likelihood methods, enabling us to compute a marginal change in WTP_i when one independent variable increases by one unit, holding other variables fixed. In summary, the probit and Tobit regression models are employed to characterize public acceptance of LTHP technology from both the "qualitative" and "quantitative" decisions households make, focusing on the marginal probability in $\text{WTA}_i = 1$ and the marginal change in WTP_i.

2.4 Results and discussion

Table 2.7 reports the marginal effects of the independent variables on people's WTA and WTP. In general, the variables of gender, income, science literacy, local environmental concern and the area dummies are significant factors that affect both WTA and WTP, whereas age has a significant impact only on WTA, and house heating area only affects WTP. [6]

2.4.1 Effects of socioeconomic and household factors

As shown in table 2.7, annual household income has a significantly positive effect on people's WTA and WTP, as expected. Specifically, a 10 000 RMB increase in annual household income is associated with a 2.400 % increase in the probability that people will accept the LTHP, and their WTP will accordingly increase by 128.293 RMB. This result indicates that as China's economy grows, people's tendency to adopt this technology in rural areas may gradually increase. Regarding the marginal effect of gender, females are 7.900 % more willing to adopt the technology than males. Similarly, regarding the WTP value, females are, on average, willing to pay 308.997 RMB more than males. This is in contrast to the findings of Erdem et al. (2010), who indicate that in Turkey, males are more likely to pay a higher premium for hybrid electric vehicles (HEVs) than females. A possible explanation is that coal is the primary heating resource in rural households, and females are primarily responsible for the frequent fuel replacement in coal stoves, which are inconvenient and usually generate observable smog and a foul odor. Females are expected to clean the house every day, and thus they may prefer to use more environmentally friendly heating products and exhibit higher WTP than males.

There is no statistically significant relationship between education and people's WTA and WTP, although the coefficients of the Tobit and probit regressions are positive. Our result is consistent with previous findings from Sun et al. (2016a) that education and the WTP to address the smog crisis in China are positively correlated, but the effect is insignificant. Our results show that age has a small positive impact on WTA (0.300 %) at the 5 % significance level but has no effect on WTP. This finding implies that older people are more interested in replacing their existing heating systems with LTHPs. This is the opposite of the finding of Sopha et al. (2010) that it is more difficult to change older people's

[6] To check the reliability of our results, we run various specifications of regressions by adding additional variables and interaction variables in both the probit and Tobit regressions. Our results in this paper are identified to be robust because we observe the same qualitative results in other specifications as well.

Table 2.7: Marginal effects of probit and Tobit regressions

	Probit	Tobit
	WTA[1]	WTP[2]
Socioeconomic variables		
Age	0.003**	6.614
	(0.002)[3]	(5.318)
Gender	-0.079**	-308.997***
	(0.034)	(119.049)
Education	0.009	14.359
	(0.008)	(28.531)
Household size	-0.006	19.887
	(0.012)	(39.858)
Heating area	-0.000	-2.574**
	(0.000)	(1.069)
Income	0.024**	128.293***
	(0.011)	(34.909)
Environmental concern and perception variables		
Global environmental concern	0.002	3.225
	(0.002)	(8.092)
Local environmental concern	0.029***	94.081***
	(0.004)	(15.426)
Science literacy scale	0.021***	88.077***
	(0.008)	(26.601)
Area dummy variables (Base group = Plains areas)		
Mountainous dummy	0.569***	2435.239***
	(0.039)	(228.440)
Hilly dummy	0.381***	1851.772***
	(0.037)	(206.005)

***significant at the 1 percent level, **at the 5 percent level and *at the 10 percent level.

[1] "WTA" represents willingness to adopt.

[2] "WTP" represents willingness to pay.

[3] Standard error in parentheses.

behavior by encouraging them to switch from an existing heating system to a heat pump or wood pellet stove. We conjecture that compared to younger people, older people devote considerable attention to their own health and that of other household members due to their gradual decline in physical function and greater responsibility to the whole family. Thus, they may have a greater demand for a healthy environment, especially for warmth during a long winter.

The area of a house that needs to be heated is estimated to have a significantly negative but relatively small effect on WTP, meaning that people's WTP falls by 2.574 RMB with a 1 m^2 increase in area. Although the impact appears quite small, it is not small when the impact is evaluated given a one-standard-deviation increase in house area (≈ 58.340). We find that if the area of a house is increased by one standard deviation, people's WTP decreases by 150.167 RMB ($2.574 \times 58.340 \approx 150.167$), on average. However, the probit regression indicates that the area to be heated has no significant influence on WTA. In one sense, having a larger home area means that there are more rooms to be heated. It is reasonable that respondents with large homes may be more motivated to obtain several units of the product at a time. Due to budget constraints, they are particularly incentivized to pay low prices for the LTHP. However, since the promoted LTHP is a non-traded product in the free market, it is difficult for such respondents to clearly express their attitude on whether to adopt the technology.

2.4.2 Impacts of perception factors

One interesting finding of this paper is that local environmental concern positively affects both WTA and WTP at the 1 % significance level, whereas the effect of global environmental concern is insignificant. This result implies that compared to global environmental concern, greater concern about local environmental issues increases the motivation of people to adopt the LTHP at higher prices. More precisely, our results reveal that a one-point increase in local environmental concern results in a 2.900 % rise in the likelihood of adoption. Accordingly, such people are willing to pay 94.081 RMB more to purchase the LTHP on the average. In our analysis, a one-standard-deviation increase in local environmental concern (≈ 4.040) increases the WTA probability and the associated WTP by 11.716 %

$(2.900 \times 4.040 \approx 11.716\,\%)$ and 380.087 RMB $(94.081 \times 4.040 \approx 380.087)$, respectively.

Global environmental concern has an insignificant influence on both WTA and WTP, although the sign of the coefficient is positive. This finding may reflect the direct impact of local environmental problems on people's quality of life, in contrast to the impacts of global environmental issues. People may take prompt actions to address specific local issues such as air pollution. In other words, the local environmental concern that people develop on the basis of their everyday life is more important for public acceptance of new electric heating systems than the global environmental concern that people may have developed from consuming books, TV and other media.

Science literacy has a positive relationship with both WTA and WTP for the technology. The probit model estimates that increasing the science literacy score by one point leads to a 2.100 % rise in the probability of adopting the technology. Accordingly, the Tobit regression reveals that people are willing to pay 88.077 RMB more following a one-point increase in the science literacy score. This result provides evidence that science literacy plays an important role in public acceptance of this new environmentally friendly technology. People with greater scientific knowledge and literacy may find it easier to recognize the desirable features of a technology even in a short time. It is reasonable that they are more likely to adopt the technology in their home and have a higher WTP.

2.4.3 Effects of regional differences

Another interesting finding is that, contrary to our expectation, people living in mountainous areas express the highest WTA and WTP for the LTHP, followed by people living in hilly and plains areas. It reveals that people living in mountainous and hilly areas are 56.900 % and 38.100 % more likely to adopt the technology and exhibit higher WTP with values of 2435.239 RMB and 1851.772 RMB, respectively. One possible reason is that more remote mountainous areas present fewer job opportunities due to the greater distance and lower access to urban areas. Because there are no farming activities in remote mountainous and hilly areas during the winter, people in such areas naturally have to spend more time at home and are more concerned about the indoor environment. Therefore, they are more motivated to adopt the LTHP. In addition, because plains area is a focus of promotion policies and prioritized for the diverse promotion of clean energy technologies such as solar energy, electricity and natural gas, people in the plains area have a wider variety of alternative energy choices than those in mountainous and hilly areas. As a consequence, it is reasonable that people in mountainous areas express higher WTA and WTP on LTHP than those in plains area once a convenient and good energy technology is available to them, such as the LTHP. Moreover, the difference in climate may play a role. The temperature in mountainous areas is normally lower than that in plains areas by 3 °C to 5 °C. Since this technology performs well in cold climates, people in mountainous areas might have higher WTP for LTHP than those in plains area.

In recent years, respondents in plains areas have been used as focus groups for the promotion of clean energy technologies, including LTHP technology, to achieve the target of zero coal consumption (General Office of Beijing Municipal People's Government, 2016, 2017). The involvement of these plains areas may reflect their more severe haze pollution. However, our analysis finds that public acceptance of LTHPs is highest in mountainous areas, followed by hilly areas and then by plains areas. On the basis of this result, we argue that if mountainous areas can be prioritized for LTHP promotion, it is more likely that the LTHP technology will be more successfully and efficiently accepted and distributed with lower government investment and spending on promotion. Achieving such success in mountainous areas can be expected to positively influence public acceptance of LTHP technology in other areas such as hilly and plains areas. The important findings in this paper can be summarized as follows. First, income remains a key factor in determining public acceptance of LTHP technology. Second, people with higher levels of science literacy and local environmental concern are more willing to adopt the technology by spending more money, whereas global environmental concern has no significant effect. Third, people in mountainous areas have the greatest interest in adopting the technology and the highest WTP, followed by those in hilly and plains areas.

2.5 Conclusions and policy implications

This paper analyzes the determinants of people's willingness to adopt (WTA) and willingness to pay (WTP) for LTHP technology in rural Beijing. We find that income, science literacy and local environmental concern are important factors that affect the likelihood of the adoption of LTHP technology, whereas global environmental concern does not have any effect. These findings represent new contributions to the literature since few studies empirically include science literacy and two levels of environmental concern (local and global) in the analysis of public acceptance of environmentally friendly technologies. We illustrate that science literacy and local environmental concern are the main determinants of public acceptance of this environmentally friendly heating technology. These results not only expand important dimensions of research on technological acceptance but also reveal important roles of science literacy and local environmental concern in promoting environmentally friendly technologies in practice.

People in mountainous areas express the highest WTA and WTP for the LTHP, followed by those in hilly and plains areas. We argue that people in mountainous areas are more concerned about the indoor environment and thus are more likely to accept LTHP technology for the following reasons. First, people in mountainous areas spend more time at home than those in plains areas because of the lack of farming activities in winter and the few job opportunities other than farming. Second, people in plains area have a wider variety of options for alternative energy choices than those living in mountainous and hilly areas. The plains area is prioritized for various promotion policies for clean energy technologies, such as solar energy, electricity and natural gas. This finding also implies that people in mountainous areas may be more motivated to adopt a new technology such as LTHP once the new technology becomes available for purchase. Third, climate differences could be another important reason for differences in WTA and WTP for LTHPs. The temperature in mountainous areas is lower than that in plains areas by 3 °C to 5 °C. Once people in mountainous areas understand that this technology can perform well in cold climates, they will be more eager to adopt the LTHP than those in plains areas.

These results suggest some important policy implications. Our results provide new evidence of the importance of the science literacy level for public acceptance of environmentally friendly technologies. In 2002, China enacted the Law of the People's Republic of China on the Promulgation of Science and Technology, and improving the public science literacy level has become a main target in the sector of science popularization. Thus, we suggest that greater resources and investment could be introduced in rural areas to promote technological acceptance in energy fields. Another policy strategy is to focus more on public education to strengthen rural people's awareness of the local environment compared to the global environment. Once people become more knowledgeable about local environmental issues (i.e., harmful effects of air pollution on health), they are more willing to consider a switch toward cleaner energy consumption.

In addition, it would be preferable to prioritize mountainous areas in promotion strategies for LTHP technology because public acceptance is highest in these areas. The promotion campaign should then target hilly and plains areas, following the order of public acceptance. We believe that successes of LTHP promotion in mountainous areas will positively influence public acceptance in other areas such as hilly and plains areas, thus allowing LTHP technology to be more widely accepted and distributed in the lowest-cost manner. Ultimately, this increased acceptance will cause households in rural Beijing to switch energy sources from coal to electricity, thereby improving the environment. Moreover, since LTHP technology is mostly promoted in small-scale stages of demo projects and the subsidy scheme is not organized, our result is also meaningful for policy makers to design mechanisms of subsidies based on people's highest nonzero mode of WTP value for each unit of LTHP in rural Beijing.

Overall, this paper provides crucial findings for decision makers regarding where to begin and how to efficiently promote LTHP technology in rural Beijing. We believe that our findings make an important contribution to addressing the excessive coal consumption in rural China. This paper might also serve as an important reference on 1) the prospects for the adoption of this technology in other parts of China that rely heavily on coal as a heating source; 2) the development of other environmentally friendly technologies; and 3) the market prospects for manufacturers or sellers that trade in environmentally friendly technologies. Finally, we admit that this study faces limitations. Although we did our best to introduce and explain the information of LTHP technology during the face-to-face surveys, some unavoidable and unexpected biases in WTA and WTP might exist. Therefore, further research on the public acceptance of LTHP technology could be developed and conducted to confirm the robustness of our results during the real promotion periods. Such research is crucial to ensure a smooth transition from coal to cleaner energy in the long run.

2.6 Appendix: Low temperature air-source heat pump (LTHP)

The LTHP is an environmentally friendly electric heating technology. It is a mechanical compression cycle refrigeration system powered by electricity from an air source that can be reversed to heat a room. It has the desirable characteristics of low initial investment and operating costs, ease of installation and operation, and no pollution emissions. The steady-state coefficient of performance (COP) will not be lower than 2.0 on average throughout a winter season when the temperature is higher than or equal to $-20\,^{\circ}\mathrm{C}$. Note that in the actual application, all of the information was provided to respondents in the local Chinese language. Because the respondents are familiar with the expenses of using coal, we only provide details regarding the running costs for LTHP, as scientifically determined in the demonstration projects.

Table 2.8: Performance of the LTHP for a 80 m^2 residence in typical rural homes

	LTHP	LTHP with peak-valley price policy[1]
Electricity price (RMB/kWh)	0.5	0.1 - 0.5
Annual energy consumption (kWh)[2]	2500	2500
Annual heating fee (RMB)	1250	920
Annual heating fee per square meter (RMB)	15	11.5
Annual $PM_{2.5}$ emission	0	0

[1] With a peak-valley time price policy, the price would be 0.1 RMB/kWh at the peak and 0.5 RMB/kWh in the valley. Assuming that the LTHP operates 24 hours per day, the heating fee is identified as in table 2.8 based on realistic assumptions regarding the peak and valley times.

[2] Annual energy consumption can be regarded as an increase in electricity consumption for heating by using LTHP in the whole winter season.

[3] The installation cost of an LTHP was approximately 5900-6600 RMB per unit in 2016.

Chapter 3

Low-quality or high-quality coal? Household energy choice in rural Beijing

3.1 Introduction

China is the leading coal consumer in the world, representing 48.0 % of global coal consumption in 2015 (Enerdata, 2016). Coal combustion is an important contributor to ambient air pollution $PM_{2.5}$ and was connected to 366 000 deaths in China in 2013 alone (GBD MAPS Working Group, 2016).[1] It was also reported that poor coal quality is a major cause of severe air pollution in China (Litvinenko, 2016) and that raw coal burning by rural households is responsible for even higher emissions than those of the industrial sector (Zhi et al., 2015; Chai et al., 2016). Cheng et al. (2016) proved that high concentrations of CO and $PM_{2.5}$ emissions result from incomplete combustion of household coal use. Special attention to low-quality coal emission is required since this factor is key to controlling haze pollution in rural China (Zhi et al., 2015). Beijing has taken the lead in promoting high-quality coal by providing price subsidies and promoting the adoption of new-type coal stoves (General Office of Beijing Municipal People's Government, 2013a). The subsidies have been increased and diversified across Beijing's rural districts since 2015 (Gao, 2015). These subsidy policies are expected to be important in accelerating the transition from low-quality to high-quality coal and in mitigating haze pollution. This paper addresses the policies and factors that influence household coal consumption behaviors with respect to coal quality in China.

Previous studies have analyzed energy transitions and the potential for renewable energy use in different sectors, such as food production (Leach, 1975), transport (Harijan et al., 2009a) and green electricity generation (Harijan et al., 2009b, 2010, 2011, 2015).[2] In private households, a substantial

[1] PM (particulate matter) is the sum of all solid and liquid particles suspended in the air. Particles with a diameter of 2.5 micrometers and smaller, denoted by $PM_{2.5}$, pose the greatest health risk.

[2] From a technical perspective, recent studies have also focused on the energy performance of thermal or cold storage materials in the application of space heating or cooling technologies (Li et al., 2012;

challenge facing developing countries is forest degradation caused by a heavy reliance on fuelwood consumption (Leach, 1975; Heltberg et al., 2000). Consequently, past studies have widely analyzed household fuel switching from non-commercial fuel, such as biomass, to cleaner ones using an energy ladder model in developing countries (Heltberg, 2004, 2005; Peng et al., 2010; Rahut et al., 2014; Mottaleb et al., 2017; Rahut et al., 2017d).[3] These studies reveal that sociodemographic factors (i.e., household income, age, education or gender of the head of household) and energy prices are the key drivers of household fuel switching. Rahut et al. (2017a) further investigate the influence of severe weather and village remoteness on household fuel choices in the Himalaya areas of Pakistan.

Another group of studies have focused on household adoption of cleaner and renewable energy. Rahut et al. (2017c,e) empirically illustrate that lack of infrastructure access limits household electricity consumption in Africa. Hence, off-grid renewable energy emerges as an alternative solution to ensure the market demand for electricity (Harijan et al., 2015; Rahut et al., 2017d; An innovation of World Bank Groups, 2017). Rahut et al. (2017b) use data based on living standards measurement surveys in Sub-Saharan Africa and show that wealthy, female-headed or highly educated households are more likely to consume clean and renewable energy. Rahut et al. (2017f) also find that household demographics, education and wealth influence household adoption of solar energy in Ethiopia, Tanzania and Uganda. Wang and Jiang (2017) conduct field surveys in 25 provinces of China and suggested that a higher income level is necessary for renewable energy development to address environmental problems in rural China.

None of the past studies have analyzed the determinants of household coal consumption behaviors across levels of coal quality within an analytical framework. Such research is particularly important because coal is the main fuel source for heating and contributes to severe air pollution in China (Li et al., 2015). More broadly, air pollution is a prominent issue facing most developing countries (e.g., India). Moreover, direct switching from low-quality coal to another source of cleaner energy, such as

Li, 2013; Li et al., 2013, 2014; Li and Liu, 2014).

[3]The energy ladder hypothesis is conceptualized as a three-stage fuel-switching process from traditional fuels (i.e., firewood) to transition fuels (i.e., kerosene or coal) and to a final stage of modern fuels (i.e., electricity) (Leach, 1992).

electricity or renewable fuels, is known to be time consuming due to infrastructure requirements and the need for sizable government investment; thus, the promotion of high-quality coal is regarded as an important and necessary step for a practical energy transition in China (Xiao, 2016). Thus, it is salient to analyze the determinants of household energy choices and consumption between low-quality and high-quality coals in rural China. Using survey data in rural Beijing, this paper aims to examine the effectiveness of government policies and influence of cognitive & psychological and socioeconomic factors on household coal choices and consumption behavior by employing bivariate probit regression and Tobit regression.

There are several novel aspects of this research relative to the existing literature. First, this study newly includes cognitive & psychological variables in the analysis, considering the importance and increasing concerns of nonpecuniary interventions on changing people's energy consumption behaviors in policy making and research (Allcott and Mullainathan, 2010; Pollitt and Shaorshadze, 2013). In addition to two levels of environmental concerns (local and global), we collect the information of people's critical thinking disposition and social value orientation (SVO). Critical thinking disposition represents people's logical awareness and ability to understand situations and execute precautionary actions accordingly by a self-reported questionnaire (Nakagawa, 2015). SVO refers to people's preferences on the allocation of resources (e.g., money) between oneself and another and categorizes people's social values into either cooperative, competitive or individualistic types (Van Lange et al., 1997, 2007b). We consider SVO an important factor since selfishness is assumed to be an obstacle in public acceptance of environmentally friendly energy sources such as renewable energy (Sovacool, 2009).

Another important contribution is the evaluation of subsidy policies (e.g., new-type coal stoves and price subsidies on high-quality coal) on household coal switching behavior when these policies are still in an early stage of implementation. Third, few studies have analyzed fuel transition behavior only for heating purposes, which is particularly valuable for countries with a long-term cold winter season. Fourth, most previous works have analyzed energy choices without focusing on energy expenditure and consumption analysis (Rahut et al., 2014, 2017d). In this research, in addition to bivariate probit regression to analyze coal choices, we use Tobit regression to characterize the determinants of consumption behaviors between two types of coals. As demonstrated in table 3.6, both low-quality and high-quality coal consumption has a considerable portion of zero values. In this situation, Tobit regression is known to be the most appropriate regression approach (Hill et al., 2008; Wooldridge, 2008, 2010). Specifically, when the observations of a dependent variable contain a considerable proportion of 0 values, other OLS-type regression approaches generate biased and inconsistent estimates. In contrast, Tobit regression can take into account the distribution of a dependent variable left-censored at 0 by expressing it through an underlying latent variable, enabling the estimated regression parameters to be unbiased and consistent. Although there are several novel aspects as mentioned above, we must note some limitation in our research. This paper constitutes an observational study examining correlational evidence on the determinants of household fuel choices and consumption behaviors between two types of coals.

3.2 Data and methodology

As China's capital city, Beijing comprises 16 administrative county-level districts, among which 6 are urban districts and 10 are suburban and rural districts. The total area of Beijing is 16 410.5 km^2. A relatively small area, 1368.3 km^2, is urban, with the remainder being rural (Beijing Municipal Government, 2012a). Beijing is also a typical region that heavily relies on coal as a heating source in rural areas and has suffered from severe haze pollution since 2013. Therefore, Beijing has actively taken countermeasures to address air pollution, such as the promotion of high-quality coal and new-type coal stoves. Due to considerable differences in the geographical and socioeconomic characteristics across Beijing's rural areas, it is expected that we can obtain sufficient variation in the data by implementing field surveys. We covered 5 rural and suburban areas in our survey: Yanqing, Miyun, Pinggu, Fangshan and Daxing (see figure 3.1).

In March 2016, we conducted household field surveys in rural Beijing. In total, 602 households were randomly selected, and the decision makers of each household were interviewed. The respondents were asked to answer whether they used low-quality and/or high-quality coals in Febru-

Figure 3.1: Administrative divisions of Beijing

ary 2016. The answers were used to assign two binary variables with four possible outcomes: 1. low-quality coal $=$ high-quality coal $= 1$ if the household consumes both low-quality and high-quality coals, 2. low-quality coal $=$ high-quality coal $= 0$ if the household consumes neither low-quality nor high-quality coal, 3. low-quality coal $= 1$ & high-quality coal $= 0$ if the household consumes only low-quality coal and 4. low-quality coal $= 0$ & high-quality coal $= 1$ if the household consumes only high-quality coal. In addition, we elicited the corresponding consumption on low-quality and/or high-quality coals if the head of household answered "I have used it." The questionnaire contained additional three parts: (1) socioeconomic characteristics: income, household size, heating area, and education; (2) cognitive and psychological variables: SVO, critical thinking disposition and environmental concerns; and (3) policy variables: possession of new-type coal stoves and price subsidies for high-quality coal. Table 3.1 provides the definition of the variables used in this paper.

This study considers cognitive & psychological factors as possible determinants of household coal consumption, including environmental concerns, critical thinking disposition and social value orientation. There are two types of environmental concerns: global and local (Nakagawa, 2018). Following Nakagawa (2018), global environmental concern is measured by 12 questions (see table 3.2). Apart from the 11 questions asked in Nakagawa (2018), a question on global warming is added since the burning of fossil fuel leads to global warming and we are interested in the association between household concerns about coal consumption and global warming. Each question is recorded on a 5-point scale: $1 =$ strongly disagree, $2 =$ disagree, $3 =$ neutral, $4 =$ agree and $5 =$ strongly agree. Global environmental concern ranges from 12 to 60. Local environmental concern is measured by 6 questions concerning specific environmental issues in Beijing (see table 3.3). With the exception of the 4-point scale for question 6, all questions are recorded on a 5-point scale: $1 =$ strongly disagree, $2 =$ disagree, $3 =$ neutral, $4 =$ agree and $5 =$ strongly agree. Hence, the index of local environmental concern ranges from 6 to 29. Following Nakagawa (2015), critical thinking disposition is determined from 13 questions focusing on the logical awareness and ability subscale (see table 3.4). Each question is recorded on a 5-point scale: $1 =$ strongly disagree, $2 =$ disagree, $3 =$ neutral, $4 =$ agree and $5 =$ strongly agree. Thus, critical thinking disposition ranges from 13 to 65.

Table 3.1: Descriptions of the variables

Variables	Descriptions
Socioeconomic variables	
Household size	Number of household or family members.
Heating area	Area in square meters that needs to be heated in winter.
Education	Takes the value 1 when the respondent is educated through primary school, 2 middle high school, 3 high school and 4 university.
Income	Annual household income in 2015 in 10 000 RMB.
Cognitive and psychological factors	
Global environmental concern	An index of 12 global environmental issues ranging from 12 to 60.
Local environmental concern	An index of 6 local (Beijing) environmental concerns ranging from 6 to 29.
Critical thinking disposition	An index of 13 questions ranging from 13 to 65.
Prosocial	Takes the value 1 when the respondent is prosocial; otherwise, 0.
Policy variables	
Modern coal stove	Takes the value 1 when the household possesses a modern coal stove; otherwise, 0.
Relative coal price	High-quality coal price after the subsidy divided by the low-quality coal price.

Table 3.2: Measures of global environmental concern

Questions	Descriptions
1	I am concerned about global warming.
2	I am concerned about the relationship between energy and the environment.
3	I am concerned about environmental protection.
4	I enjoy reading books about environmental problems.
5	I want to consider environmental problems proactively.
6	I would like to learn more about environmental problems.
7	I watch TV programs or read articles about the environment with interest.
8	I am interested in the biosphere.
9	I am interested in natural energy, such as solar energy.
10	I would like to be actively engaged in addressing environmental problems.
11	I am concerned about energy problems.
12	I am interested in the protection of species in danger of extinction.

Table 3.3: Measures of local environmental concern

Questions	Descriptions
1	I am concerned about air quality in Beijing.
2	I am concerned about water/soil pollution problem in China.
3	I am concerned about news or knowledge about air pollution control.
4	I am concerned about the harmful effect of air pollution on health.
5	I am concerned about the daily Air Quality Index forecast.
6	I am concerned about the tradeoff between life convenience and energy conservation:
	a. Life convenience always has the higher priority.
	b. I prioritize conserving energy without sacrificing life convenience.
	c. I prioritize protecting the environment even if it requires sacrificing life convenience to some extent.
	d. Environmental conservation always has the higher priority.

Table 3.4: Critical thinking disposition

Questions	Descriptions
1	I am good at thinking about complex problems in an orderly fashion.
2	I am good at collecting my thoughts.
3	I am confident in thinking about things precisely.
4	I am good at making persuasive arguments.
5	I am confused when thinking about complex problems.
6	I am the one to make decisions because my peers believe I can make fair determinations.
7	I can concentrate on and address problems.
8	I can continue working on a challenging problem that is not straightforward.
9	I can think about things coherently.
10	My shortcoming is that I am easily distracted.
11	When I think of a solution, I cannot think about alternatives.
12	I can inquire into things carefully.
13	I am constructive in proposing alternatives.

Following Van Lange et al. (1997, 2007b), we introduce SVO to measure people's social preferences. The participants are randomly paired such that the identity of the partner is unknown, and they are asked to play a game with 9 questions. Each question comprises a triple-dominance decomposed game in which each participant is asked to make a single choice from among three options, A, B and C. Each option is a vector of numerical outcomes for oneself and the other player (see table 3.5). In table 3.5, option A represents a competitive orientation since subjects who choose A tend to maximize the gap between oneself and the other ($500 - 100 = 400$). Option B represents a prosocial orientation because these subjects tend to maximize the joint outcome ($500 + 500 = 1000$). Option C is an individualistic orientation since these subjects tend to maximize their own outcome at 550 regardless of the other player's outcome. All 9 questions in the SVO game are based on the same logic as the example in table 3.5. According to Van Lange et al. (1997, 2007b), when a participants makes 6 or more choices from among the 9 questions that are consistent with a particular orientation, the participant is identified as either of prosocial, competitive and individualistic types. Otherwise, the participant is categorized as unidentified.

Before the SVO game, we provided oral instructions to the respondents of the field surveys. Each respondent was informed that all the numbers in the game have meaning and that the more numbers the respondent receives, the more money they will receive. After finishing the questionnaire, their choices were paired and matched randomly. To elicit the subject's real choices in the SVO game, we provided real money by calculating the subject's 9 choices and those of the partner and applying an experimental exchange rate to the total payoff of each respondent in the SVO game.[4] Because we implemented individual household field surveys, a post-survey SVO game was organized to distribute the monetary reward to each respondent. The maximum individual gain was 10 RMB (≈ 1.54 USD), and the mean gain was 8 RMB (≈ 1.24 USD).[5] As noted by Sutterlin et al. (2013), we expect that prosocial people are more likely to use high-quality coal than are individualists and competitors; thus, this paper highlights

[4]The calculation of the total individual payoff in the SVO game is explained in Van Lange et al. (1997).

[5]In March 2016, the exchange rate was 1 USD ≈ 6.48 RMB.

the comparison of the prosocial orientation and the other value orientations.

We applied two types of regressions (bivariate probit and Tobit) using the same set of independent variables. The bivariate probit model is specified as follows:

$$C^*_{ki} = \boldsymbol{\alpha}_k \mathbf{x}_{ik} + \boldsymbol{\beta}_k \mathbf{p}_{ik} + \boldsymbol{\delta}_k \mathbf{s}_{ik} + \epsilon_k, \qquad (3.1)$$

$$(\epsilon_h, \epsilon_l) \sim N[\mathbf{0}, \boldsymbol{\Omega}]$$

where subscript k is an index to represent high-quality coal (h) and low-quality coal (l), respectively; i is the ID number of the household; and C^*_{hi} and C^*_{li} are latent variables of high-quality and low-quality coal choices, respectively, for the household i. The binary variable of high- and low-quality coal choices is represented by the indicator function $C_{ki} = 1_{[C^*_{ki}>0]}$ in the bivariate probit regression, $\mathbf{x}_{ik}$ is a vector of socioeconomic variables, $\mathbf{p}_{ik}$ is a vector of cognitive and psychological variables, $\mathbf{s}_{ik}$ is a vector of policy variables, and ϵ_h, ϵ_l are error terms for high-quality and low-quality coal, respectively, with means $\mathbf{0}$ and covariance matrix $\boldsymbol{\Omega}$.[6] Finally, $\boldsymbol{\alpha}_k, \boldsymbol{\beta}_k$ and $\boldsymbol{\delta}_k$ are the vectors of parameters associated with socioeconomic, cognitive & psychological and policy variables, respectively, to be estimated through maximum likelihood for C_{ki}.

In the second regression, we analyze the determinants of high-quality and/or low-quality coal consumption by applying a Tobit regression using the same set of independent variables as the bivariate probit regression in equation (3.1), but the dependent variables in the Tobit regression are the quantities of high-quality and low-quality coal consumption designated Q_{hi} and Q_{li}, respectively, noting that the consumption data contain a considerable portion of zero observations (table 3.6). The Tobit regression is expressed as

$$Q^*_{ki} = \mathbf{a}_k \mathbf{x}_{ik} + \mathbf{b}_k \mathbf{p}_{ik} + \mathbf{d}_k \mathbf{s}_{ik} + \varepsilon_k, \qquad (3.2)$$

where Q^*_{ki} is a latent variable satisfying the relation $Q_{ki} = \max\{0, Q^*_{ki}\}$ and $\varepsilon_k \sim N[\mathbf{0}, \boldsymbol{\Omega}]$ is an error term such that the probability distribution of Q_{ki} is normally distributed over positive support and

[6] The bivariate probit regression takes into account the correlation between ϵ_h and ϵ_l by estimating the covariance ρ. The estimation result yields $\hat{\rho} = -0.807$ at the 1 % significance level, implying a negative association and substitutability between low-quality and high-quality coals.

Table 3.5: An example of numerical outcomes for oneself and the other player

	A	B	C
You receive	500	500	550
The other receives	100	500	330

censored at zero over negative support. Under the assumptions, the vectors of parameters associated with socioeconomic, cognitive & psychological and policy variables, $\mathbf{a}_k, \mathbf{b}_k$ and $\mathbf{d}_k$, respectively, are estimated via maximum likelihood for Q_{ki} in the Tobit regression (Wooldridge, 2008, 2010). The bivariate probit and Tobit regressions are used for analysis because we are interested in characterizing consumption and switching behavior between high-quality and low-quality coals both qualitatively and quantitatively. The bivariate probit regression enables us to characterize household choices between the two types of coals, considering four possible outcomes ($(C_{hi}, C_{li}) = \{(1,1),(1,0),(0,1),(0,0)\}$) within a single framework. In particular, the bivariate probit regression estimates the marginal probability that households choose one type of coal with an increase in an independent variable. Using the Tobit regression, we can quantitatively identify the marginal impact of key independent variables on high-quality and low-quality coal consumption and on their substitution.

3.3 Results

Summary statistics

Table 3.6 presents the frequency of binary choices for low-quality and/or high-quality coals. A total of 75 (12.46 %) households do not use any type of coal, while 46 (7.64 %) households consume both types of coals. The table also reveals that 306 (50.83 %) households consume only low-quality coal, while 175 (29.07 %) households consume only high-quality coal. Overall, 58.47 % of the households use low-quality coal, and 36.71 % of them use high-quality coal. Based on the reported frequency of household choices between low-quality and high-quality coal, we can conclude that government policies in rural Beijing have prompted some rural households to switch to high-quality coal consumption, although low-quality coal remains the main source for the rural households. Table 3.7 gives an overview of one month of low-quality and high-quality coal consumption in February 2016. The mean and median low-quality coal consumption are 0.64 t month^{-1} and 0.5 t month^{-1}, respectively. The mean and median high-quality coal consumption are both low, totaling 0.38 t month^{-1} and 0 t month^{-1}, respectively. Considering that high-quality coal is still in the early stages of introduction, as demonstrated in table 3.7, we expect that it will take more time for high-quality coal to be widely accepted and consumed by local people in rural Beijing.

As shown in table 3.7, the ranges for household size and house heating areas exhibit wide variation, ranging from 1 to 11 and from 12 to 500, respectively. A considerable income gap is also observed: the annual household income (as of 2015) ranges from 2000 to 120 000 RMB. On average, the annual household income is 25 600 RMB, which is higher than the median, suggesting that poor households are dominant in rural Beijing. With respect to education status, rural residents (on average) are educated only up to the primary-school level. The average levels of global environmental concern and local environmental concern are 43.96 and 20.48, respectively. Critical thinking disposition scores vary from 27 to 46; the average score is 41.72. With respect to SVO, 60 % of the participants are identified as prosocial in rural Beijing. The relative price of high-quality coal to low-quality coal ranges from 0.23 to 1.77. The average relative price is 0.71, indicating that subsidized high-quality coal can be even less expensive than low-quality coal. The possession rate for new-type coal stoves is 13.0 % (see table 3.7).[7]

Regression results

Tables 3.8 to 3.10 reports the marginal effects of socioeconomic, cognitive & psychological and policy variables, respectively, as shown in Model 1. The results of the bivariate probit regression and Tobit regression are mutually consistent. In general, local environmental concern, SVO and possession of new-type coal stoves are identified as very important factors in people's choices and consumption of low-quality and/or high-quality coals. Household income and relative coal price affect only the probability of choosing low-quality coal, and critical thinking disposition affects only the probability of choosing high-quality coal. The heating area is found to have a small economic effect on the quantity of low-quality coal consumption.

Regarding household income, the Tobit regression does not show any significant effect. The bi-

[7]The possession of new-type coal stoves depends on whether each household knows about the promotion policies. Most households that possess new-type coal stoves know about the policies, while those who do not possess stoves generally neither know nor care about the policies.

Table 3.6: Frequency of choices for low-quality and high-quality coal

		High-quality coal		Total
		0	1	
Low-quality coal	0	75 (12.46 %)	175 (29.07 %)	250 (41.53 %)
	1	306 (50.83 %)	46 (7.64 %)	352 (58.47 %)
Total		381 (63.29 %)	221 (36.71 %)	602 (100 %)

Table 3.7: Summary statistics of the variables with 602 observations

	Average (Median)[1]	SD[2]	Min	Max
Dependent variables (ton/month)				
Low-quality coal consumption	0.64 (0.5)	0.67	0	3.5
High-quality coal consumption	0.38 (0)	0.62	0	5
Independent variables				
Household size (persons)	3.82 (4)	1.57	1	11
Heating area (square meters)	106.32 (90)	58.83	12	500
Education	1.85 (2)	0.78	1	4
Income (10 000 RMB per year)	2.56 (2)	1.85	0.2	12
Global environmental concern (12-60)	43.96 (44)	7.25	24	60
Local environmental concern (6-29)	20.48 (21)	4.07	7	29
Critical thinking disposition (13-65)	41.72 (41)	5.73	27	61
Prosocial (Yes = 1)	0.6 (1)	0.49	0	1
Modern coal stove (Yes = 1)	0.13 (0)	0.34	0	1
Relative coal price[3]	0.71 (0.69)	0.16	0.23	1.77

[1] Median in parentheses.

[2] SD refers to the standard deviation.

[3] High-quality coal price after subsidies divided by the low-quality coal price.

Table 3.8: Marginal effects of socioeconomic variables

	Bivariate probit (Model 1)		Bivariate probit (Model 2)		Tobit (Model 1)		Tobit (Model 2)	
	Low-quality	High-quality	Low-quality	High-quality	Low-quality	High-quality	Low-quality	High-quality
House size	0.016	0.021			0.039	0.105**		
	(0.014)	(0.014)			(0.030)	(0.044)		
Heating area	0.001**	−0.001			0.004***	−0.000		
	(0.000)	(0.000)			(0.001)	(0.001)		
Heating area per member			0.002*	−0.002**			0.006***	−0.006**
			(0.001)	(0.001)			(0.002)	(0.003)
Education	0.010	−0.036	0.016	−0.034	0.092	−0.003	0.107*	0.008
	(0.028)	(0.027)	(0.028)	(0.027)	(0.056)	(0.083)	(0.058)	(0.083)
Income	−0.022*	−0.013	−0.012	−0.012	−0.036	−0.049	−0.003	−0.299
	(0.012)	(0.012)	(0.012)	(0.012)	(0.026)	(0.036)	(0.025)	(0.035)

Heating area per member $= \frac{\text{Heating area}}{\text{Household size}}$.

***Significant at the 1 percent level, **5 percent level and *10 percent level.

Table 3.9: Marginal effects of cognitive and psychological variables

	Bivariate probit (Model 1)		Bivariate probit (Model 2)		Tobit (Model 1)		Tobit (Model 2)	
	Low-quality	High-quality	Low-quality	High-quality	Low-quality	High-quality	Low-quality	High-quality
Global environmental concern	0.000	0.002	−0.000	0.002	−0.008	0.008	−0.010	0.006
	(0.003)	(0.003)	(0.003)	(0.003)	(0.007)	(0.010)	(0.007)	(0.010)
Local environmental concern	−0.022***	0.018***	−0.020***	0.019***	−0.047***	0.061***	−0.045***	0.063***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.012)	(0.018)	(0.012)	(0.018)
Critical thinking disposition	−0.002	0.008**	−0.001	0.008**	−0.004	0.020	0.000	0.022*
	(0.004)	(0.004)	(0.004)	(0.004)	(0.009)	(0.013)	(0.009)	(0.013)
Prosocial	−0.085*	0.150***	−0.096**	0.149***	−0.231***	0.392***	−0.277**	0.374***
	(0.044)	(0.043)	(0.043)	(0.043)	(0.088)	(0.133)	(0.090)	(0.133)

Table 3.10: Marginal effects of policy variables

	Bivariate probit (Model 1)		Bivariate probit (Model 2)		Tobit (Model 1)		Tobit (Model 2)	
	Low-quality	High-quality	Low-quality	High-quality	Low-quality coal	High-quality	Low-quality	High-quality
Modern coal stove	−0.222***	0.326***	−0.221***	0.326***	−0.486***	0.972***	−0.502***	0.972***
	(0.068)	(0.067)	(0.068)	(0.068)	(0.137)	(0.175)	(0.141)	(0.176)
Relative coal price	0.270*	−0.122	0.209	−0.124	0.310	−0.364	0.178	−0.438
	(0.154)	(0.149)	(0.152)	(0.151)	(0.295)	(0.456)	(0.303)	(0.460)

variate probit regression reveals a negative relationship between household income and the probability of choosing low-quality coal. An increase in annual household income by 10 000 RMB decreases the likelihood of choosing low-quality coal by 2.2 %. This evidence indicates the importance of economic growth on people's motivation to transition away from low-quality coal in rural China. However, since people with higher incomes have more options for replacing low-quality coal, it is not clear whether they ultimately switch to high-quality coal or to other, cleaner energy sources such as electricity and renewable energy.

Household size does not affect whether people choose low-quality or high-quality coal in the bivariate probit regression, but it is positively associated with a change in high-quality coal consumption in the Tobit regression. The results indicate that for each additional family member, households tend to consume more high-quality coal by 0.105 t month^{-1}. Once households have adopted high-quality coal, a large family may consume more high-quality coal to sustain indoor temperatures. On the other hand, the more members there are in a household, the longer it may take to reach a decision about whether to change the heating source. Education status is found to have no significant impact on either low-quality or high-quality coal consumption.

Regarding the house heating area, the bivariate probit regression shows a positive effect on the likelihood of choosing low-quality coal but no effect on that of choosing high-quality coal. In the Tobit regression, the house heating area positively affects low-quality coal consumption only. Specifically, when the house heating area increases by 1 m^2, people are more likely to choose low-quality coal by 0.1 %, and the household consumes an additional 0.004 t month^{-1} of low-quality coal. Finally, one standard deviation (≈ 58.825 m^2) in the house heating area is applied to observe the practical impact on daily life of a household in the analysis. We find that when the house heating area increases by 58.825 m^2, the probability of choosing low-quality coal increases by 5.883 % ($0.1 \times 58.825 \approx 5.883\%$); accordingly, low-quality coal consumption increases by 0.235 t month^{-1} ($0.004 \times 58.825 \approx 0.235$). It is reasonable that households with larger areas to heat tend to use more low-quality coal to provide warmth in their houses than those with smaller areas to heat. In other words, they are more familiar with low-quality coal and more uncertain about the heating costs of high-quality coal. Therefore, they might be hesitant to switch to high-quality coal.

As described in table 3.9, by comparing global and local environmental concerns, we find that local environmental concern is an important factor affecting consumption of both types of coals, while global environmental concern does not exhibit a significant impact. The bivariate probit regression estimates that when local environmental concern increases by one unit, the likelihood of choosing low-quality coal decreases by 2.2 %, and the likelihood of choosing high-quality coal increases by 1.8 %. Accordingly, the Tobit regression reveals that people that score one unit higher on local environmental concern tend to consume less low-quality coal by 0.047 $t\,month^{-1}$ but more high-quality coal by 0.061 $t\,month^{-1}$. These results reflect the importance of local environmental concern in the transition from low-quality to high-quality coal. People who care about the local environment are motivated to create better living conditions and thus take real actions to change their energy consumption behavior on a daily basis. Those with higher global environment concern might not actively choose high-quality coal because their knowledge of the global environment comes from books or public media instead of their personal experience.

One interesting finding is that prosocial people are more likely to consume high-quality coal than low-quality coal. The bivariate probit regression also reveals that relative to other value orientations, prosocial people are 8.5 % less likely to choose low-quality coal and 15 % more likely to choose high-quality coal. The Tobit regression indicates that prosocial people consume less low-quality coal by 0.231 $t\,month^{-1}$ and more high-quality coal by 0.392 $t\,month^{-1}$. By definition, prosocial people are more concerned with benefiting other people and society as a whole. Thus, they might be more eager to switch to and consume high-quality coal. With respect to critical thinking disposition, people with a score one unit higher are 0.8 % more likely to choose high-quality coal. Critical thinkers are known to have better logical abilities and comprehension. Thus, they might consume high-quality coal because of their deep understanding of the need to save the environment.

As shown in table 3.10, the promotion of new-type coal stoves is effective in helping households' transition from low-quality to high-quality coal. Specifically, households with new-type coal stoves are 22.2 % less likely to choose low-quality coal and 32.6 % more likely to choose high-quality coal.

Likewise, they tend to consume less low-quality coal by 0.486 t $month^{-1}$ and more high-quality coal by 0.972 t $month^{-1}$. New-type coal stoves are designed to improve both indoor and outdoor environmental conditions, and their performance is optimized when high-quality coal is burned. Although such new-type coal stoves are proven to be highly effective, many households in our study neither know nor care about the stoves. Therefore, further promotion is necessary to disseminate the new stoves.

Promotion policies such as subsidies on high-quality coal are revealed to be effective in reducing the likelihood of choosing low-quality coal only. Specifically, a decrease in the relative coal price (or an increase in price subsidies on high-quality coal) reduces the probability of choosing low-quality coal by 27 % at the 10 % significance level, but it has no impact on the probability of choosing high-quality coal. The Tobit regression shows a nonsignificant effect on both low-quality and high-quality coal consumption. This finding indicates that subsidies on high-quality coal are effective in helping households cease using low-quality coal but do not lead to the acceptance of high-quality coal.

Considering that the introduction of high-quality coal is still in the early stages, it might take time for high-quality coal to be widely accepted and consumed. Some households also shared their opinions with use about why they have not used high-quality coal even under the government subsidies during the survey. They think that high-quality coal is hard to burn, cannot sustain a fire for a long period and needs to be replenished more frequently.[8] This type of inconvenience in use and consumption is considered to lead to higher costs and to lower people's motivations to choose high-quality coal. Some households are still suspicious about the "high-quality" coal currently being sold in the market. Note that high-quality coal performs best when it is burned in a new-type coal stove; however, many households still use it in a traditional coal stove. This may be another reason for people not to choose high-quality coal. Alternatively, people might lack knowledge and skills on how to better use high-quality coal. If people cannot immediately see the benefit of switching to high-quality coal within a short period, they might continue to use low-quality coal even when subsidies exist for high-quality coal.

[8]These opinions are based on their own experiences or rely on other households' opinions without their own experience.

For the robustness check, we merge the household size and house heating area as a new independent variable named heating area per member. With this, we run the bivariate probit and Tobit regressions. The regression results are displayed in Model 2. By comparing the results of Models 1 and 2, the main findings remain consistent and robust. For instance, local environmental concern, prosocial value orientation and possession of new-type coal stoves are still the key factors in people's choices and consumption of low-quality and/or high-quality coals, while global environmental concern does not show any significance. Higher critical thinkers are more likely to choose and consume high-quality coal.

Regarding the heating area per member, the bivariate probit regression shows a positive (negative) effect on the likelihood of choosing low-quality coal (high-quality coal). When the heating area per member increases by 1 m^2, people are more likely to choose low-quality coal by 0.2 % and less likely to choose high-quality coal by 0.2 %. Similarly, in the Tobit regression, if the heating area per member rises by 1 m^2, people tend to consume more low-quality coal by 0.006 t $month^{-1}$ and less high-quality coal by 0.006 t $month^{-1}$. However, the magnitude of these effects appears to be small and practically insignificant. Income and relative coal price also remain statistically insignificant in terms of coal choices and consumption in Model 2. Overall, the results in Model 2 are quite consistent with those in Model 1 with respect to statistical significance and the signs of the estimated coefficients and their magnitudes.

In summary, we obtain the following results through regression analysis. First, prosocial people are more likely to consume high-quality coal than low-quality coal. Second, local environmental concern is important for switching from low-quality coal to high-quality coal, while global environment concern does not have a significant effect. Third, the government policies are found to be effective. In particular, the promotion of new-type coal stoves is demonstrated to be effective in the transition from low-quality to high-quality coal consumption in rural Beijing. Overall, these results suggest that cognitive & psychological factors and promotion policies can be considered significant for coal consumption behavior. Public education on local environmental awareness and prosociality, in addition to the use of new-type coal stoves, should be further promoted to accelerate the transition from low-quality to high-quality coal.

3.4 Conclusion

The promotion of high-quality coal is an important measure to reduce air pollution caused by low-quality coal consumption in rural China. Together with governmental policies, consumers' cognitive & psychological and socioeconomic factors are hypothesized to be important determinants of the consumption of coal of varying quality. In this regard, this paper has empirically characterized the determinants of people's consumption of low-quality and/or high-quality coals in rural Beijing. We find the following principal results. Cognitive & psychological factors, such as local environmental concern and prosocial value orientation, play a key role in motivating people's energy transition from low-quality coal to high-quality coal, while global environmental concern does not exhibit a significant effect. The promotion of new-type coal stoves significantly facilitates fuel switching between two types of coals, while a less expensive price of high-quality coal after subsidies does not motivate public acceptance of high-quality coal.

The findings of this research suggest important policy implications. The implementation of government policies has stimulated household energy transition from low-quality coal to high-quality coal, although low-quality coal remains the main source in rural areas. Further effort to promote high-quality coal is required. Our empirical results also suggest that new-type coal stoves could be further prioritized and promoted to induce a wider acceptance of high-quality coal in the market. With respect to price subsidies on high-quality coal, based on the feedback from the households, additional instructions on knowledge and skills of how to efficiently use high-quality coal with new-type coal stoves are necessary to induce high-quality coal consumption and improve the image of the product in the market.

Together with the promotion policies, an education campaign or program on encouraging prosocial values and behaviors at the individual level is also required. Although it takes time to impart individual cooperative and contribution behaviors, it is worthwhile to provide such societal instruction in rural areas. Another important strategy is that relative to global environmental concern, more emphasis could be placed (in rural China) on increasing local environmental awareness, such as air quality problems and its harmful impact on human health. As the population becomes more knowledgeable about these issues, the switch from low-quality coal to high-quality coal will be more likely to be accelerated.

While we believe that this study provides important evidence regarding coal consumption behaviors, we acknowledge limitations in our analysis. We examine the transition from low-quality to high-quality coal and the associated policy impacts on coal consumption in rural Beijing. However, we do not consider other environmentally friendly energy sources, such as electricity and renewable energy, in the analysis. Nor do we consider later stages of the energy transition. Future research should consider such environmentally friendly energy sources to provide a complete picture of the energy consumption transition in rural China.

3.5 Appendix

For a further robustness check, we have included some interaction terms of key covariates based on Model 2. In this appendix, we present the estimation results of the regression when an interaction term of local environmental concern and prosocial value orientation is considered. We hypothesize that the impact of local environmental concern on coal choices and consumptions is different depending on whether people are prosocial. As shown in table 3.11, the results in Model 3 are consistent with the previous findings in Models 1 and 2; the main findings do not change. Regarding the interaction term of local environmental concern and prosocial value orientation, the results show a nonsignificant impact on low-quality coal choice and consumption but show a 5 % statistical significance for high-quality coal choice and consumption with some negative impact. However, the joint effect that is calculated from the coefficients on local environmental concern and the interaction term remains positive. Therefore, local environmental concern and prosociality are important in household choices and the consumption of two types of coals. Various models including other interaction terms were also estimated and confirmed that the main results established in this paper remain the same.

Table 3.11: Marginal effects of bivariate probit and Tobit regressions

	Bivariate probit (Model 3)		Tobit (Model 3)	
	Low-quality coal	High-quality coal	Low-quality coal	High-quality coal
Socioeconomic variables				
Heating area per member [1]	0.002*	−0.002**	0.006***	−0.006**
	(0.001)	(0.001)	(0.002)	(0.003)
Education	0.016	−0.034	0.107*	0.006
	(0.028)	(0.027)	(0.058)	(0.083)
Income	−0.013	−0.010	−0.006	−0.023
	(0.012)	(0.012)	(0.025)	(0.034)
Cognitive and psychological variables				
Global environmental concern	0.000	0.001	−0.009	0.002
	(0.004)	(0.003)	(0.007)	(0.010)
Local environmental concern	−0.025***	0.035***	−0.065***	0.120***
	(0.009)	(0.009)	(0.018)	(0.030)
Critical thinking disposition	−0.001	0.009**	−0.001	0.024**
	(0.004)	(0.004)	(0.009)	(0.013)
Prosocial	−0.232	0.646***	−0.949**	2.137***
	(0.227)	(0.221)	(0.453)	(0.732)
Prosocial × Local environmental concern	0.007	−0.024**	0.033	−0.084**
	(0.011)	(0.011)	(0.022)	(0.034)
Policy variables				
Modern coal stove	−0.221***	0.329***	−0.503***	0.973***
	(0.068)	(0.068)	(0.141)	(0.175)
Relative coal price	0.207	−0.129	0.167	−0.458
	(0.151)	(0.150)	(0.302)	(0.459)

[1] Heating area per member $= \frac{\text{Heating area}}{\text{Household size}}$.

***Significant at the 1 percent level, **5 percent level and *10 percent level.

Chapter 4

Social value orientation and topography in urbanization: The case of Beijing, China

4.1 Introduction

The literature on environmental psychology has demonstrated an importance of physical environment for psychological wellbeing (Ulrich et al., 1991; Kahn et al., 2008; Bringslimark et al., 2009; Ryan et al., 2010). Certain experiments illustrate that short-term exposure to different physical environments via videos and/or slides has an impact on prosocial behaviors such as helping and generosity (Weinstein et al., 2009; Gueguen and Stefan, 2014; Zhang et al., 2014). However, little is known about how long-term exposure to different physical environments in real life influences prosocial preferences and behaviors, as noted in Weinstein et al. (2009) and Keniger et al. (2013). As human preferences are claimed to be formed by long-term exposure to various environments (Richerson and Boyd, 2000; Allik and McCrae, 2004; Henrich, 2004, 2014; Calo-Blanco et al., 2017), this paper addresses the relationship between individual social preferences and physical environment in fields.

Topography may directly influence individual social preferences. Past studies have analyzed the relationship between short-term exposure to various physical environments and prosociality. Using a decomposed social value orientation (SVO) game, Zelenski et al. (2015) document that watching a video of natural views lead to more prosocial SVOs than watching building views due to an increase (decrease) in self-control (materialistic) aspiration. Joye and Bolderdijk (2015) reveal that, with more feelings of awe such as humbleness, watching slides of extraordinary nature (e.g., high mountains) cause individuals to be more prosocial than watching slides of mundane nature (e.g., small-scale vegetation). These studies illustrate that short-term exposure to different physical environments via slides and/or videos in laboratory experiments influences individual prosociality.

Topography may indirectly influence individual social preferences through a channel of urbanization. Past studies, such as McClintock (1974), have analyzed the relation between social preferences and urbanization along with economic and cultural aspects. Using the Madsen cooperation board and marble-pull apparatus games, Madsen and Yi (1975) and Madsen and Lancy (1981) observe that rural children are more cooperative than urban children. Using a dictator game, Rochat et al. (2009) reveal a higher generosity and fairness of rural children than of urban children. Using the SVO game, Shahrier et al. (2016) and Timilsina et al. (2017) observe a higher proportion of prosocial individuals in rural areas than in urban areas. Overall, these papers demonstrate that individuals become less prosocial with urbanization.

None of past studies have addressed how social preferences are characterized by long-term exposure to various physical environments in real life and the corresponding urbanization within a single framework. This study assumes that long-term exposure to various physical environments is well-proxied by topography of living environment, such as mountains, hilly and plains areas, reflecting different accessibility to and experiences with natural environment, wilderness and culture in people's daily life (Price et al., 2004; Schirpke et al., 2016; Calo-Blanco et al., 2017). Given that Beijing has such topographical variations and represents China's rapid urbanization, this paper examines topographical differences in SVOs together with urbanization in Beijing.

4.2 Data and Methodology

Survey data

China has the largest population and highest economic growth in the world since Reform and Opening-Up Policy in 1978. As a capital city as well as a political, economic and cultural center, Beijing embodies China's rapid urbanization and economic development. Beijing's population reached 19.6 million in 2010, a 44.5 % rise as reported at the year of 2000 (Beijing Municipal Bureau of Statistics, 2016b). Overall, Beijing has an area of 16 410.5 km^2, comprising 6 urban and 10 suburban and rural districts. In addition to relatively smaller urban areas (1368.3 km^2), 92 % of Beijing belongs to suburban and rural areas (Beijing Municipal Government, 2012c). Another important fact is that there is a wide variation among the districts of Beijing with respect to the topography and the degree of urbanization (Beijing Municipal Bureau of Statistics, 2016a). Hence, we consider Beijing as an appropriate field for the micro-level analysis in our research.

Field surveys and experiments

In March 2016, we conducted field surveys in Beijing. Our study areas cover five suburban and rural districts (figure 4.1), which are categorized into mountainous areas (Yanqing and Miyun), hilly areas (Pinggu and Fangshan) and a plains area (Daxing), with the populations of 710, 1200 and 660 thousand people, respectively (Beijing Municipal Bureau of Statistics, 2016a). We randomly selected IDs from the residential list and contacted and invited respondents through collaboration with each local government office. Finally, 605 respondents agreed to be interviewed, with a distribution of 150, 300 and 155 respondents in the mountainous, hilly and plains areas, respectively. The sample ratio (of the sample size to the total population) reached 0.211, 0.250 and 0.235 per thousand people, ensuring the representativeness of our data. We conducted interviews face-to-face at respondents' homes or open venues in villages.

We conducted field surveys and experiments based on 605 respondents; sociodemographic information and SVOs were collected through face-to-face interviews in Beijing. We randomly selected the respondents based on the population of the five districts and these respondents agreed to join the interview. Overall, 710, 1200 and 660 thousand people live in the mountainous (Miyun and Yanqing), hilly (Fangshan and Pinggu) and plains (Daxing) areas, respectively (Beijing Municipal Bureau of Statistics, 2016a). The distribution of our sample size for mountainous, hilly and plains areas were 150, 300 and 155, respectively. Therefore, the sample ratio (sample size to total population) in each area is 0.211, 0.250 and 0.235 per thousand people, respectively, which were close to ensure the representativeness of our data. In the end, 596 questionnaires were applied in the data set because of the missing observations in 9 questionnaires. We merged individualistic and competitive types into the "proself" category because only 20 participants (3.36 %) were identified as competitive. We dropped 57 observations with

Figure 4.1: The survey areas in Beijing.

"unidentified" orientation, and 539 questionnaires were processed in the dataset.

During the face-to-face survey, we first explained our research purpose and social value orientation (SVO) game individually. We further confirmed the respondents' understanding of SVO game by asking whether they had questions. Following this, we began the surveys by collecting respondents' sociodemographic information and then conducted the SVO game. Each interview took 15-20 minutes on average. The sociodemographic information contains age, gender, education, occupation, annual household income and the number of children in a household. Table 3.1 lists the detailed definitions for all the sociodemographic variables collected in the surveys. Education is an ordered categorical variable from 1 to 4 representing the orders of education levels from low to high. Age and household income are numerical variables to capture their influence on SVOs. The occupation and the number of children in a household are hypothesized as important determinants of people's social preferences, following Shahrier et al. (2016). In regard to occupation, we take it as a dummy variable by asking whether they engage in farming as a main occupation. If "No," it means that they do not engage in farming, taking jobs in the business and service sectors.

As a measurement of urbanization, we consider population density at township level in the survey areas, because it is the finest and most reliable one that we can possibly obtain. Our data covers six townships: Qingyundian (in Daxing district), Qinglonghu and Yancun (in Fangshan district), Wangxinzhuang (in Pinggu district), Gaoling (in Miyun district) and Kangzhuang (in Yanqing district). To obtain the most reliable data, we first consulted local government offices from each township to confirm the official data resources, and the associated population density data in each township is obtained. Gaoling and Kangzhuang have population densities of 167 people km^{-2} and 395 people km^{-2} in 2016, respectively (Gaoling Township People's Government of Miyun District, 2017; Kangzhuang Township People's Government of Yanqing District, 2017). The population densities of Qinglonghu, Yancun and Wangxinzhuang are 479 people km^{-2}, 979 people km^{-2} and 347 people km^{-2} respectively (Qinglonghu Township People's Government of Fangshan District, 2017; Beijing Fangshan Municipal Bureau of Statistics, 2017; Beijing Municipal Public Security Bureau, 2017b,a; Beijing Pinggu Municipal Bureau of Statistics, 2017). Qingyundian has a population density of 463 people km^{-2} in 2016 (Qingyundian

Township People's Government of Daxing District, 2017; Beijing Daxing Municipal Bureau of Statistics, 2017). Among the six townships, Yancun exhibits the highest population density, as a result of the government policy focusing on the Fangshan district to be a center of modern manufacturing and new material industries (Beijing Municipal People's Government, 2004).

A decomposed social value orientation (SVO) game is employed to measure people's social preferences, categorizing the social preferences into four types of SVOs: prosocial, competitive, individualistic or unidentified (Van Lange et al., 1997, 2007b). This SVO game consists of 9 questions, each of which asks subjects to choose one option among three. Each option comes with two numbers as in the enumeration of options A, B and C shown below, representing the payoffs for "oneself" (You) and "the other," respectively. The oneself (You) and the other are considered a pair of two persons where "the other" is forever unknown to "You". A specific example for one question in the SVO game is as follows:

Option A: You receive 500; the other receives 100.

Option B: You receive 500; the other receives 500.

Option C: You receive 550; the other receives 330.

Suppose that one subject chooses one option among three options A, B or C. Subjects who choose option A are considered to be competitive since this option reflects the motivation to maximize the gap between oneself and the other ($500 - 100 = 400$). Subjects who choose option B are considered to be prosocial because they tend to maximize the joint outcome ($500 + 500 = 1000$). Option C represents an individualistic orientation because of the highest personal outcome among the three options (550), regardless of the outcome of the other.

When a subject makes at least 6 consistent choices of options with one orientation among the prosocial, the competitive and the individualistic over 9 questions, she is judged to have a specific orientation and is otherwise "unidentified" (Van Lange et al., 2007b). For the explanation of the SVO game, we distributed a written instruction and made the presentation individually. They were informed that all the numbers in the options of questions represent the payoffs for oneself and the other in a pair. The subjects are informed when they are randomly paired with another person in this game, but the identity of the partner is never revealed. We explain that the payment to each subject is calculated by summing the payoffs earned from 9 options selected by oneself for "oneself" and 9 options selected by the partner for "the other." The maximal individual gain is 10 RMB ($\approx$ 1.54 USD) and the mean of the individual's gain is 8 RMB ($\approx$ 1.24 USD).[1]

4.3 Results

Table 4.1 describes the summary statistics for the variables.[2] Overall, 33.8 % of subjects are identified as proself. Mountainous areas have a lower proportion of proself individuals (20.3 %) than do the plains and hilly areas ($\approx$ 38.0 % in both areas). On average, household income is the highest in plains areas and the lowest in mountainous areas. Subjects in mountainous areas have the lowest education. The youngest subjects are found in plains areas. The number of children in a household ranges from 0 to 2 because of China's child policies. Subjects in plains areas are more likely to be male than in other areas. Mountainous areas have the highest proportion of farmers and the lowest population density on average. Overall, income, education, farming and population density in mountainous areas differ significantly from those in other areas.

We use the logit regression to estimate the marginal impact of an independent variable on the probability that a subject is in the proself group, taking the prosocial group as the reference group.[3] Table 4.2 reports the regression results. Age, farmer, education and population density do not show a significant

[1] In the March of 2016, the exchange rate is 1 USD $\approx$ 6.48 RMB.

[2] We use a chi-squared test; the value is 13.59 ($p < 0.01$), rejecting the null hypothesis that SVOs are identical in mountainous, hilly and plains areas.

[3] Some researchers may claim reverse causality in our regression, i.e., that competitive individuals move to and live in urban cities. However, many studies establish that poor economic conditions push individuals to migrate from rural to urban areas (Dudwick et al., 2011; Young, 2013; Brueckner and Lall, 2015), and greater opportunities including health and employment in urban areas are observed to be the primary motivations (Todaro, 1996; Zhang and Song, 2003). Shahrier et al. (2016) show that there is no reverse causality between area dummies and SVOs in Bangladesh. None of these studies suggest that proself individuals tend to migrate to more urbanized societies.

Table 4.1: Summary statistics for all variables.

	Areas			Overall
	Mountainous	Hilly	Plains	
SVO (Proself = 1)[1]				
Average (Median)[2]	0.203 (0.00)	0.380 (0.00)	0.379 (0.00)	0.338 (0.00)
SD[3]	0.40	0.49	0.49	0.47
Min	0	0	0	0
Max	1	1	1	1
Household income (in 10 000 RMB)[4]				
Average (Median)	1.47 (1.00)	2.79 (2.60)	2.97 (3.00)	2.52 (2.00)
SD	1.01	1.98	1.77	1.84
Min	0.2	0.2	0.2	0.2
Max	5	12	8	12
Age				
Average (Median)	56.63 (56.00)	53.69 (55.00)	53.65 (54.00)	54.38 (55.00)
SD	11.46	14.37	10.67	12.87
Min	20	20	21	20
Max	91	88	86	91
Education[5]				
Average (Median)	1.66 (2.00)	1.97 (2.00)	1.80 (2.00)	1.85 (2.00)
SD	0.65	0.85	0.74	0.79
Min	1	1	1	1
Max	3	4	4	4
Children[6]				
Average (Median)	0.33 (0.00)	0.48 (0.00)	0.59 (1.00)	0.47 (0.00)
SD	0.49	0.60	0.61	0.58
Min	0	0	0	0
Max	2	2	2	2
Gender (Male = 1)				
Average (Median)	0.65 (1.00)	0.56 (1.00)	0.80 (1.00)	0.64 (1.00)
SD	0.48	0.50	0.40	0.48
Min	0	0	0	0
Max	1	1	1	1
Farmer[7]				
Average (Median)	0.95 (1.00)	0.67 (1.00)	0.69 (1.00)	0.74 (1.00)
SD	0.23	0.47	0.47	0.44
Min	0	0	0	0
Max	1	1	1	1
Population density (1 people km^{-2})				
Average (Median)	359.38 (395)	537.80 (520)	463 (463)	476 (463)
SD	83.11	242.71	0	190.78
Min	167	347	463	167
Max	395	979	463	979
Sample size	128	271	140	539

[1] The prosocial group is the reference group.

[2] Median in parentheses.

[3] Standard deviation.

effect on SVOs. Income exhibits a statistically significant effect on individuals' likelihood of being proself, but the magnitude is practically small. The number of children in a household is negatively associated with individuals' likelihood of being proself. Males have a higher probability of being proself than do females by 7.4 %. People in plains and hilly areas are observed to be more proself by 13.9 % and 15.4 %, respectively, than those in mountainous areas, implying a direct effect of topography on prosociality.

Compared to plains and hilly areas in Beijing, mountainous areas have a higher quality of aesthetic landscapes and nature (Sun et al., 2005; Pan et al., 2009; Xianru Mao, 2016). Recall that short-term exposure to nature promotes more prosociality than that to artificial views due to an increase in self-control or greater feelings of awe (Zelenski et al., 2015; Joye and Bolderdijk, 2015). It is plausible that experiencing such cognitions and emotions on a daily basis in mountainous areas induces individuals to be prosocial. In addition, life in mountainous areas is nature-dependent on the basis of eco-based services, tourism and agriculture along with the necessity of close human interactions for survival. We conjecture that long-term exposure to and experience in such a living environment and culture due to the mountainous physical conditions induce people to cooperate and be more prosocial (Price et al., 2004; Calo-Blanco et al., 2017). On the other hand, plains and hilly areas in Beijing experience economic development; expansion of industries, large-scale residential buildings, artificial surroundings and traffic jams are common (Sun et al., 2005). The daily life in such an environment might lead individuals to be proself, being consistent with previous experimental studies.

4.4 Conclusion

Topography is hypothesized to directly and indirectly influence individual SVOs via physical environment and urbanization. To examine this relationship, we conduct field surveys in Beijing, observing that social preferences tend to transition from prosocial to proself as the living environment changes from mountainous to hilly and plains areas, while urbanization does not show a significant effect. The results imply that a new social mechanism is necessary to direct individual social preferences toward

Table 4.2: Marginal effects of logit regression.

	Proself
Household income (in 10 000 RMB)	0.022*
	(0.012)
Education	−0.042
	(0.031)
Children	−0.065*
	(0.036)
Gender	0.074*
	(0.044)
Age	−0.003
	(0.002)
Farmer	−0.024
	(0.056)
Population density	0.0001
	(0.0001)
Area dummy (base group = mountainous areas)	
Plains areas	0.139**
	(0.063)
Hilly areas	0.154***
	(0.060)
Sample size	539

Regression coefficients without parentheses.

Standard errors in parentheses.

$^{***}p < 0.01$, $^{**}p < 0.05$ and $^{*}p < 0.1$.

The value of the likelihood ratio χ^2 is 28.75 ($p < 0.01$).

prosociality when more people live in plains and hilly areas. In the absence of such a mechanism, important social issues such as air pollution, which require cooperation to solve, will pose a greater danger in the future.

We note limitations of our study and identify directions for future research. First, this is an observational study examining the correlation of topographical differences in SVOs, whereas future studies should be conducted to establish causality. Second, due to time and budget limitations, we do not include samples of individuals in the center of Beijing. However, we conjecture that the primary result would not change if these samples were included. Third, our result associated with area dummies may suffer from confounding effects such as other area-specific factors, human interactions or interclass correlations at individual and group levels, although we did our best to control every variable such as urbanization. However, we think that such potential confounding effects mostly originate from area-specific factors, and in this case, our result will still be valid, as it may be reinterpreted as an overall area-specific effect. Future research should be able to decompose the overall area-specific effect into several finer factors by collecting more detailed data. These caveats notwithstanding, this paper is an important first step in addressing how social preferences change with physical environment or topography.

Chapter 5

Conclusion

We first analyze people's WTA and WTP for LTHP technology in rural Beijing and find that income, science literacy and local environmental concern are important factors that affect the likelihood of the adoption of LTHP technology, whereas global environmental concern does not have any effect. We also find that people in mountainous areas express the highest WTA and WTP for the LTHP, followed by those in hilly and plains areas. The novel aspects are that we find a new evidence of the importance of science literacy and two levels of environmental concern (local and global) in public acceptance of environmentally friendly technologies. These results not only expand important dimensions of research on technological acceptance but also reveal the importance of science literacy and local environmental concern in promoting environmentally friendly technologies in practice. In addition, the findings provide crucial insights on designing promotion strategies and subsidy mechanisms across mountainous, hilly and plains areas based on people's WTA and WTP, as well as the highest nonzero mode of WTP value for each unit of LTHP in rural Beijing.

Second, we empirically examine the factors influencing people's choices and consumption between low-quality coal and high-quality coal in rural Beijing. We reveal that cognitive & psychological factors (e.g., local environmental concern and prosocial value orientation) play significant roles in inducing energy transition from low-quality coal to high-quality coal in rural areas, while global environmental concern does not significantly exhibit a significant effect. The promotion of new-type coal stoves significantly facilitates fuel switching between two types of coals, while a less expensive price of high-quality coal after subsidies does not motivate public acceptance of high-quality coal. The findings of this research suggest practical implications on how to further promote fuel transition to high-quality coal in private households from a market perspective.

Based on the findings from these two research papers, we can conclude that perception variables (e.g., local environment concern), basic knowledge and understanding of science, and psychological factors (e.g., SVOs) play important roles in household energy transition from low-quality coal to high-quality coal and to electricity. From these findings, we can also conjecture that perception, cognition and psychological factors might be important for public acceptance of other cleaner energy sources and technologies, such as solar and wind power energy (technologies), which are not examined in current research but could be important issues in future research.

On the other hand, to address the public goods problems such as air pollution, individual voluntary contributions and efforts are necessary together with the government effort. In addition, since prosocial preference is identified as an important determinant of fuel switching to better energy in our study and of proenvironmental behavior in past studies, we are interested in people's SVOs with topographical differences in progress of urbanization. In particular, we hypothesize that topography directly and indirectly influence individual SVOs via physical environment and urbanization. We find that social preferences tend to transition from prosocial to proself as the living environment changes from mountainous to hilly and plains areas, while urbanization does not show a significant effect. The novelty of this study is that we newly examine how social preferences are characterized by long-term exposure to various physical environments in real life and the urbanization within a single framework. The results imply that a new social mechanism is necessary to direct individual social preferences toward prosociality when more people live in plains and hilly areas. Without such a mechanism, important social issues such as air pollution, which require cooperation to solve, might pose a greater danger in the future.

NOMENCLATURE

CV Contingent valuation

HEV Hybrid electric vehicle

LTHP Low temperature air source heat pump

PM Particulate matter

RMB Renminbi, Chinese currency

SVO Social value orientation

TCE Tons of Coal Equivalent

WTA Willingness to adopt

WTP Willingness to pay

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BIBLIOGRAPHY

Adaman, F., Karali, N., Kumbaroglu, G., Or, I., Ozkaynak, B., and Zenginobuza, U. (2011). What determines urban households willingness to pay for CO_2 emission reductions in Turkey: A contingent valuation survey. *Energy policy*, 39:689–698.

Allcott, H. and Mullainathan, S. (2010). Behavior and energy policy. *Science*, 327:1204–1205.

Allik, J. and McCrae, R. R. (2004). Toward a geography of personality traits patterns of profiles across 36 cultures. *Journal of cross-cultural psychology*, 35:13–28.

An innovation of World Bank Groups (2017). Lighting africa. Wangshington DC: World Bank.

Baharoon, D. A., Rahman, H. A., and Fadhl, S. O. (2016). Publics' knowledge, attitudes and behavioral toward the use of solar energy in Yemen power sector. *Renewable and sustainable energy reviews*, 60:498–515.

Balliet, D., Parks, C., and Joireman, J. (2009). Social value orientation and cooperation in social dilemmas: A meta-analysis. *Group processes & intergroup relations*, 12:533–547.

Beijing Daxing Municipal Bureau of Statistics (2017). Beijing Daxing district yearbook 2017.

Beijing Fangshan Municipal Bureau of Statistics (2017). Beijing Fangshan district yearbook 2017.

Beijing Municipal Bureau of Statistics (2016a). Beijing regional statistical yearbook 2016. Technical report, China statistics press.

Beijing Municipal Bureau of Statistics (2016b). Beijing statistical yearbook 2016. Technical report, China statistics press.

Beijing Municipal Environmental Protection Bureau (2014). $PM_{2.5}$ contribution resource analysis in Beijing (in Chinese). Technical report, Beijing Municipal Environmental Protection Bureau.

Beijing Municipal Government (2012a). Plans for the main functional area in Beijing. Technical report, Beijing Municipal Government.

Beijing Municipal Government (2012b). Plans for the main functional area in Beijing (in Chinese).

Beijing Municipal Government (2012c). Plans for the main functional area in Beijing (in Chinese).

Beijing Municipal People's Government (2004). Beijing urban master plan (2004-2020) (in Chinese).

Beijing Municipal Public Security Bureau (2017a). Wangxinzhuang police station.

Beijing Municipal Public Security Bureau (2017b). Yancun police station.

Beijing Pinggu Municipal Bureau of Statistics (2017). Beijing Pinggu district yearbook 2017.

Braun, F. G. (2010). Determinants of households' space heating type: A discrete choice analysis for German households. *Energy policy*, 38:5493–5503.

Bringslimark, T., Hartig, T., and Pati, G. G. (2009). The psychological benefits of indoor plants: A critical review of the experimental literature. *Journal of environmental psychology*, 29:422–433.

Brueckner, J. and Lall, S. (2015). Cities in developing countries: Fueled by rural-urban migration, lacking in tenure security, and short of affordable housing. In Duranton, G., Henderson, V., and Strange, W., editors, *Handbook of regional and urban economics*, chapter 21, pages 1399–1455. North Holland.

Byrnes, B., Jones, C., and Goodman, S. (1999). Contingent valuation and real economic commitments: Evidence from electric utility green pricing programmes. *Journal of environmental planning and management*, 42:149–166.

Calo-Blanco, A., Kovarik, J., Mengel, F., and Romero, J. G. (2017). Natural disasters and indicators of social cohesion. 12:e0176885.

Carlsson, F. and Stenman, O. J. (2000). Willingness to pay for improved air quality in Sweden. *Applied economics*, 32:661–669.

Chai, F., Xue, Z., Zhi, G., Du, J., Luo, Y., Ren, Y., and Ye, J. (2016). Complex control measures for rural coal combustion pollution (in Chinese). *Environmental protection*, 44:15–19.

Champp, P., Boyle, K., and Brown, T., editors (2003). *A Primer on nonmarket valuation*. Kluwer academic publishers.

Chan, C. K. and Yao, X. (2008). Air pollution in mega cities in China. *Atmospheric environment*, 42:1–42.

Chen, W., Zhang, Y., Pengwang, C., and Gao, W. (2017). Evaluation of urbanization dynamics and its impacts on surface heat islands: A case study of Beijing, China. *Remote sensing*, 9:453.

Cheng, N., Zhang, D., Li, Y., and Fan, M. (2016). Residential emissions in Beijing: About 400 × 104t. *Proceedings of the National Academy of Sciences of the United States of America*, 113:E5778–E5779.

Claudy, M., Michelsen, C., and O'Driscoll, A. (2011). The diffusion of microgeneration technologies—Assessing the influence of perceived product characteristics on homeowners' willingness to pay. *Energy policy*, 39:1459–1469.

Cui, W. (2017). Sustainable development of clean energy for heating (in Chinese). Beijing daily.

Dawkins, R. (2006). *The selfish gene*. Oxford university press.

Daziano, R. A. and Bolduc, D. (2013). Incorporating pro-environmental preferences towards green automobile technologies through a bayesian hybrid choice model. *Transportmetrica A: Transport science*, 9:74–106.

Dubin, J. and McFadden, D. (1984). An econometric analysis of residential electric appliance holdings and consumption. *Econometrica*, 52:345–362.

Dudwick, N., Hull, K., Katayama, R., Shilpi, F., and Simler, K. (2011). *From farm to firm: Rural-urban transition in developing countries*. World Bank publications.

Enerdata (2016). Global energy statistical yearbook 2016. Technical report, Enerdata.

Erdem, C., Senturk, I., and Simsek, T. (2010). Identifying the factors affecting the willingness to pay for fuel-efficient vehicles in Turkey: A case of hybrids. *Energy policy*, 38:3038–3043.

Fang, C., Ma, H., and Wang, J. (2015). A regional categorization for "new-type urbanization" in China. 10:e0134253.

Frederiks, E., Stenner, K., and Hobman, E. (2015). Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renewable and sustainable energy reviews*, 41:1385–1394.

Gao, J. (2015). Rural coal consumption will be reduced by 1.4 million tons, and 7 rural districts improved the subsidies to high-quality coal. Beijing Daily.

Gaoling Township People's Government of Miyun District (2017). Overview of Gaoling township (in Chinese).

Garling, T., Fujii, S., Garling, A., and Jakobsson, C. (2003). Moderating effects of social value orientation on determinants of proenvironmental behavior intention. *Journal of environmental psychology*, 23.

GBD MAPS Working Group (2016). Burden of disease attributable to coal-burning and other major sources of air pollution in China. Technical report, Health Effects Institute.

General Office of Beijing Municipal People's Government (2013a). Coal replacement, clearn air actiion in Beijing's rural areas. Technical report, General Office of Beijing Municipal People's Government.

General Office of Beijing Municipal People's Government (2013b). Five-year clean air action plan (2013-2017) in Beijing (in Chinese). Technical report, General Office of Beijing Municipal People's Government.

General Office of Beijing Municipal People's Government (2014). Act on coal replacement, reduction and clean air in Beijing rural areas (in Chinese). Technical report, General Office of Beijing Municipal People's Government.

General Office of Beijing Municipal People's Government (2016). Act on coal reduction, replacement and coal switch to cleaner nenrgy in Beijing rural areas (in Chinese). Technical report, General Office of Beijing Municipal People's Government.

General Office of Beijing Municipal People's Government (2017). Act on clean heating in winter in Beijing's rural area (in Chinese). Technical report, General Office of Beijing Municipal People's Government.

Green, D., Jacowitz, K., Kahneman, D., and McFadden, D. (1998). Referendum contingent valuation, anchoring, and willingness to pay for public goods. *Resource and energy economics*, 2:85–116.

Gueguen, N. and Stefan, J. (2014). "Green altruism": Short immersion in natural green environments and helping behavior. *Environment and behavior*, 48:324–342.

Gupta, N., Fischer, A., and Frewer, L. (2011). Socio-psychological determinants of public acceptance of technologies: A review. *Public understanding of science*, 21:782–795.

Haab, T. and McConnell, K. (2002). *Valuing environmental and natural resources: The econometrics of non-Market valuation*. Edward elgar publishing.

Hallsworth, M., Parker, S., and Rutter, J. (2011). Policy making in the real world. Technical report, Institute for Government.

Hanley, N., Shogren, J., and White, B. (2007). *Environmental economics in theory and practice*. Palgrave macmillan.

Harijan, K., Memon, M., Uqaili, M. A., and Mirza, U. K. (2009a). Potential contribution of ethanol fuel to the transport sector of Pakistan. *Renewable and sustainable energy reviews*, 13:291–295.

Harijan, K., Uqaili, M. A., Memon, M., and Mirza, U. K. (2009b). Assessment of centralized grid connected wind power cost in coastal area of Pakistan. *Renewble energy*, 34:369–373.

Harijan, K., Uqaili, M. A., Memon, M., and Mirza, U. K. (2010). Potential of on-shore wind power in the coastal areas of balochistan, Pakistan. *Wind engineering*, 34:167–179.

Harijan, K., Uqaili, M. A., Memon, M., and Mirza, U. K. (2011). Forecasting the diffusion of wind power in Pakistan. *energy*, 36:6068–6073.

Harijan, K., Uqaili, M. A., and Mirza, U. K. (2015). Assessment of solar PV power generation potential in Pakistan. *Journal of clean energy technologies*, 3:54–56.

Heltberg, R. (2004). Fuel switching: Evidence from eight developing countries. *Energy economics*, 26:869–887.

Heltberg, R. (2005). Factors determining household fuel choice in Guatemala. *Environment and development economics*, 10:337–361.

Heltberg, R., Arndt, T. C., and Sekhar, N. U. (2000). Fuelwood consumption and forest degradation: A household model for domestic energy substitution in rural India. *Land economics*, 76:213–232.

Henrich, J. (2004). Cultural group selection, coevolutionary processes and large-scale cooperation. *Journal of economic behavior and organization*, 53:3–35.

Henrich, J. (2014). Rice, psychology, and innovation. *Science*, 344:593–594.

Hill, R., Griffiths, W. E., and Lim, G. C. (2008). *Principles of econometrics*. Wiley.

Jiang, J., Zhang, Y., Ye, J., Zhang, F., Ma, R., Xiong, D., Zhang, L., Wang, P., Fu, Y., and Yang, X. (2016). Effectiveness comparison and analysis of alternative solutions to coal-fired heating in rural Beijing (in Chinese). *Journal of heating ventilation & air conditioning*, 36:39–43.

Jingchao, Z. and Kotani, K. (2012). The determinants of household energy demand in rural beijing: Can environmentally friendly technologies be effective? *Energy economics*, 34:381388.

Joye, Y. and Bolderdijk, J. W. (2015). An exploratory study into the effects of extraordinary nature on emotions, mood, and prosociality. *Frontiers in psychology*, 5:1577.

Kahn, P. H. J., Friedman, B., Gill, B., Hagman, J., Severson, R. L., Freier, N. G., Feldman, E. N., Carrere, S., and Stolyar, A. (2008). A plasma display window?—The shifting baseline problem in a technologically mediated natural world. 28:192–199.

Kangzhuang Township People's Government of Yanqing District (2017). Overview of Kangzhuang township (in Chinese).

Karytsas, S. and Theodoropoulou, H. (2014). Public awareness and willingness to adopt ground source heat pumps for domestic heating and cooling. *Renewable and sustainable energy reviews*, 34:49–57.

Keniger, L. E., Gaston, K. J., Irvine, K. N., and Fuller, R. A. (2013). What are the benefits of interacting with nature? *International journal of environmental research and public health*, 10:913–935.

Leach, G. (1975). Energy and food production. *Food policy*, 1:62–73.

Leach, G. (1992). The energy transition. *Energy policy*, 20:116–123.

Lee, C.-J., Scheufele, D. A., and Lewenstein, B. V. (2005). Public attitudes toward emerging technologies examining the interactive effects of cognitions and affect on public attitudes toward nanotechnology. *Science communication*, 27:240–267.

Li, G. (2013). *Review of thermal energy storage technologies and experimental investigation of adsorption thermal energy storage for residential application*. PhD thesis, University of Maryland at College Park, United States.

Li, G., Hwang, Y., and Radermacher, R. (2012). Review of cold storage materials for air conditioning application. *International journal of refrigeration*, 35:2053–2077.

Li, G., Hwang, Y., and Radermacher, R. (2014). Experimental investigation on energy and exergy performance of adsorption cold storage for space cooling application. *International journal of refrigeration*, 44:23–35.

Li, G., Hwang, Y., Radermacher, R., and Chun, H.-H. (2013). Review of cold storage materials for subzero applications. *Energy*, 51:1–17.

Li, L. and Liu, D. (2014). Study on an air quality evaluation model for Beijing city under haze-fog pollution based on new ambient air quality standards. *International journal of environmental research and public health*, 11:8909–8923.

Li, X., Lin, C., Wang, Y., Zhao, L., Duan, N., and Wu, X. (2015). Analysis of rural household energy consumption and renewable energy systems in Zhangziying town of Beijing. *Ecological modelling*, 318:184–193.

Lillemo, S. C., Alfnes, F., Halvorsen, B., and Wik, M. (2013). Households' heating investments: The effect of motives and attitudes on choice of equipment. *Biomass and bioenergy*, 57:4–12.

Litvinenko, V. (2016). *XVIII International Coal Preparation Congress: 28 June — 01 July 2016 Saint-Petersburg, Russia*. Springer.

Lu, B. (2016). Technical testing for the government promotion of air source heat pump in the market (in Chinese). Technical report, Building energy and environment testing center of CABR.

Madsen, M. C. and Lancy, D. F. (1981). Cooperative and competitive behavior: Experiments related to ethnic identity and urbanization in Papua New Guinea. *Journal of cross-cultural psychology*, 12:389–408.

Madsen, M. C. and Yi, S. (1975). Cooperation and competition of urban and rural children in the Republic of South Korea. *International journal of psychology*, 10:269–274.

Mahapatra, K. and Gustavsson, L. (2008). An adopter-centric approach to analyze the diffusion patterns of innovative residential heating systems in Sweden. *Energy policy*, 36:577–590.

McClintock, C. G. (1974). Development of social motives in Anglo-American and Mexican-American children. *Journal of personality and social psychology*, 29:348–354.

Messick, D. M. and McClintock, C. G. (1968). Motivational bases of choice in experimental games. *Journal of experimental social psychology*, 4:1–25.

Michelsen, C. C. and Madlener, R. (2012). Homeowners' preferences for adopting innovative residential heating systems: A discrete choice analysis for Germany. *Energy economics*, 34:1271–1283.

Michelsen, C. C. and Madlener, R. (2013). Motivational factors influencing the homeowners' decisions between residential heating systems: An empirical analysis for Germany. *Energy policy*, 57:221–233.

Michelsen, C. C. and Madlener, R. (2016). Switching from fossil fuel to renewables in residential heating systems: An empirical study of homeowners' decisions in Germany. *Energy policy*, 89:95–105.

Miller, J. (1998). The measurement of civic scientific literacy. *Public understanding of science*, 7:203–223.

Ministry of environmental protection of the people's republic of China (2016). Techinical guidence of comprehensive countermeasures on household coal consmption emission (in Chinese). Technical report, Miinistry of environmental protection of the people's republic of China.

Mitchell, R. C. and Carson, R. T. (1989). *Using surveys to value public goods: The contingent valuation method*. RFF Press.

Mottaleb, K. A., Rahut, D. B., and Ali, A. (2017). An exploration into the household energy choice and expenditure in Bangladesh. *Energy*, 135:767–776.

Mozumder, P., Vasquez, W. F., and Marathe, A. (2011). Consumers' preference for renewable energy in the southwest USA. *Energy economics*, 33:1119–1126.

Nakagawa, Y. (2015). Effect of critical thinking disposition on household earthquake preparedness. *Natural hazards*, 81:807–828.

Nakagawa, Y. (2017). Psychological and behavioral predictors of rural in-migration. *Rural sociology*, 81:807–828.

Nakagawa, Y. (2018). Psychological and behavioral predictors of rural in-migration. *Rural sociology*, 83:24–50.

National Bureau of Statistics of China (2016). China statistical yearbook 2016. Technical report, China statistics press.

Nyrud, A., Roos, A., and Sande, J. B. (2008). Residential bioenergy heating: A study of consumer perceptions of improved woodstoves. *Energy policy*, 36:3169–3176.

Ostrom, E., Dietz, T., Dolsak, N., Stern, P. C., Stonich, S., and Weber, E., editors (2002). *The drama of the commons*. National academy press.

Pan, Y., Xiao, H., and Yu, Z. (2009). Spatial evaluation on ecological and aesthetic quality of Beijing agricultural landscape (in Chinese). *Chinese journal of applied ecology*, 20:2455–2460.

Peng, W., Hisham, Z., and Pan, J. (2010). Household level fuel switching in rural Hubei. *Energy for sustainable development*, 14:238–244.

Pollitt, M. G. and Shaorshadze, I. (2013). The role of behavioural economics in energy and climate policy. In Fouquet, R., editor, *Handbook on energy and climate change*, chapter 24, pages 523–546. Edward Elgar.

Price, M. F., Jansky, L. F., and Iatsenia, A. A., editors (2004). *Key issues for mountain areas*. United nations university press.

Qinglonghu Township People's Government of Fangshan District (2017). Overview of Qinglonghu township (in Chinese).

Qingyundian Township People's Government of Daxing District (2017). Overview of Qingyundian township (in Chinese).

Rahut, D. B., Ali, A., and Mottaleb, K. A. (2017a). Understanding the determinants of alternate energy options for cooking in the Himalayas: Empirical evidence from the Himalayan region of Pakistan. *Journal of cleaner production*, 149:528–539.

Rahut, D. B., Behera, B., and Ali, A. (2017b). Factors determining household use of clean and renewable energy sources for lighting in Sub-Saharan Africa. *Renewable and sustainable energy reviews*, 72:661–672.

Rahut, D. B., Behera, B., Ali, A., and Marenya, P. (2017c). A ladder within a ladder: Understanding the factors influencing a household's domestic use of electricity in four African countries. *Energy economics*, 66:167–181.

Rahut, D. B., Das, S., Groote, H. D., and Behera, B. (2014). Determinants of household energy use in Bhutan. *Energy*, 69:661–672.

Rahut, D. B., Mottaleb, K. A., and Ali, A. (2017d). Household energy consumption and its determinants in Timor-Leste. *Asian development review*, 34:167–197.

Rahut, D. B., Mottaleb, K. A., Ali, A., and Aryal, J. (2017e). The use and determinants of solar energy by Sub-Saharan African households. *International journal of sustainable energy*, 37:718–735.

Rahut, D. B., Mottaleb, K. A., Ali, A., and Aryal, J. P. (2017f). Energy consumption transition through the use of electricity for lighting and cooking: evidence from Bhutan. *Renewable energy focus*, 18:11–21.

Reynolds, T., Murray, B. T., Kolodinsky, J., and Howell, J. (2015). Contrasting self-reported willingness to pay and demonstrated purchase behavior for energy-saving technologies in a small island developing state. *Energy for sustainable development*, 27:18–27.

Richerson, P. J. and Boyd, R. (2000). Climate, culture and the evolution of cognition. In Heyes, C. and Huber, L., editors, *The Evolution of Cognition*, chapter 18, pages 329–345. MIT press.

Rochat, P., Dias, M. D. G., Liping, G., and Broesch, T. (2009). Fairness in distributive justice by 3- and 5-year-olds across seven cultures. *Journal of cross-cultural psychology*, 40:416–442.

Rouvinen, S. and Matero, J. (2013). Stated preferences of Finnish private homeowners for residential heating systems: A discrete choice experiment. *Biomass and bioenergy*, 57:22–32.

Ruokamo, E. (2016). Household preferences of hybrid home heating systems: A choice experiment application. *Energy policy*, 95:224–237.

Ryan, R. M., Weinstein, N., Bernstein, J., Brown, K. W., Mistretta, L., and Gagne, M. (2010). Vitalizing effects of being outdoors and in nature. 30:159–168.

Scarpa, R. and Willis, K. (2010). Willingness-to-pay for renewable energy: Primary and discretionary choice of british households' for micro-generation technologies. *Energy economics*, 32:129–136.

Schirpke, U., Timmermann, F., Tappeiner, U., and Tasser, E. (2016). Cultural ecosystem services of mountain regions: Modelling the aesthetic value. *Ecological indicators*, 69:78–90.

Shahrier, S., Kotani, K., and Kakinaka, M. (2016). Social value orientation and capitalism in societies. 11:e0165067.

Snow, C. E. and Dibner, K. A., editors (2016). *Science literacy: Concepts, contexts and consequences*. National academies press.

Sopha, B. M., Klockner, C. A., Skjevrak, G., and Hertwich, E. G. (2010). Norwegian households' perception of wood pellet stove compared to air-to-air heat pump and electric heating. *Energy policy*, 38:3744–3754.

Sovacool, B. K. (2009). Rejecting renewables: The socio-technical impediments to renewable electricity in the United States. *Energy policy*, 37:4500–4513.

Sun, C., Yuan, X., and Xu, M. (2016a). The public perceptions and willngness to pay: From the perspective of the smog crisis in China. *Journal of cleaner production*, 112:1635–1644.

Sun, C., Yuan, X., and Yao, X. (2016b). Social acceptance towards the air pollution in China: Evidence from public's willingness to pay for smog mitigation. *Energy policy*, 92:313–324.

Sun, Y., Wang, Q., and Lu, Z. (2005). Effects of urbanization on landscape pattern of Beijing (in Chinese). *Journal of applied ecology*, 16:1366–1369.

Sutcliffe, S. and Court, J. (2005). Evidence-based policy making: What is it? how does it work? what relevance for developing countries? Technical report, Overseas Development Institute.

Sutterlin, B., Brunner, T. A., and Siegrist, M. (2013). Impact of social value orientation on energy conservation in different behavioral domains. *Journal of applied social psychology*, 43:1725–1735.

Timilsina, R. R., Kotani, K., and Kamijo, Y. (2017). Sustainability of common pool resources. 12:e0170981.

Todaro, M. (1996). Income expectations, rural-urban migration and employment in Africa. *International labour review*, 135:421–444.

Ulrich, R. S., Simons, R. F., Losito, B. D., Fiorito, E., Miles, M. A., and Zelson, M. (1991). Stress recovery during exposure to natural and urban environments. *Journal of environmental psychology*, 11:201–230.

Vaage, K. (2000). Heating technology and energy use: a discrete/continuous choice approach to norwegian household energy demand. *Energy economics*, 22:649–666.

Van Lange, P. A., Bekkers, R., Shuyt, T. N., and Vugt, M. V. (2007a). From games to giving: Social value orientation predicts donation to noble causes. *Basic and applied social psychology*, 29:375–384.

Van Lange, P. A., Bekkers, R., Shuyt, T. N., and Vugt, M. V. (2007b). From games to giving: Social value orientation predicts donations to noble causes. *Basic and applied social psychology*, 29:375–384.

Van Lange, P. A., De Bruin, E. M., Otten, W., and Joireman, J. A. (1997). Development of prosocial, individualistic, and competitive orientations: Theory and preliminary evidence. *Journal of personality and social psychology*, 73:733–746.

Van Vugt, M., Meertens, R. M., and Van Lange, P. A. (1995). Car versus public transportation? The role of social value orientations in a real-life social dilemma. *Journal of applied social psychology*, 25:258–278.

Wang, R. and Jiang, Z. (2017). Energy consumption in China's rural areas: A study based on the village energy survey. *Journal of cleaner production*, 143:452–461.

Wang, Y. and Zhang, Y.-S. (2009). Air quality assessment by contingent valuation in Ji'nan, China. *Journal of environmental management*, 90:1022–1029.

Ward, D., D.Clark, C., Jensen, K. L., T.Yen, S., and S.Russell, C. (2011). Factors influencing willingness-to-pay for the energy star label. *Energy policy*, 39:1450–1458.

Weinstein, N., Przybylski, A. K., and Ryan, R. M. (2009). Can nature make us more caring? Effects of immersion in nature on intrinsic aspirations and generosity. *Personality and social psychology bulletin*, 35:1315–1329.

Wilson, D. S., O'Brien, D. T., and Sesma, A. (2009). Human prosociality from an evolutionary perspective: Variation and correlations at a city-wide scale. 30:190–200.

Wooldridge, J. M. (2008). *Introductory econometrics*. South-Western college publishing, 4 edition.

Wooldridge, J. M. (2010). *Econometric analysis of cross section and panel data*. MIT Press.

Wu, J., Zhang, P., Yi, H., and Qin, Z. (2016). What causes haze pollution? An empirical study of $\mathrm{PM}_{2.5}$ concentrations in Chinese cities. *Sustainability*, 8:132.

Xianru Mao, Heigang Xiong, Y. Z. (2016). Comprehensive evaluation and analysis of county tourism environmental quality in Beijing city (in Chinese). *Areal research and development*, 35:91–95.

Xiao, Q. (2016). The difficulties to remove the coal (in Chinese). People's Daily. May 9.

Yoo, S. and Kwak, S. (2009). Willingness to pay for green electricity in Korea: A contingent valuation study. *Energy policy*, 37:5408–5416.

Young, A. (2013). Inequality, the urban-rural gap and migration. *Quarterly journal of economics*, 128:1727–1785.

Zelenski, J. M., Dopko, R. L., and Capaldi, C. A. (2015). Cooperation is in our nature: Nature exposure may promote cooperative and environmentally sustainable behavior. 42:24–31.

Zhang, J., Piff, P. K., Iyer, R., Koleva, S., and Keltner, D. (2014). An occasion for unselfing: Beautiful nature leads to prosociality. 37:61–72.

Zhang, K. H. and Song, S. (2003). Rural-urban migration and urbanization in China: Evidence from time-series and cross-section analyses. *China economic review*, 14:386–400.

Zhi, G., Yang, J., Zhang, T., Guan, J., Du, J., Xue, Z., and Meng, F. (2015). Rural household coal use survey, emission estimation and policy implications (in Chinese). *Research of environmental sciences*, 28:1179–1185.

Zografakis, N., Sifaki, E., Pagalou, M., Nikitaki, G., Psarakis, V., and Tsagarakis, K. (2010). Assessment of public acceptance and willingness to pay for renewable energy sources in Crete. *Renewable and sustainable energy reviews*, 14:1088–1095.