



Green transition of energy systems in rural China: National survey evidence of households' discrete choices on water heaters



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ABSTRACT

Energy systems in rural China are experiencing a transition from traditional fossil fuels to renewables. This paper aims to investigate the potential factors that influence the choices of rural residents regarding water heaters with a focus on the low-carbon transition to solar water heating systems. To this end, a face-to-face questionnaire survey is undertaken with 3404 rural households randomly selected among 12 representative provinces. A comprehensive set of discrete choice modelling approaches were used. The empirical results show that (1) sociodemographic variables have significant effects on residents' first-stage choice of a water heater (*to buy or not to buy*) but few effects on the second-stage decision to choose electric, LPG, or solar water heaters (*which type to buy*); (2) information spillover is important to facilitate the usage of water heaters, particularly of solar products; (3) the electricity price, which is regulated at a very low rate, has no apparent effect on the choice of solar water heaters; (4) government subsidy has a significant effect in the first stage but no differentiated effect on the decision choice in the second stage. Policy and managerial implications are presented to speed up the ongoing low-carbon transition of energy systems in China.

1. Introduction

As China continues on a path of rapid economic growth, it faces rising environmental challenges, including worsening air pollution and the threat of climate change, evidenced by the fact that China is the world's biggest carbon dioxide emitter, producing each year roughly the equivalent of the US and the European Union combined (Liu, 2015). To address these concerns, the country has begun implementing ambitious programmes in renewable energy and energy efficiency in recent years (Ma et al., 2014; Zhu and Ruth, 2015). These programmes include the national milestone Renewable Energy Law, which took effect in January 2006, the national Medium- and Long-Term Development Renewable Energy Plan, launched in September 2007, and the Medium- and Long-Term Energy Conservation Plan launched in November 2004. Upscaling the development and deployment of renewable energy is also strongly supported by China's recent Five Year Plans, such as the 13th and the 12th Five Year Plans. Through these efforts, China hopes to improve its energy supply and energy security, enhance the quality and competitiveness of its economy, reduce pressure on the environment, and mitigate the effects of climate change. Meanwhile, the Chinese government has ramped up investment in low-carbon energy and put in

place a growing array of climate and energy policies. For example, in 2015, China set its low carbon energy targets for non-fossil fuels to generate 20% of total primary energy by 2030 (Xinhua Net, 2015).

However, China's rising demand means new fossil fuel capacity is added continuously: the overall share of renewables within the total energy supply is stagnating at best, despite impressive investments in low-carbon energy technology and a wide array of climate and energy policies. In fact, China is investing more than any other country in the world in renewable energy, including hydropower, wind energy, and solar energy (Zeng et al., 2014). In China, 85 million solar water heating systems have been installed and can be found in every province (Urban et al., 2016). Yet, solar water heaters are still far from mainstream. There is huge potential and an as-yet under-exploited market. China's approach to solar energy has mainly focused on large-scale technologies and interventions such as large-scale ground-mounted solar photovoltaic (PV) farms and concentrated solar power. However, a small-scale technology has made a significant contribution that goes largely unnoticed. Domestic solar water heaters are ubiquitous and massively successful in China: they are the rarely-mentioned champion of low-carbon energy (Urban et al., 2016).

Since solar water heaters are useful tools for achieving a low-carbon

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society in China, this study aims to examine how Chinese consumers choose water heaters, and in particular what drives consumers to purchase solar water heaters. To tackle this issue, a face-to-face questionnaire survey of 3404 rural households randomly selected among 12 representative provinces was undertaken. By examining consumers' choices of electric, liquefied petroleum gas (LPG), and solar water heaters, a comprehensive set of discrete choice modelling approaches (both multinomial logit model and nested logit model) were used. It is worth mentioning that rural China does not have natural gas pipelines installed, hence, natural gas is not used to provide hot water in rural China, but is a common type in many OECD countries. According to our survey, the leading purpose of installing a water heater is for showers in rural China. Nearly 97.0% of the respondents of our survey considered showers as the primary usage. Other primary usages include cleaning the kitchen (1.7%), space heating (0.3%), and heating feed for livestock (0.4%). This is consistent with the situation reported by Yuan et al. (2011), whose survey revealed that showers, cleaning, and laundry accounted for 82.1% of hot water usage by solar water heaters in China.

The empirical results show that (1) sociodemographic variables such as income level, household size, and homeowner age have significant effects on residents' first-stage choice of a water heater (*to buy or not to buy*) but no effects on the second-stage choice (*which type to buy*); (2) information exchange between rural and urban areas is important to facilitate the usage of water heaters, particularly of solar products for rural residents; (3) electricity price has no apparent effect on the choice of solar water heater because it is highly regulated at a very low rate and keeps unchanged for years; (4) government subsidy exerts a significant effect in the first stage but has no differentiated effect on the choice of the three types of water heaters in the second stage. Policy implications for promoting low carbon solar water heaters and green transition of energy system in rural China are drawn from this empirical study.

This study is novel in that, compared with the large amount of literature targeting mainly European and American countries, quantitative studies of consumer choice regarding energy appliances in China are rather limited. Particularly, largely due to a lack of data, no study has investigated the research topic on water heaters in rural China. This study is intended to fill a gap in the literature by examining Chinese data from a household survey. An additional merit of our analysis is that we applied a series of logit models to examine two related issues: The first is the determinants of a binary outcome of using versus not using water heaters (*to buy or not to buy*), which does not appear to be a relevant issue in the developed countries because water heating or residential space heating systems are widely used in these countries in people's daily lives. In rural China, however, the installation ratio of water heaters is low (only 34.05% in rural China) and hence usage or non-usage of a particular appliance is an issue of high relevance. The second issue is the determinants of multinomial choices of water heaters (*which type to buy*), facilitating policy implications for promoting solar water heaters and the green transition of energy systems in rural China. Another advantage of this study is that we take into consideration two novel variables in the empirical models, namely the travel frequency of family members of the surveyed respondent and the distance between the respondent's place of residence and the nearest town or urban centre. As we hypothesize that rural households' decision-making could be affected by knowledge spillovers through social interactions in urban areas, this study attempts to shed some light on the likelihood of spatial interaction effects on rural consumers' choices of water heaters.

The structure of this study is organized as follows. Section 2 reviews relevant studies on residents' choices regarding the adoption of electric appliances or solar products. Section 3 describes the empirical modelling techniques used to address the determinants of consumer choices regarding different water heaters. Section 4 introduces the questionnaire design and data collection issues, and the empirical results are reported in Section 5. Section 6 discusses some policy implications for

promoting energy-efficient solar water heaters in China. The last section concludes this study and comments on some potential limitations of the present study as well as suggests options for future research.

2. Literature review

Various scholars have examined, theoretically or empirically, residential choices regarding electric appliances and energy at national, state, and local levels. In general, existing studies can be broadly classified into the following three strands.

2.1. Research objectives

studies regarding residential choices on electric appliances focus mainly on the consumers' choices of household space heating equipment (Braun, 2010; Decker and Menrad, 2015; Michelsen and Madlener, 2012, 2013, 2016; Ruokamo, 2016), air conditioners and refrigerators with different energy efficiency labels (Shen and Saijo, 2009), and willingness to pay for renewable energy technologies like solar PV, micro-wind, solar thermal, heat pumps, biomass boilers, and pellet stoves (Scarpa and Willis, 2010). For instance, Braun (2010) focused on the determinants of the heating mode choices in Germany. The results implied that regional effects and dwelling features are important for heating system choices. Michelsen and Madlener (2012, 2013, 2016) examined space heating choices of German homeowners. Specifically, Michelsen and Madlener (2016) analysed data from a 2010 questionnaire survey among owners of existing single-family and duplex houses that had received financial grants to install (partly) renewable residential heating systems (i.e. condensing boiler with solar thermal support, heat pump, or wood pellet boiler). They show that environmental protection, a lower dependency on fossil fuels, and a higher degree of residential heating system-related knowledge are key drivers.

In contrast, studies on households' hot water systems are scant. By applying the mixed and nested logit models, Goto et al. (2011) examined how consumers select ecologically efficient water heaters in Japan. They mainly found that energy price is an important determinant of consumers' choices of energy-efficient appliances. Using a discrete choice experiment, Wasi and Carson (2013) studied the switching behaviour of New South Wales homeowners from electric water heaters to more environmentally friendly versions like solar water heaters targeted by hot water system rebate programmes and they evaluated the effectiveness of the programmes. Since this kind of analysis relies heavily on the availability of microdata, to date, no studies were found on discrete choices of households regarding water heaters in China.

2.2. Research areas

household's appliance choice studies in the developed countries, especially Germany, represent by far the largest share of the relevant literature. These include studies by Braun (2010), Decker and Menrad (2015), and Michelsen and Madlener (2012, 2013, 2016) in Germany, Gill et al. (2015) and Wasi and Carson (2013) in Australia, Goto et al. (2011) in Japan, Ruokamo (2016) in Finland, Scarpa and Willis (2010) in the UK, and Dubin and McFadden (1984) and Liao and Chang (2002) in the US. Being the most economical, mature, and popular renewable technology (Chang et al., 2009; Han et al., 2010), solar water heaters have been the topic of several studies in China. This line of studies mainly focused on several relevant aspects of the deployment of this renewable technology and different innovation paths (Urban et al., 2016). Different aspects of the deployment include social acceptance and public awareness of solar water heaters (Yuan et al., 2011), economic feasibility analysis of diffusion of solar water heaters (Han et al., 2010; Li et al., 2011; Ma et al., 2014), institutional analysis of factors to make solar water heating systems successful (Li et al., 2011; Goess et al., 2015), and evaluations of incentive programmes (Chang et al.,

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