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Solar energy adoption in rural China: A sequential decision approach

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ABSTRACT

Adoption of renewable energy such as solar energy has been recognized as an important way to reduce rural carbon emissions and enrich the energy supply of rural households in China. Using a survey sample of 972 rural residents from Jiangxi Province in South China, this study investigates the factors that affect individual rural resident decisions on whether to adopt solar water heaters and the levels of usage after adoption. Unlike previous studies, this study assumes the two decisions are sequential and addresses them with a Heckman model approach. Results show that geographic factors, household attributes, and resident characteristics play different roles in the two stages of the decision process. The awareness of the subsidy policy is crucial in determining whether to adopt, while the awareness of solar water heater technology influences the usage level. These results provide useful insights to identify effective policy instruments to promote renewable energy use in rural China.

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1. Introduction

China is a country with rich solar energy resource. The use of solar water heaters (SWHs) is one of the most common applications of solar energy systems (Gautam et al., 2017). Currently, China's solar energy use accounts for 70.6% of the globally installed capacity (Mauthner et al., 2015). Despite the high total capacity, the adoption rate among Chinese households is still relatively low. The adopted capacity was only 194.3 KWh per 1000 households in 2013, which was much lower than 385.2 in Austria, 373.8 in Israel, and 271.5 in Greece (Mauthner et al., 2015). However, China has a large demand for water heating, especially in rural areas. A survey in rural China indicated that more than 90% of the sample residents claimed that they needed more hot water in everyday life (Han et al., 2010). Traditionally, Chinese rural residents use firewood or coal to boil water. The combustion of fossil fuels and woods causes carbon emissions and environmental degradation. Acquiring these nonrenewable fuels also causes a financial burden for households. Given the high demand for hot water and relatively low energy costs using SWHs, there is a large potential for SWH adoption in rural China. Adoption of SWHs will reduce energy expenditure and improve the welfare of rural residents.

A vast literature has examined rural residents' adoption of new technologies and practices (Michelsen and Madlener, 2016; Wang et al., 2016a, 2016b). Studies that specifically addressed the adoption of SWHs by rural residents are limited (Wang et al., 2016a, 2016b). Benli (2016) examined the determinants of SWH adoption in Turkey and found that the probability of adoption was affected by economic conditions, regional population, climatic conditions, and the prices of SWHs. Chang et al. (2008) found the adoption of SWHs in Taiwan was influenced by factors such as climatic conditions, population composition, building types of housing, the cost of SWHs, and energy prices. Although the adoption of SWHs in China has received increasing attention, research on SWHs is limited. Ma et al. (2014) suggested establishing government incentive programs to improve the willingness to adopt SWHs.

It is worth noting that boosting the share of renewable energy in residents' daily energy consumption is dependent on not only the adoption of SWHs, but also the level of SWH usage after adoption. A common issue in relation to SWHs in rural China is the low usage level. Survey data in this study show that, although 56% of rural residents installed SWHs, more than one-third of the residents who adopted SWHs reported a low level of usage. Therefore, it is important to understand both the adoption and usage decisions.

This paper intends to make three contributions to the literature. First, unlike previous studies that modeled either the adoption or usage decisions, this study accounts for both decisions and allows

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for correlations between the two. This is the first study to model both adoption and usage decisions of SWHs. It assumes that the adoptiondecision and the usage decision are sequential. Individual rural residents weigh potential benefits and costs and decide whether to adopt. After adoption, they decide the usage level (Fig. 1). This paper uses the Heckman approach to address the correlation. Second, it allows two different mechanisms for the sequential decisions. The literature on technology adoption typically uses the Tobit model, which imposes a restrictive assumption that the same underlying mechanism applies to both decisions. In contrast, the Heckman model is flexible enough to account for the possibility that factors influencing willingness to adopt are different from those influencing the usage level. This study found that resident characteristics, resident perceptions, and attitudes significantly affect the adoption decision, while geographic factors and household attributes influence the level of usage. Finally, this paper pays special attention to possible policy solutions to promote usage of SWHs in rural areas, which has not received much attention in the literature.

The remainder of the paper is organized as follows. Section 2 presents the empirical model of the sequential adoption-usage decisions. Section 3 describes the data. Section 4 presents the estimation results. The final section presents conclusions and discusses policy implications.

2. The sequential decision model

The discrete-choice model is commonly used in the literature to model the adoption decision. It provides useful insights on how different factors may affect the probability of adopting SWHs. However, it does not address the sequential decision problem. Some studies have used the Tobit model to investigate rural residents' adoption decisions of new technologies (Awotide et al., 2016). The Tobit model takes the non-adopters as zero-usage observations. This is a restrictive assumption because it requires that the process that generates the zeros be the same as the process that generates the positive outcomes. In other words, it assumes that the adoption and usage decisions are determined by the same underlying process. When studying renewable energy adoption among Californian farmers, Beckman and Xiarchos (2013) empirically showed that whether to invest in renewable energy and how much to invest are actually determined by two different decision processes. Cragg (1971) proposed the hurdle model as an extension to the Tobit model. The hurdle model is flexible enough to allow two different mechanisms for the sequential decisions but restrictive in the sense that the two-step decisions are independent. This section first formulates the sequential decisions and then applies the Heckman model to account for the potential correlation between the SWH adoption and the usage decisions.

Let y be the usage level of SWHs chosen by an individual rural resident, which is a function of a binary adoption decision variable z, and the continuous choice of a nonnegative usage y^*:

$$y = z \cdot y^* \tag{1}$$

When the resident chooses to adopt the SWH ($z = 1$), a positive usage frequency $y^* = y$ is chosen and observed. When the resident chooses not to adopt ($z = 0$), then y^* is not observed and $y = 0$.

In the first step, a probit model is used to estimate the binary decision z. An individual rural resident is willing to use SWHs only if the net utility gain from using them is greater than zero. Thus, the net utility gain or loss, z, is assumed to be generated by a linear latent variable model:

$$z^* = x_1\gamma + \upsilon, \quad \upsilon|x_1 \sim N(0, 1), \tag{2}$$

$$z = \begin{cases} 1, & if\ z^* < 0 \\ 0, & if\ z^* \geq 0 \end{cases}, \tag{3}$$

$$P(z = 1|x_1) = E(z|x_1) = \Phi(x_1\gamma), \tag{4}$$

where x_1 is a vector of explanatory variables that determine rural residents' willingness to adopt SWHs, including resident characteristics, their perceptions and attitudes toward SWHs, household attributes, and geographic factors. The random term ν is assumed to be independent of x_1 and follows a standard normal distribution.

In the second step, the usage of y is chosen based on a vector of attributes x_2, such as resident characteristics and household attributes that affect usage choices. The usage is positive and equal to y^* only if the resident decides to adopt SWHs and zero otherwise. Both the truncated normal distribution and the lognormal distribution could be assumed when modeling this decision-making process because all zeros are truncated in this stage. In the case of truncated distribution, y is assumed to have a truncated normal distribution.

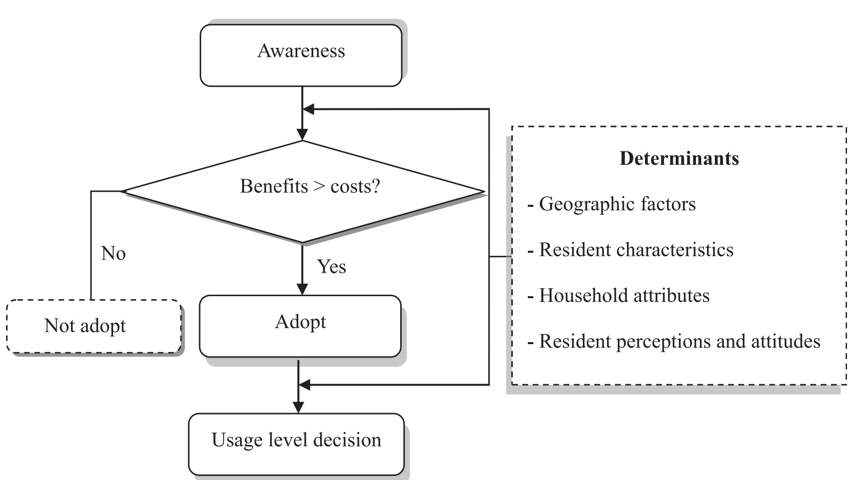

Fig. 1. Flow chart of rural residents' two-stage decision in SWH adoption.