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A meta-analysis on the price elasticity and income elasticity of residential electricity demand

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ABSTRACT

Price elasticity and income elasticity can quantitatively measure the impact of price volatility and income diversity on household electricity demand. To analyze household electricity demand and better identify the main factors affecting residential electricity demand elasticity in previous literature, a meta-analysis based on a comprehensive and systematic summary of 103 articles is presented in this study. The influencing factors are identified, with a weighed least squares (WLS) linear regression model to evaluate their strength. The price elasticities and income elasticities are discussed from three dimensions, namely short-term, long-term and unmarked. The results show that residential electricity demand is almost price-inelastic and income-inelastic in the short-term. But in the long-term, some residential electricity demand is price-elastic and income-elastic. The results also reveal that residential electricity demand elasticity is affected by many factors, such as time interval and sample period. These conclusions can support the formulation of more effective electricity price and energy policy.

1. Introduction

Energy is an important driving force for social progress and development. Electricity is a kind of clean secondary energy, which refers to it is converted from primary energy that directly from the natural world, including raw coal, crude oil, and natural gas. It is closely related to the industrial development, national economy development and people's livelihoods. According to Energy Market Authority, 2017, more than 15% of the electricity was used for households, and most of the electricity is generated using imported natural gas in Singapore (Energy Market Authority, 2017). Similarly, China Energy Statistics 2017 shows that household electricity consumption accounts for 13% of total electricity consumption, of which 70% of electricity is generated by thermal power (China Energy Statistics, 2017). In some countries, the household sector is one of the main areas of electricity consumption. A large amount of electricity consumption exacerbates annual greenhouse gas emissions. In order to mitigate the negative impact of energy consumption on the environment, many measures have been taken, such as strengthening research on renewable energy and organic materials (Marousek, 2012; Marousek et al., 2015), formulating appropriate environmental taxes (Ghaith and Epplin, 2017; Oderinwale and Weijde, 2016), and subsidizing environmentally friendly electricity production (Mardoyan and Braun, 2014; Marousek et al., 2014).

Although renewable energy research and policy regulations are important ways to promote energy conservation and improve energy efficiency, more and more people are gradually realizing that behavioral factors are of great significance for achieving energy conservation (Zhou and Yang, 2016). Changes in household electricity consumption behavior can effectively achieve the household energy saving. At present, there are many studies that consider energy price and household income as some of the determinants of household electricity consumption behavior (Esmaeilimoakher et al., 2016; Silva et al., 2017). However, energy price is affected by various factors. For example, the ban of nuclear energy, public demand for renewable resources, and the formulation of environmental taxes. There are also significant differences in household income due to differences in work, education, and regions. The volatility of electricity prices and the diversity of household

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Nomenclature

Indices

i	The number of explanatory variables
n	The total amount of explanatory variables

Parameters

η	The price elasticity and income elasticity collected from previous studies
X_i	The set of potential independent variables
$\beta 0$	When all explanatory variables are zero
βi	Correlation coefficients
ε	Error term

Acronyms

WLS	Weighted least squares method
GLS	Generalized least squares method
OLS	Ordinary least squares method
IV	Instrumental variable method
ML	Maximum likelihood method
ECM	The error components model

incomes increase complexity of research problems. Price elasticity and income elasticity are quantitative indicators to measure the impact of price changes and income changes on electricity demand. Their introduction can evaluate the response of household electricity consumption to price changes and income changes. Ultimately, the consumption pattern can effectively support the regulation of residential electricity markets (Nakajima and Hamori, 2010), the formulation of energy policies (Kwon et al., 2016), residential electricity demand forecasts (Cabral et al., 2017), electricity infrastructure planning (Collins et al., 2017), and measuring the effectiveness of environmental taxes (Benavides et al., 2015).

In recent years, the field of economics has produced a large amount of residential electricity demand research literature, which provides considerable empirical evidence for the analysis of electricity demand (Romero-Jordán et al., 2016; Wang and Mogi, 2017). However, these studies establish different evaluation models, use different evaluation methods, and distinct types of data from different countries covering different periods, and draw conclusions in specific situations. The high heterogeneity of existing empirical studies hinders the general adaptive conclusions to be made that support for policy decisions.

Meta-analysis offers an effective and appropriate way to solve this problem (Labandeira et al., 2017). It is a review method based on statistical analysis, proposed by Glass in 1976, then introduced into the field of economics by Stanley and Jarrell (1989), to fill the gaps of the quantitative literature review method. Meta-regression is a popular meta-analysis method used in economics (Chen et al., 2015). Espey (1996) first proposed using meta-analysis to determine whether there are systematic factors affecting gasoline prices and income elasticity estimates in the US. His study considered the data characteristics, model structure, and estimation technique as explanatory variables. In his subsequent study, Espey (1998) used demand specifications, data characteristics, environmental characteristics, and the estimation method used as explanatory variables to estimate the global long-run and short-run gasoline prices and income elasticity. A considerable amount of subsequent research is based on this study. Espey and Molly (2004) used meta-analysis to quantitatively summarize previous studies of residential electricity demand by both GLS estimation and ML estimation. Labandeira et al. (2017) used meta-analysis methods to evaluate the price demand elasticity of a variety of energy goods, including electricity, natural gas, gasoline, and diesel. Other research uses meta-analysis focused on the demand elasticity of water (Houtven et al., 2017), food (Chen et al., 2015), transportation noise nuisance (Bristow et al., 2012), alcohol (Gallet, 2007), pesticides (Böcker and Finger, 2017), etc. On the whole, however, the use of meta-analysis to study elasticity estimates of electricity demand is still quite limited. Espey and Molly (2004) selected peer-reviewed journal articles published between 1971 and 2000 covering the time period from 1947 to 1997, lost the latest reference value. Labandeira et al. (2017) focused on a variety of energy goods, their research covering residential, industrial and commercial aspects. However, different energy goods have different performance levels and storage requirements, and can meet the needs of people under different scenarios. Therefore, there are differences in the factors that affect them. We exclude such energy sources as diesel and gasoline, and only select electricity as the object of the research. In comparison, the study of electricity demand in this paper is more accurate and precise.

We comprehensively collect the results of previous studies involving the demand elasticity of residential electricity. The meta-regression method is used to determine the following points. First, we need to determine how much elasticity estimates are sensitive to the demand specification, difference in data sources, background environment and estimation method. Second, whether short-term elasticity estimates differ from long-term estimates is determined. Third, we need to consider the different responses of price elasticity and income elasticity to a range of factors. Finally, we judge whether the price elasticity and income elasticity are elastic in the short- and long-term. To accomplish this, we summarize the elasticity of electricity demand, and identify the factors that influence electricity demand - extracting useful estimates from the latest academic articles. Then we take the price elasticity and income elasticity of residential electricity demand as dependent variables, with demand specification, estimation technique, data characteristics, and environmental characteristics as explanatory variables. A regression analysis of cross studies is conducted to obtain the determinants of residential electricity demand elasticity.

For the remainder of this article, Section 2 introduces our data sources; then we establish the meta-regression model and determine the explanatory variables in Section 3. Section 4 presents the empirical results, and Section 5 contains our concluding remarks.

2. Data sources

In order to complete relevant studies, empirical studies were obtained from a variety of databases, including the Web of Science, Chinese Journal Full-text Database, Google Scholar, and used the keywords “electricity” and “demand” and “price elasticity” or “income elasticity”. Then, a manual scanning of the abstracts was conducted. Articles that do not meet the research requirements were eliminated. Eventually, this paper summarizes the 103 articles on the theme of residential electricity demand. The articles used in the meta-analysis are shown in Table A.1 in Appendix A. These articles were published between 1990 and 2017 covering the period from 1950 to 2014. These studies yielded 175 and 196 short- and long-term price elasticity estimates respectively, 148 and 151 short- and long-term income elasticity estimates respectively, and 228 and 151 price and income elasticity estimates that did not specify short- or long-term.

Table 1 provides a statistical summary of the elasticities. The short-term price elasticity estimates range from −0.948 to 0.61 with a mean of −0.228. For the long-term price elasticity estimates, the mean is −0.577, range from −4.2 to 0.6. Short term income