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The determinants of household electricity consumption in Taiwan: Evidence from quantile regression

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ABSTRACT

This paper employs quantile regression to analyze the determinants of household electricity consumption in Taiwan over the period 1981–2011. Our results show that the effects of demographic, socio-economic, and household dwelling characteristics on household electricity consumption may differ across quantiles and may change over time. We found that household income and household size were significant in all quantiles for each year. We identify the characteristics of high-electricity-consuming households. Households with higher income, larger household size, and more elderly members consumed more electricity. In terms of dwelling attributes, larger housing areas, homes with more appliances, and owner-occupied, business-used, and multi-floor houses contributed to higher household electricity consumption. Strategies for reducing electricity consumption should focus on specific groups that tend to exhibit higher electricity use. However, we also found that the low-income and small-size households may have higher electricity consumption on a per capita basis. Thus, as household size decreased, the increase of per capita electricity demand driven by the change of household size should be a matter of concern.

1. Introduction

With industrialization and urbanization, rapid growth in energy consumption has taken place in most Asian countries. In Taiwan, total energy consumption increased from 86 million KLOE (kiloliters of oil equivalent) in 2000 to 112 million KLOE in 2012. Thus, total energy consumption increased by 30%, which was higher than the average global increase of 26% [1]. Electricity consumption accounted for 50% of total energy consumption, while nearly 80% of electricity production came from fossil fuels. In 2012, Taiwan's per capita electricity consumption was 10.3 MWh. It ranked first in Asia and the 12th in the world. Thus, electricity conservation and energy efficiency are particularly important for sustainable development in Taiwan. In the residential sector, it was also revealed that electricity consumption increased over time. From 2000 to 2012, Taiwan's residential electricity consumption increased by 25%. Electricity expenditures constituted 67% of total household energy expenditures, accounted for the largest share of household energy expenditure. It is imperative to use effective strategies to promote household electricity saving. In this study, we therefore try to identify the determinants of household electricity consumption and detect the characteristics of high electricity-consuming households.

Previous studies have found that household energy consumption is related to various factors, including economic ability [2–6], socio-demographic characteristics [7–10], physical characteristics of the dwelling [11–13], residential location [4,11,14], environmental and climate factors [12,13], and the costs of energy use [15,16]. Most of these studies investigate the factors that contribute to household energy consumption. Some studies focus on analyzing the characteristics of household electricity consumption and its driving factors [12,17–19]. Few studies have examined how the determinants may differ across household groups. Tuan and Lefevre [2] used a household energy survey in Vietnam to evaluate household energy demand patterns. They examined the income effects on energy demand patterns for different categories of households and found that income is a strong factor that affects quantity and structure of energy use. Nesbakken [15] analyzed how different preferences affect estimated energy demand in Norway. The pooled data were divided into two subsets according to income level. The results show that energy price sensitivity in residential energy consumption is higher for high-income households than for low-income households. Poyer et al. [20] studied energy demand

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for different population groups and found significant differences in the consumption patterns between Latino and non-Latino households. Yamasaki and Tominaga [21] highlighted the relative high energy consumption of elderly households compared to other households in Japan. In addition, some studies have focused on the variation in energy use between rural and urban areas [8,11,14,22]. Therefore, energy consumption may vary across household groups in many respects, such as level of income, race, age, and region.

However, these studies that choose a subsample or divide the sample into some groups are clouded by sampling bias [23]. To avoid sampling bias, Kaza [7] and Valenzuela et al. [13] employed a QR (quantile regression) approach that used the entire sample to estimate the effects of explanatory variables on the energy use distribution. Their studies suggested that explanatory variables generally have different effects on household energy use depending on whether household energy use is in a high or low quantile. Accordingly, the effects of the factors influencing household energy consumption may exhibit variations in magnitude and sign in different quantiles.

In this paper, we employ quantile regression to analyze the determinants of household electricity consumption for different levels of electricity use in Taiwan. In contrast to previous cross-sectional studies that mainly focus on the dataset for a specific year, this paper uses cross-section surveys from 1981 to 2011 and investigates how the effects of demographic, socioeconomic, and dwelling characteristics on household electricity consumption have changed over time.

2. Methods

2.1. Quantile regression model

Due to the great diversity of behavior, household consumption may exhibit a pattern of heterogeneity. Deaton [24] showed that the elasticity of household expenditures varies across quantiles. With the high variability in electricity consumption datasets, the classical OLS (ordinary least squares) regression would draw dubious conclusions [25]. In particular, when the response is skewed, the OLS regression may result in misleading regression coefficients [26]. To account for the heterogeneity and skewed distribution in the data, we employ quantile regression to investigate the determinants of household electricity consumption. Quantile regression, developed by Koenker and Bassett [27], estimates the effects of predictor variables on specific quantiles of a dependent variable.

Consider a regression model of the form $y_i = x_i'\beta + \varepsilon_i$; the parameter coefficients estimated using the OLS regression method can be expressed as follows:

$$\min_{\beta \in R^k} \sum_{i=1}^{n} (y_i - x_i'\beta)^2 \tag{1}$$

where y is the endogenous variable, x is a vector of exogenous variables and β is the parameter vector to be estimated. While the OLS regression estimates the conditional mean, QR estimates the conditional quantiles. Let p be a number between 0 and 1, and the p quantile of the distribution of a random variable y is denoted by $Q(p)$. $Q(p)$ can be obtained by sorting the values of y from smallest to largest. In the quantile regression model, the parameter vector β can be estimated for any quantile p by minimizing the following expression with respect to β [27]:

$$\min_{\beta \in R^k} \sum_{i=1}^{n} p(y_i - x_i'\beta)^2 \quad \text{for any quantile} \quad p \in (0,1) \tag{2}$$

$$\min_{\beta \in R^k} \left[\sum_{i \in \{i: y_i \geq x_i\beta\}} p|y_i - x_i'\beta| + \sum_{i \in \{i: y_i < x_i'\beta\}} (1-p)|y_i - x_i'\beta| \right] \tag{3}$$

The general pth sample statistics quantile $Q(p)$ may be solved as an optimal solution to minimize the sum of asymmetrically weighted absolute error terms ε_i, with different weights for positive and negative residuals, depending on the chosen quantile p. The different parameter vectors of β for a given p can be obtained using linear programming algorithms. In contrast to the OLS method, which estimates the regression slope by minimizing the sum of squared residuals, QR estimates the regression slope by minimizing the sum of absolute residuals.

In terms of econometric techniques, QR can be more efficient than the OLS method when the residual series is non-normal. The estimated coefficient vector of QR is more robust to outliers [28]. In addition, the QR approach uses the whole sample rather than selects a subsample to estimate the effects of independent variables on a specific quantile of the dependent variable. Therefore, this method can avoid the problem of sampling bias [23]. Conversely, as a tool of comparative analysis, QR provides a complete view of the effects of possible factors on household electricity consumption. The responses of household electricity consumption to a specific predictor may vary across the bottom and top quantiles. The QR approach also can help us detect the characteristics of high electricity users to develop coping strategies to reducing electricity consumption.

2.2. Data

In this paper, household data were derived from Taiwan's FIES (Family Income and Expenditure Survey), a nationwide cross-sectional survey that has been conducted annually by the Taiwanese government. Approximately 15,000 households are sampled each year, but households are not tracked. This database collects household characteristics and demographic information such as property and facilities, income, and expenditures.

2.2.1. The dependent variable

The dependent variable is household electricity consumption, defined as total annual electricity use per household and measured in kWh. However, the FIES database only collected household electricity expenditure, and household electricity use was not available. Accounting for the progressive electricity tariff system, we used electricity prices to transform household electricity expenditure into household electricity use. The electricity prices data are derived from TPC (Taiwan Power Company), which is a state-owned monopoly. The electricity prices are consistent across all areas served by the state-owned utility.

Table 1 reports the descriptive statistics for household electricity consumption. The mean value of household electricity consumption increased from 1783 kWh in 1981–5101 kWh in 2001, and then dropped slightly to 4864 kWh in 2011. We also found that the standard error decreased from 2324 in 2001–2015 in 2011. This result reflected the change of the electricity tariff structure. In 2004, the electricity tariffs had a sharp rise. The brackets increased and were set with higher prices for high electricity users. Then, the electricity tariffs continued to rise and adjusted more frequently than before. We found that the units of 90th percentiles were approximately three times higher than those of the 10th percentiles for each dataset. We use the Jarque–Bera test to examine the null hypothesis that the variable is normally distributed. The null hypothesis of normal distribution is rejected for each dataset. The results confirm that the QR approach is suitable for estimation.