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Residential electricity demand in Taiwan: Consumption behavior and rebound effect

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ABSTRACT

The residential electricity demand in Taiwan was investigated using survey data of 7677 households between 2014 and 2017. Right-skewed regression models were employed to study key determinants affecting the household and appliance-specific electricity consumption. Appliances covered air conditioner, lighting, television, and refrigerator. The difference of electricity consumption between appliances with and without energy efficiency label was also studied; thus rebound effects were obtained. The estimated results indicate that household income, indoor floor area, and owning the house had positive influences on electricity consumption. Electricity consumption behavior was different among age groups and appliances. Moreover, rebound effect was large for air conditioner and refrigerator in Taiwan.

1. Introduction

Electricity consumption behavior is the results from individual decisions, which is often driven by external factors such as socioeconomic conditions, demographics, and regulations. Identifying these factors and their contributions in determining energy demand is important to affect consumption behavior and make it more energy efficient. The national goal of Taiwan is reducing greenhouse gas emissions by 20% from 2005 to 2030, based on the Executive Yuan.[1] To achieve this goal, understanding energy consumption behavior and related determinants is the first step. Then the policy makers have force points to manage the growing energy demand.

The growing economy and population increased the electricity consumption in Taiwan (Su, 2018), but the improving electrical efficiency decreased the growth rate. The electrical efficiency[2] in Taiwan had improved by approximately 15.4% from 2001 to 2016, according to the Bureau of Energy (BOE). In Fig. 1, electricity consumption in Taiwan increased annually by 1.26% in the post-financial crisis period from 2010 to 2016. In the same period, the growth rate of residential electricity consumption in Taiwan was 1.5%, higher than the aggregated one. This annual growth rate between 2001 and 2007 was 4.89% for aggregation and 4.39% for residential sector. In other words, even though the electrical efficiency has been improved, residential electricity consumption grew faster than other sectors in recent years. Addressing to the faster growth of residential electricity demand, this study finds out key determinants, such as income, indoor floor area, ownership of house, or residents' age, which affect the demand in the micro level. In addition, separating this demand into appliances can focus on the appliance-specific electricity consumption behavior and related affecting factors.

Energy efficiency (EE) is key to ensuring a safe, reliable, affordable and sustainable energy system for the future, based on International Energy Agency (IEA). One of the important EE measures in Taiwan was promoting EE label since 2001. Application with EE label was officially recognized as higher energy efficiency. However, higher EE does not necessarily represent less electrical power will be consumed, because consumers tend to consume more electricity due to economic benefit from efficiency improvement. Thus, the difference of electricity consumption between appliance with and without EE label was investigated in this study. Compared the actual saving to theoretical expected saving, the appliance-specific rebound effects were also studied.

Data came from a questionnaire survey of household electricity consumption in Taiwan. The data covered 7677 households from 2014 to 2017. The micro-level household data reveal more information of appliance-specific electricity consumption, dwelling condition, and socioeconomic status. These data are ideal for studying the electricity

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[1] The Executive Yuan is the executive branch of Taiwan government, headed by the premier who is directly appointed by the president. The Bureau of Energy (BOE) is the administrative agency under the Ministry of Economic Affairs which is under the Executive Yuan.

[2] The improvement of electrical efficiency is measured according to the negative change of electrical intensity. The electrical intensity is often used and easily available based on International Energy Agency (IEA, 2017).

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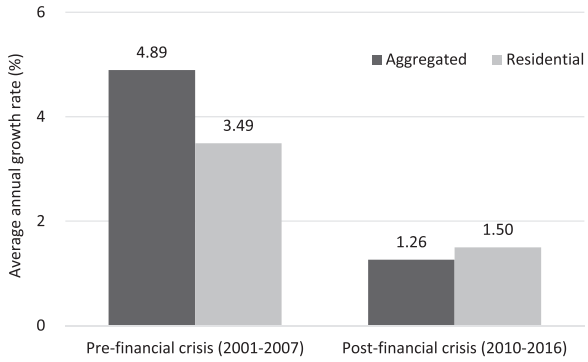

Fig. 1. Average annual growth rates of electricity consumption in Taiwan.

consumption behavior, instead of macro data. Moreover, questions addressing to the EE label of each appliance are key index to separate the different electricity consumption behavior between using high EE and general appliances; thus, the actual electricity saving due to the improvement of EE can be studied.

Household electricity consumption is a non-negative integer and had a right-skewed distribution based on the dataset. As the result, Poisson and negative binomial regression models were employed to fit the data and avoid the estimation bias due to incorrect assumption of distribution. Estimated results indicate that household income, indoor floor area, and owning the house had positive influences on electricity consumption. Electricity consumption behavior was different among age groups and appliances. Moreover, the rebound effect was significantly large for air conditioner and refrigerator, representing households change their consumption behavior and save little electricity when using these appliances with EE label. This effect was small for lighting and television so using these appliances with EE label can actually save electricity.

The remainder of this paper is organized as follows: Section 2 presents the background of residential electricity consumption in Taiwan, and introduces the endorsement label of energy efficient appliances and rebound effect. Section 3 introduces the Poisson and negative binomial regression models. Data from the questionnaire survey of residential energy consumption are presented in Section 4. Section 5 reports the estimated results of household electricity consumption and appliance-specific rebound effect. Finally, Section 6 concludes this paper.

2. Background

2.1. Residential electricity consumption

Starting from Houthakker (1951), vast research modeled the electricity demand in the residential sector. Different approaches were employed to adapt to different types of data. Regression models were often used to deal with cross sectional data (Lariviere and Lafrance, 1999), especially for the one-off household survey (Filippini and Pachauri, 2004; Lijesen, 2007; Yoo et al., 2007). Even though collecting household data costs more time and money compared to aggregated data, it was in widespread used in recent research to provide detailed estimates of micro-level parameters (Krishnamurthy and Kriström, 2015; Fell et al., 2014; Alberini et al., 2011; Reiss and White, 2005) and avoid aggregated biases (Fell et al., 2014; Bohi, 1982).

Residential electricity consumption in Taiwan was approximately 47.6 billion kilowatt hour (kW h) in 2017, which is 18% of total electricity consumption, based on the BOE. The histogram of annual electricity consumption per household between 2014 and 2017 was drawn in Fig. 2 according to the survey data of this study. The distribution was right-skewed, which was supported by the positive skewness (SK = 1.86 > 0).[3] The right-skewness can also be observed in Fig. 2, compared to the curve of normal distribution. The skewed sample will cause estimated results biased when the ordinary least squared (OLS) regression is used (Coxe et al., 2009). To fix this problem, appropriate right-skewed regression models were employed in this study.

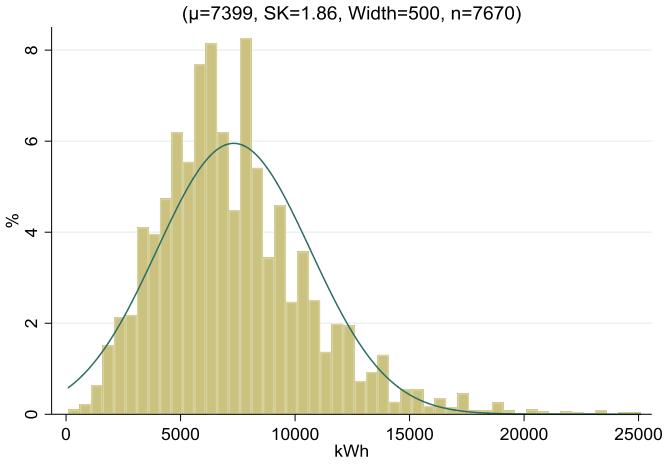

Fig. 2. Annual residential electricity consumption in Taiwan (2014–2017).

Electricity is demanded for appliances that provide services to the household. Electricity consumption depended heavily on ownership of energy intensive appliances (Brounen et al., 2012; Reiss and White, 2005). The percentages of electricity consumption of appliances from 2014 to 2017 in the residential sector were shown in Fig. 3, based on the survey data of this study. Air conditioner (AC) was the highest electricity-consuming appliance, which consumed 35.74% of total electricity. Following were lighting (20.45%), television (TV; 8.75%), and refrigerator (6.98%). The histogram of these appliances were shown in Fig. 4. The right-skewed distribution can also be observed, and all of the skewness were positive.

The appliance-specific models reveal more information related to the household electricity consumption behavior. However, there is a little research discussing this topic due to the limitation of data collection (Kelly and Knottenbelt, 2015; Fang et al., 2012; Depuru et al., 2011). The right-skewed regression models were also rarely discussed in previous research. The household electricity consumption was estimated based on a questionnaire survey in this study. Appliance-specific models were also built to address the right-skewed distributed electricity consumption of AC, lighting, TV, and refrigerator in the micro level. Constructing models provides more information to discover key factors affecting electricity consumption, which can assist government in policy formulation.

2.2. Label for energy efficiency appliances

The voluntary Energy Efficiency Label Program is executed by the BOE in Taiwan since 2001. Appliances with this endorsement label is recognized by the government that its energy efficiency is ranked at top 30% compared to the similar products in the market. This energy efficient is 10–50% higher than Taiwan's National Standards. The efficiency criteria are then periodically reviewed and revised to reflect technology advancement and ensure the credibility. EE label covered 51 product categories. By September 2018, 7365 products, which belong to 326 brands, were available for purchase consideration.[4]

[3] Skewness (SK) is a measure of the asymmetry of the probability distribution of a real-valued random variable. The skewness value can be positive (right-skewness) or negative (left-skewness), or 0 (Groeneveld and Meeden, 1984).

[4] According to the official website of EE label in Taiwan (www.energylabel.org.tw/englishlabel).