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How do household characteristics affect appliance usage? Application of conditional demand analysis to Japanese household data

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HIGHLIGHTS

- We conduct conditional demand analyses to study household appliance usage.
- Micro-level data from the National Survey of Family and Expenditure in Japan are analyzed.
- We show how household characteristics determine appliance usage.
- High-income households use specific appliances less intensively than low-income households.
- The replacement of old TVs and PCs lead to greater electricity consumption.

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ABSTRACT

Although both appliance ownership and usage patterns determine residential electricity consumption, it is less known how households actually use their appliances. In this study, we conduct conditional demand analyses to break down total household electricity consumption into a set of demand functions for electricity usage, across 12 appliance categories. We then examine how the socioeconomic characteristics of the households explain their appliance usage. Analysis of micro-level data from the Nation Survey of Family and Expenditure in Japan reveals that the family and income structure of households affect appliance usage. Specifically, we find that the presence of teenagers increases both air conditioner and dishwasher use, labor income and nonlabor income affect microwave usage in different ways, air conditioner usage decreases as the wife's income increases, and microwave usage decreases as the husband's income increases. Furthermore, we find that households use more electricity with new personal computers than old ones; this implies that the replacement of old personal computers increases electricity consumption.

1. Introduction

For many decades, the determinants of residential electricity demand have been analyzed in a wide variety of scholarly journals. Among the factors that affect residential electricity demand, the effects of socioeconomic, dwelling, and appliance factors have been studied most intensively in the literature. Jones et al. (2015) review a large number of studies on residential electricity demand and identify the factors that systematically enhance residential electricity demand: (1) socioeconomic factors (occupants, the presence of teenagers, household income, and disposable income), (2) dwelling factors (dwelling age, number of rooms, number of bedrooms, and total floor area), and (3) appliance factors (number of appliances, and ownership of a desktop computer, television, electric oven, refrigerator, dishwasher, and tumble dryer).

Thus far, researchers have already garnered some knowledge about the determinants of residential electricity demand; nonetheless, previous studies have not yet analyzed the effects of household characteristics on the electricity usage of appliances in great detail.[1]

Socioeconomic characteristics of households influence the appliance usage. For instance, a household with many members will use a washing machine more frequently. Similarly, a household with hungry teenagers will use a dishwasher more frequently. However, we do not know how much electricity is used in cleaning the laundry of additional family members or in cleaning extra dishes, for example.

[1] One exception are Mizobuchi and Takeuchi (2016). They conducted a survey to examine whether energy-efficient ACs lower the electricity consumption of Japanese households. However, the number of sample households in their study is 339.

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Gronau and Hamermesh (2008) argue that high and low-income earners spend their time in different ways. If high and low-income earners do indeed have different lifestyles, then we expect that they will use appliances differently. By analyzing time-use survey data from Australia, Israel, and West Germany, Gronau and Hamermesh (2008) find that low-income (and generally less-educated) persons spend more time watching television. Brenčič and Young (2009) study how the adoption of time-saving appliances affects the time allocation of households. By analyzing data from the 2003 Survey of Households Energy Use in Canada, they find that households allocate to other home activities part of the extra time obtained by adopting time-saving appliances. The two aforementioned studies report that time allocation and appliance usage are related decisions.

The purpose of this study is to show how the socioeconomic characteristics of households affect their appliance usage, by analyzing micro-level data captured through Japan's Nation Survey of Family and Expenditure (NSFE) (Statistical Bureau, Ministry of Internal Affairs and Communications, 2015a). Do high-income earners use a specific appliance more/less intensively than low-income earners? Does electricity consumption increase if there are teenagers in the household? This study will provide possible solutions to these questions through statistical modeling.

Socioeconomic characteristics of households affect both appliance ownership and usage. To separate ownership and usage effects, we introduce the two-step estimation procedure into the conditional demand analysis of residential electricity use. We first classify households into different groups according to the number of appliances they own and then we study the variation in the intensity of the use of specific appliances in a particular group due to differences in the socioeconomic characteristics of households. For instance, we can examine whether the presence of a teenager affects electricity consumption for ACs within the group of households that own two-ACs. By taking this two-step procedure, we separate ownership and usage effects and show how household socioeconomic characteristics affect appliance usage.

The rest of the paper is organized as follows. Section 2 provides a brief literature review on residential electricity demand analyses and presents the contributions of this study to the literature. Section 3 explains the data used in this study. Section 4 explains the two-step estimation procedure and the details of the empirical model. In Section 5, we report the estimation results and Section 6 concludes.

2. Residential electricity demand analyses

In previous studies, both top-down and bottom-up approaches have been used to analyze residential electricity demand. With the top-down approach, a researcher analyzes aggregate data to characterize electricity demand as a function of economic, demographic, dwelling, and climate variables. For instance, Blázquez et al. (2013) conduct province-level panel data analysis in Spain and report that electricity demand is price-inelastic but-income elastic. Henceforth, it is expected that energy demand will increase with future income growth. With the bottom-up approach, data are collected through household surveys. Since information on socioeconomic conditions and the ownership of appliances of each household is captured through the survey, household behavior can be studied more precisely with the bottom-up approach.

Some studies compare top-down and bottom-up approaches and discuss their strengths and weaknesses (Swan and Ugursal, 2009); yet other studies combine these two approaches (Jaccard and Baille, 1996; Druckman and Jackson, 2008; Wiesmann et al., 2011) to compensate for these inherent weaknesses.

Within the bottom-up approach, three methods have been used to estimate the energy consumption of individual appliances (Newsham and Donnelly, 2013).[2] The first method uses sub-metering, where the electricity consumption of each appliance can be measured by installing an energy meter. For instance, in the project named the Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe (REMODECE, 2008), the electricity consumption of 1300 households from 12 representative European Union countries was metered. de Almeida et al. (2011) analyze REMODECE data and estimate that the electricity consumption of the residential sector could be reduced by 48%, simply by using existing technologies and improving energy-consumption behavior. However, such metering analyses are relatively uncommon, given their high implementation costs.

The second bottom-up approach uses the engineering method (EM). The energy consumption of each appliance is estimated based on its rating or characteristics (Swan and Ugursal, 2009). The most attractive feature of EM is perhaps its model flexibility, as a researcher can apply EM to undertake an impact assessment of new technologies. Nevertheless, a pattern of appliance usage must be assumed prior to estimation. Making reasonable assumptions about appliance usage often becomes a cumbersome task, since households are heterogeneous.

The third bottom-up approach uses conditional demand analysis (CDA), which we use in the current study. CDA is a regression-based analysis, and it is used to estimate the electricity consumption of households as a function of (i.e., conditional on) appliance holdings and socioeconomic variables. With the application of CDA, a researcher can break down total household electricity consumption into its constituent end-use components.

CDA was first developed by Parti and Parti (1980). By analyzing the electricity billing records of more than 5000 individual households in San Diego, they disaggregated the total household electricity into a set of component demand functions for electricity usage, into 16 appliance categories. Aigner et al. (1984) applied CDA to estimate electricity hourly loads for appliances in Los Angeles, while LaFrance and Perron (1994) applied CDA to identify the factors that led to reduced residential energy consumption in Quebec in 1980s.

In more recent years, Leahy and Lyons (2010) apply CDA to pinpoint the factors that affect residential energy consumption in Ireland; they report that vacuum cleaners, tumble dryers, dishwashers, and deep freezers increase households' electricity consumption. Newsham and Donnelly (2013) apply CDA to analyze annual energy consumption among Canadian households; they estimate that energy savings can be achieved by making appliance upgrades.

Some researchers have adopted EM and CDA simultaneously. For instance, Larsen and Nesbakken (2004) use both EM (named ERÅD) and CDA to analyze residential electricity consumption in Norway; they report that the drawbacks of ERÅD are serious, and they recommend improvements to CDA for use in future analysis. Other scholars–such as Bartels and Fiebig (1990), Hsiao et al. (1995), and Bartels and Fiebig (2000)—include metering data from specific households to improve the accuracy of CDA.

Compared to EM-based models, CDA-based models lack model flexibility. However, CDA requires less-detailed data about appliance usage. Furthermore, when a large dataset is available, the effects of socioeconomic factors on appliance usage can be estimated through the use of CDA. Considering the characteristics of our dataset, we choose in this study to use CDA models.

[2] Scholars such as Aydinalp et al. (2002, 2003) propose residential energy consumption models based on a neural network (NN) framework. NN models are simplified mathematical models of a biological neural network; they are highly suitable for determining causal relationships amongst a large number of parameters, such as those seen in energy-consumption patterns in the residential sector (Aydinalp-Koksal and Ugursal, 2008). However, applications of NN remain very limited.