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Electric Appliance Ownership and Usage: Application of Conditional Demand Analysis to Japanese Household Data

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Abstract

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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 13 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.

Keywords: Appliance Usage; Conditional Demand Analysis; Micro-level Data

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, Fuertes, and Lomas (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, we believe that previous studies bear several limitations. In any case, although both appliance ownership and usage affect residential electricity demand, the literature on appliance usage itself is scarce **(Leahy, Lyons, and Walsh, 2012)**.

Household demographic characteristics influence 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. Nonetheless, we do not know how much electricity is used in cleaning the laundry of additional family members or in cleaning extra dishes, for example.

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.

Although all studies report income as one of the most important determinants of household electric consumption, they do not distinguish types of income. Pension income among elderly people may affect appliance usage so as to differentiate them from salaried workers. Similarly, a husband's income may affect appliance usage in ways different from a wife's income.

The purpose of this study is to examine 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)**.

Most research on residential electricity demand has been conducted in either North America or Europe; research outside these two regions is limited. **Filippini and Pachauri (2004)** study electricity demand in urban Indian households and find that electricity demand is income and price-inelastic. Similarly, **Zhou and Teng (2013)** study electricity demand in China's Sichuan province and obtain similar findings; additionally, they confirm that socioeconomic, dwelling, and appliance factors greatly affect energy consumption. **Genjo et al. (2005)** study the effects of appliance ownership on electricity consumption in Japanese households and find that annual income and the number and size of some appliances all have a large impact on annual electric consumption. Although these studies report important empirical findings, further research is necessary if we are to understand residential electricity demand outside of North America and Europe, since people in those regions have lifestyles very different from those who live elsewhere.

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 conducts a regression analysis to characterize electricity demand as a function of economic, demographic, dwelling, and climate variables. For instance, **Blázquez, Boogen, and Filippini (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)**.[1] The first method uses submetering, 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 1,300 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

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[1] Scholars such as **Aydinalp, Ugursal, and Fung (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 and Ugursal, 2008)**. However, applications of NN remain very limited.

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 5,000 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, Sorooshian, and Kerwin (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 ERǺD) and CDA to analyze residential electricity consumption in Norway; they report that the drawbacks of ERǺD are serious, and they recommend improvements to CDA for use in future analysis. Other scholars—such as **Bartels and Fiebig (1990)**, **Hsiao, Moutain, and Illman (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. Data

The primary data source of this study is Japan's NSFE 2004. The NSFE is a nationwide survey that was initiated in 1959, and it is conducted every five years. Although the most recent survey was completed in 2014, neither the 2009 nor 2014 data are publicly available at present. Therefore, this study makes use of the 2004 data.

The NSFE dataset includes detailed information about household revenue, expenditures, deposits, loans, and ownership of durables. The NSFE 2004 survey was conducted from September to November, in 458 municipalities selected as a research area. The total number of households captured in the survey was 59,374; this number comprises 5,002 single-person households and 54,372 multi-person households (i.e., containing more than one person). We excluded those households lacking data vis-à-vis electricity usage, income, and appliance ownership, and we ultimately derived a final dataset containing 41,676 households.

Unfortunately, the NSFE data pose three major drawbacks. First, the data do not contain detailed housing location information; they report only whether or not a house is located in one of three major metropolitan areas (Tokyo, Nagoya, or Kansai). As a consequence, we cannot evaluate the impact of weather conditions on appliance usage. Second, the data do not report the electricity consumption (in kWh) of households; rather, it reports on monthly electricity bills. We calculate the monthly electricity consumption from the monthly electricity bill; nonetheless, this calculation contains measurement errors, since the price of electricity varies across regions and depends on the type of electricity contract held by the household. Finally, the NSFE's sampling period is limited to between September and November. Since this is a period with moderate temperatures, we will consequently underestimate electricity used for space heating and cooling.

Figure 1 Near Here

Considering our dataset's limitations, we focus on the electricity consumption of 16,643 households living in metropolitan areas. Figure 1 shows the mean daily temperature of three major metropolitan cities (Tokyo, Nagoya, and Osaka) in 2004. We expect that many households used air conditioners (ACs) for space cooling in September, and that some used ACs for space heating in November.[2] The figure indicates that there is only a minor temperature difference across the three metropolitan cities; therefore, we assume that AC usage does not substantially differ among these three metropolitan areas.

Table 1 Near Here

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[2] The majority of ACs sold in Japan have space-heating functions **(Morita, Matsumoto, and Tasaki, 2014)**.

Table 1 compares the electricity pricing scheme across three metropolitan areas. The electricity in Tokyo, Nagoya, and Osaka are provided by Tokyo Electric Power Company (TEPCO), Chubu Electric Power Company (CEPCO), and Kansai Electric Power Company (KEPCO), respectively. All three companies used three-stage block-pricing schemes.[3] The table further shows that price differences across the three electric power companies are minor. Japan imports almost all natural resources, and all electric-power companies must obtain approval from the Minister of Economy, Trade, and Industry before it can change its electricity price. Therefore, these companies' "herd behavior" is observed in the price-setting process.

Figures 2a and 2b Near HERE

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[3] In the Tokyo and Nagoya regions, the basic charge increases as the amperes contracted increases. The basic charge in Table 1 is assumed to be 20 amperes, which may be sufficient for a single-person household but insufficient for a multi-person household. By taking account of the floor area of dwellings, in the following analysis we will control for differences in basic charges.

We use the electricity price of TEPCO to calculate the monthly electricity consumption of each household. Figure 2a is a histogram of electricity consumption among single-person households, while Figure 2b is one of that among multi-person households. The monthly electricity consumption of the average single-person household is 200.85 kWh, while that of the average multi-person household is 440.71 kWh. A comparison of the two figures suggests that the distribution of multi-person households has a tail longer than that of the single-person household distribution.

The NSFE asks about the ownership of 21 different electric appliances. We estimate the electricity consumption of 12 major appliances: ACs, televisions (TVs), personal computers (PCs), washing machines, microwaves, dishwashers, refrigerators, warm water bidets, rice cookers, cellular phones, vacuum cleaners, and solar water heaters.[4] Since refrigerators are classified into two sizes—namely, small (capacity < 300 L) and large (capacity ≥ 300 L)—we treat small and large refrigerators separately. On the

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[4] Although the survey classifies TVs into four types (plasma TVs, liquid-crystal TVs, color TVs whose screen size is larger than 24 inches, and color TVs whose screen size is smaller than 24 inches), the current study does not distinguish TV type.

other hand, we aggregate the remaining nine minor appliances and estimate their electricity consumption jointly.

Table 2 Near HERE

Table 2 summarizes the ownership of appliances among the study sample. The table clearly shows that multi-person households own more appliances than single-households. The average household has more than two ACs and two TVs at home, while most households have one washing machine and one microwave. Dishwashers and solar water heaters are still less common among Japanese households than in Western countries.

At the bottom of Table 2, we report on household characteristics. The monthly electricity consumption of the average single-person household is 200.85 kWh, while that of the average multi-person household is 440.74 kWh. The table shows that detached wood houses are the most popular housing type among multi-person households. The average floor area of the dwellings is 106.32 m^2.

The average number of household members is 3.06, with the average number of teenagers (aged 10–19) being 0.36. In the subsequent analysis, we broke down household income into labor and nonlabor income, to evaluate their individual impacts on electricity demand. (This study defines "nonlabor income" as the money that remains after subtracting the family members' earned incomes from the household's regular monthly income.)

If retired persons are included in the dataset, the average labor income becomes JPY295,700 (USD2,464);[5] the average nonlabor income becomes JPY49,400 (USD387). If only households with positive labor income (i.e., working families) are included in the dataset, then the average labor and nonlabor incomes become JPY449,600 (USD3,747) and JPY27,900 (USD233), respectively. When focusing on multi-person households, the average husband's income is JPY366,100 (USD3,051), while the average wife's income is JPY50,800 (USD423).

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[5] Throughout this study, we assume an exchange rate of USD1 = JPY120.

3. Model

Although both appliance ownership and usage influence residential electricity consumption, information on appliance usage is not available from the dataset. In this study, we attempt to explain differences in appliance usage in terms of households' socioeconomic characteristics.

Both the demand for appliances and their usage involve related decisions made by households; for this reason, the simple inclusion of appliance ownership and socioeconomic variables in the electricity demand equation will lead to biased and inconsistent estimates **(Dubin and McFadden, 1984)**. One approach in resolving this simultaneity problem is to find an instrument variable (IV) that influences the purchase decision but not the usage decision. However, to apply the IV approach, we need to pinpoint one valid IV for each appliance. A typical household owns a variety of appliances at home, and thus the IV approach is practically infeasible. Therefore, we adopt in this study the CDA proposed by **Larsen and Nesbakken (2004)**.

We denote y_{hik} as the monthly electricity consumption that household h uses for the k^{th} appliance i. We then formulate the following appliance-usage equation:

$$y_{hik} = \alpha_i + \beta_i I_{hik} + \sum_{m=1}^{M} \gamma_{im}(C_{hm} - \bar{C}_{iLm}) + \varepsilon_{hik}, \quad (1)$$

where I_{hik} is an index variable that takes the value 1 for an appliance purchased more than five years previous. Thus, the parameter α_i measures the electricity required for a new appliance i and the parameter β_i measures the vintage effect of an old appliance i.[6]

We classify households owning L units of appliances i into Group L and compare the intensity of the use of appliance i within Group L. For instance, we classify households owning one microwave and examine whether the number of household members affects electricity consumption for the microwave.

The variable C_{hm} in Equation 1 is the m^{th} socioeconomic characteristic of household h, while $\bar{C}_{iLm}$ is the mean characteristic of households in Group L. Therefore, the first two terms in Equation 1 together represent the electricity consumption of the household possessing the mean characteristics of Group L, while the third term represents the adjustment to appliance usage on account of the socioeconomic variables. The parameter γ_{im} measures the effect of the m^{th} socioeconomic characteristic on the use of appliance i. For instance, given the presence of two ACs, we can examine whether high-income households use each AC more

[6] The electricity required for an old appliance i is estimated to be $\alpha_i + \beta_i$.

intensively than low-income households use theirs. The estimation of the parameter γ_{im} is the main task of this study. Finally, we assume that the last term, ε_{hik}, is an independent and identically distributed error.

Suppose that households own at most K units of appliances i at home. Then, the total electricity consumption for appliance i is

$$y_{hi} = \sum_{k=1}^{K} y_{hik} D_{hik}$$

$$= \sum_{k=1}^{K}(\alpha_i + \beta_i I_{hik}) D_{hik} + \sum_{k=1}^{K} \sum_{m=1}^{M} \gamma_{im}(C_{hm} - \bar{C}_{iLm})\, D_{hik} + \omega_{hi}, \qquad (2)$$

where D_{hik} is a dummy variable that with a value of 0 or 1 indicates whether household h owns the k^{th} appliance j and $\sum_{k=1}^{K} \varepsilon_{hik} D_{hik} \equiv \omega_{hj}$.

We assume that there are N varieties of appliances. Then, the total electricity consumption of household h becomes

$$y_h = \sum_{i=1}^{N} y_{hj} D_{hi}$$

$$= \sum_{i=1}^{N} \sum_{k=1}^{K}(\alpha_i + \beta_i I_{hik}) D_{hik}\, D_{hi} + \sum_{i=1}^{N} \sum_{k=1}^{K} \sum_{m=1}^{M} \gamma_{im}(C_{hm} - \bar{C}_{iLm})\, D_{hik}\, D_{hi}$$

$$+\tau + \mu_h, \qquad (3)$$

where D_{hi} is a dummy variable that with a value of 0 or 1 indicates whether household h owns any appliance i and $\sum_{i=1}^{n} \omega_{hj} D_{hi} \equiv \tau + \mu_h$. The parameter τ is the electricity consumption associated with appliances that are not included in the model, and the error term μ_h varies across households. We will estimate Equation 3 in the following empirical analysis.

Using the estimated parameters—namely, $\hat{\alpha}_i$, $\hat{\beta}_i$, $\hat{\gamma}_{im}$, and $\hat{\tau}$—in Equation 3, we can calculate household h' s expected electricity consumption for appliance i:

$$E[y_{hi}] = \begin{cases} 0 & L = 0 \\ L\hat{\alpha}_i + \sum_{k=1}^{L} \hat{\beta}_i I_{hik} + L(\sum_{m=1}^{M} \hat{\gamma}_{im}(C_{hm} - \bar{C}_{iLm})) & L > 0. \end{cases} \quad (4)$$

It is assumed that the effect of socioeconomic characteristics on appliance usage is the same for all L appliances.

The average electricity consumption of appliance i is

$$\hat{y}_i = \sum_{L=0}^{K} S_L L\left(\hat{\alpha}_i + s_L^{\beta} \hat{\beta}_i\right), \quad (5)$$

where S_L is the share of households owing L units of appliance i and s_L^{β} is the share of old appliances in Group L. The socioeconomic impact on appliance usage is averaged out.

4. Results

Table 3 presents the results of our residential electricity consumption analysis. Model 1 is the model that includes only appliance ownership variables (i.e., $\gamma_{im} = 0$ is assumed for $i = 1, \cdots, N$ and $m = 1, \cdots, M$). It is expected that the size of the variance increases with the number of appliances owned. To overcome the heteroscedasticity problem, we estimate a weighted least-square model that uses the number of appliances as a weight variable.

Table 3 NEAR HERE

Except for microwaves and solar water heaters, we obtain positive signs for appliance ownership; hence, households owning more appliances consume more electricity. A solar water heater reduces the electricity demand related to water-heating, and thus we expect a minus sign for it. A negative sign is obtained for microwaves, as Model 1 does not take into account intensity of usage, as we will show below. Most households living in metropolitan areas own only one washing machine; therefore, as in previous CDA studies, the washing machine variable does not become statistically significant.

It would be better to examine the validity of the estimation results before starting appliance usage analysis. As expected, we find that a refrigerator consumes the largest amount of electricity. We believe that a refrigerator is the most suitable appliance by which to examine the validity of the estimation, since the usage varies only slightly across households. According to our estimation, a small new refrigerator (i.e., capacity < 300 L) consumes 52.353 kWh of electricity per month, while a large new refrigerator (capacity > 300 L) consumes 61.127 kWh. The **Ministry of the Environment of Japan (2008)** provides a database of appliance electricity usage called *Shinkyusan*. According to this database, the monthly electricity consumption of refrigerators with a 101–300-L capacity sold in 2001 ranged from 35.8 to 65.0 kWh, while that with a 351–550-L capacity ranged from 48.3 to 75.0 kWh. Thus, we consider our estimation results reasonable.

We also find that households consume large amounts of electricity on ACs, dishwashers, and cellular phones. Specifically, we find that each month, a typical household consumes 19.182 kWh on an AC, 30.236 kWh on a dishwasher, and

39.293 kWh on a cellular phone. Since the ownership rates of these appliances have been steadily increasing since the survey year **(Cabinet Office, Government of Japan, 2015)**, we expect that households have consumed larger volumes of electricity in more recent years.

The NSFE survey captured data on the vintage of several appliances. The data in Table 3 indicate that the rate of electricity consumption among new refrigerators is lower than that among old ones; this result implies that the replacement of old refrigerators leads to a reduction in residential electricity consumption. While an old and large refrigerator consumes 78.298 kWh of electricity per month, a new one consumes only 61.127 kWh.[7] This electricity saving of 17.171 kWh per month corresponds to a monetary saving of JPY380 (USD3). Similarly, an old AC consumes 22.527 kWh of electricity per month, but a new AC consumes only 19.182 kWh; this monthly saving in terms of an electricity bill is about JPY74 (USD0.62).

However, unlike with refrigerators and ACs, the electricity consumption of old PCs is lower than that of new ones. Although the energy efficiency of new PCs is higher

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[7] Thus, we estimate that $\alpha = 78.298$ and $\beta = 17.171$ for large refrigerators, while $\alpha = 22.527$ and $\beta = 3.345$ for ACs.

than that of old ones, their intensity of usage is also higher than that of old ones. This appliance usage effect dominates the energy efficiency effect, and thus we obtain an initially counter-intuitive result. We find a similar result for TVs.

Although both appliance ownership and usage affect residential electricity consumption, detailed information on appliance usage is not available in the survey dataset. Here, we attempt to explain intensity of appliance usage in terms of variations in the socioeconomic characteristics of households. Specifically, we examine whether the number of household members, the presence of teenagers, and income level determine appliance usage. Model 2 in Table 3 shows the impact of these socioeconomic variables on appliance usage. The adjusted R^2 of Model 2 is higher than that of Model 1; hence, the inclusion of socioeconomic variables improves the explanatory power of the empirical model.

The number of household members becomes positive and statistically significant for TVs, washing machines, and microwaves; this suggests that the intensity of usage of these appliances increases as the number of household members increases. In Model 2, we estimate that 5.502 kWh of electricity is required per month for the laundry of one additional family member. Additionally, one average person uses 19.878 kWh of electricity per month in powering a microwave. In contrast, we find that the intensity of the use of dishwashers decreases as the number of family members increases.

Previous studies—such as that of **Jones, Fuertes, and Lomas (2015)**—report that the presence of teenagers increases household electricity consumption. In the present analysis, we find that the presence of teenagers (aged 10–19) increases the intensity of AC and dishwasher usage: a teenager eats a lot of food and prefers cooler temperatures at home. This result is consistent with that of **Brenčič and Young (2009)**, who find that households with many family members under the age of 18 tend to allocate more time to home production.

We obtain interesting results regarding the income variables. Model 2 shows that higher-income households use ACs less frequently. There are two possible explanations for this finding. The first explanation is as follows. Family members in a low-income household tend to share an AC in a common living room, while family members in a high-income household use personal ACs in their own private rooms. Although each member in a high-income household uses an AC less intensively, the aggregated household electricity consumption turns out to be larger, as multiple ACs are used concurrently. The second explanation is simple: high-income earners tend to spend less time at home, and they consequently use less electricity.

Model 2 also shows that the effect of nonlabor income on AC usage is larger than that of labor income. We find that increased labor income reduces microwave usage, but that nonlabor income has not effect. Dishwasher usage increases with both labor and nonlabor income.

In Model 3, we examine whether the effect of the husband's income on appliance usage differs from that of the wife's income. For obvious reasons, we use only the data of multi-person households, and we compare the income effect between husbands and wives. With regard to AC usage, the variable of the wife's income becomes negative and statistically significant, while the variable of the husband's income becomes negative but statistically insignificant. Furthermore, the coefficient of the wife's income is larger than that of the husband's income; this result probably suggests that a high-income wife spends less time at home and thus uses ACs less than stay-at-home wives or those who work part time. We also find that an increase in the husband's income reduces microwave usage, while an increase in the wife's income increases it. There are some plausible explanations for this: when the husband's income increases, a family eats out more frequently, and when wives are busy earning more money, they rely on microwaves to cook food at home.

Thus far, to reduce the measurement error in electricity consumption, we have used only data from households in three metropolitan areas. For Model 4, we add data from households outside the metropolitan areas and estimate Equation 3 to reconfirm general tendencies vis-à-vis appliance usage. Table 3 shows how the estimation results of the explanatory variables did not change overly much between Models 3 and 4. Although most households living in the metropolitan areas own only one washing machine, some households outside the metropolitan areas own multiple washing machines. Since variation in ownership increased in Model 4, the washing machine variable becomes statistically significant.

Table 4 NEAR HERE

Table 4 summarizes the estimation results with regard to the electricity consumption of 12 appliances.[8] For this calculation, we use the parameter α_i of new appliances. As previously mentioned, of all the appliances in a household, the refrigerator is the appliance that consumes the greatest amount of electricity. According to our estimation, the average household spends JPY12,356–16,277 (USD103–136) each year on electricity to power a new large refrigerator. On the other hand, the average household spends JPY3,338 (USD28) each year on electricity to power a washing machine. However, as one additional member joins a family, JPY2,835.86 (USD24) of electricity is used for to wash laundry. Indeed, the effect of the presence of teenagers (aged 10–19) is nonnegligible: if there is a teenager in the household, each year the household will need to pay JPY502–753 (USD4–6) for extra AC use and JPY1,953–2,689 (USD16–22) for extra dishwasher use.

We use Equation 5 and calculate the electricity that those households with average characteristics consumed to make use of a specific appliance. We then divide that value by the total electricity consumption of the average household in order to estimate the share of electricity usage for the specific appliance. In this estimation, we use the

[8] We removed the microwave variable, as it does not become statistically significant.

parameter values in Model 2 and take account of the size and vintage of appliances that the households own.

The last column of Table 4 shows the share of electricity consumption of each of 11 appliances. It reports that 18.83% of an average household's electricity consumption relates to preserving food in a refrigerator, and 13.28% relates to space cooling and heating. Although a dishwasher is an energy-intensive appliance, only a small fraction of the sample owns one; for this reason, the average share of electricity consumption for dishwasher usage is only 1.35%. Additionally, we find that the aggregate share of the 11 appliances accounts for 64.26% the average household's total electricity consumption.

Figures 3a, 3b, 3c, and 3d Near HERE

With the application of Equation 4, we can estimate the electricity consumption of each appliance. Figures 3a–3d compare the estimated expenditure for AC usage across four income classes. As discussed, high-income households tend to own more appliances, but use them less intensively than lower-income households. The figures simultaneously take into account ownership and usage effects. The average electricity expenditure for AC usage increases from Figure 3a to Figure 3d; therefore, high-income households consume more electricity for AC usage than low-income households (i.e., the ownership effect dominates the usage effect). These figures also show that the variation in AC usage among high-income households is substantially larger than that among low-income households; this is because high-income earners have more options with regard to time use.

5. Conclusion

Although both appliance ownership and usage determine residential electricity consumption, it is less known how households use their appliances at home. In this study, we analyzed micro-level data from the Nation Survey of Family and Expenditure (NSFE) in Japan and examined whether households' socioeconomic characteristics affect appliance usage. Our empirical results show that both the family structure and economic status of households systematically determine appliance usage.

Conventional wisdom tells us that high-income households use appliances more intensively; however, we find that high-income households use specific appliances (i.e., ACs and microwaves) less intensively than low-income households. Family members in low-income households share one appliance, but those in high-income households use their own individual appliances; therefore, each appliance in high-income households is used less intensively than those in low-income households. Furthermore, high-income earners spend more time outside the home and thus use appliances less intensively. In this sense, appliance usage reflects households' time allocation.

It is often believed that the replacement of old appliances will lead to energy savings, since the energy efficiency of new appliances is higher. However, when measuring the impact of appliance replacement, we need to take into account the intensity of appliance usage, as people may use new appliances more frequently than old ones. If such a rebound effect on appliance replacement is large, then appliance replacement will actually lead to *greater* electricity consumption. The empirical results of this study suggest that the rebound effects for TVs and PCs are large.

Many countries have implemented a wide variety of policies by which to reduce electricity consumption in the residential sector. However, in terms of policy design, there has been relatively little focus on appliance usage. Different households spend time differently and thus use appliances differently. Researchers and policymakers need to understand how households' time allocation affects their appliance usage; ultimately, the effectiveness of energy-saving policies depends on it.

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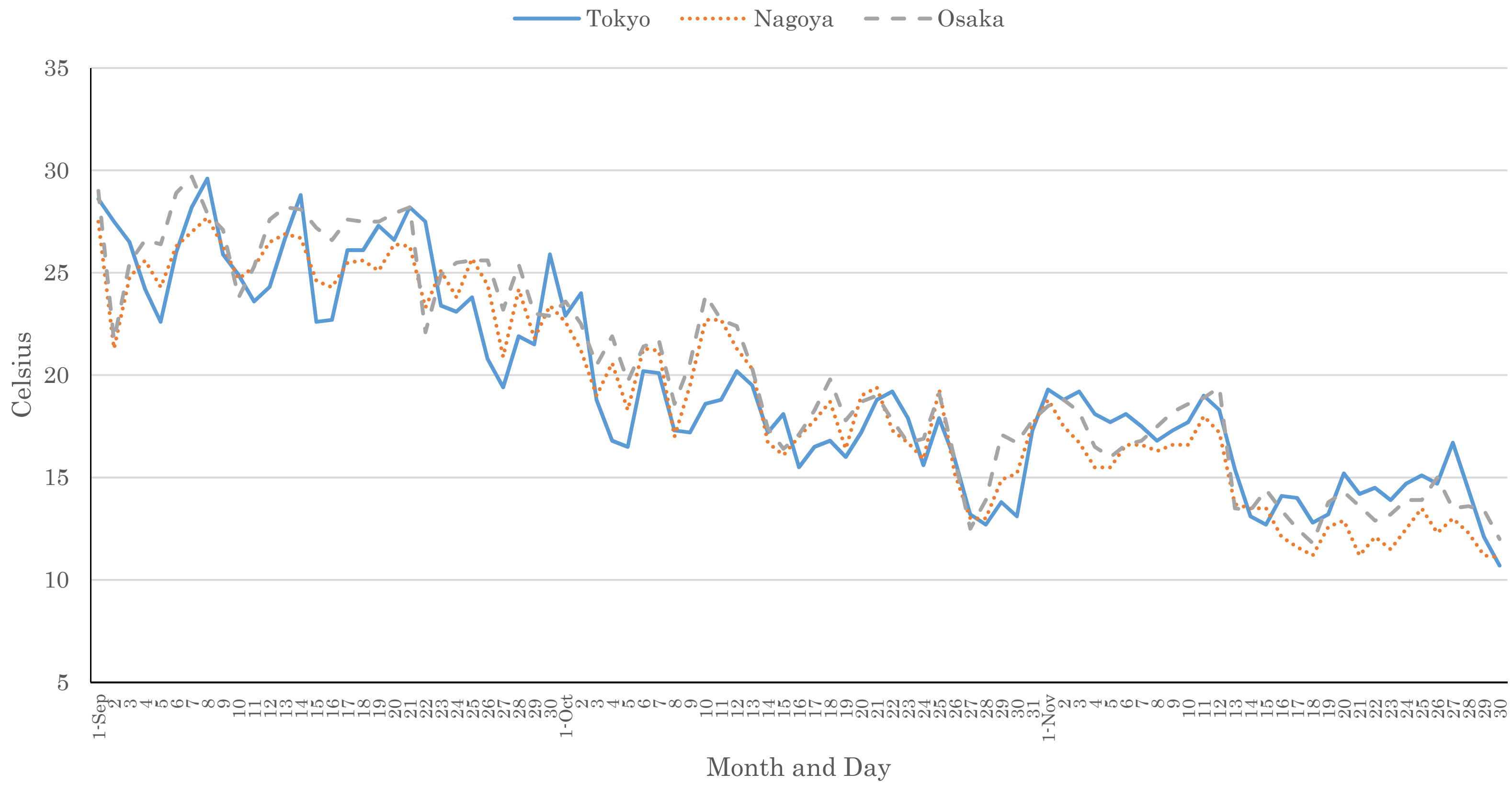
Figure 1. Daily mean temperature of three metropolitan areas in 2004



Source: Japan Meteoroidal Agency (2015)

Figure 2a. Electricity consumption of single-person households (N = 1,357)

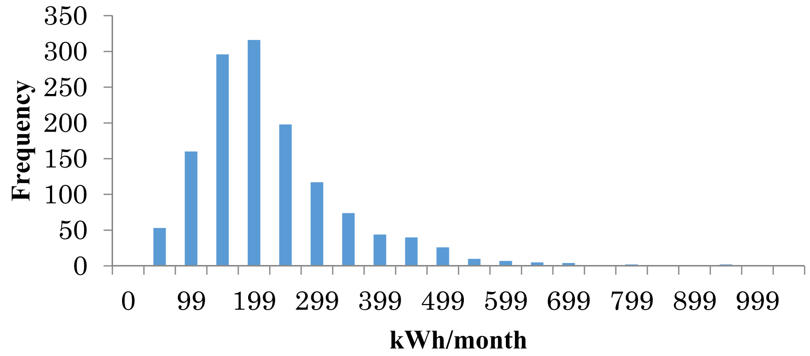


Figure 2b. Electricity consumption of multiple-person households (N = 15,286)

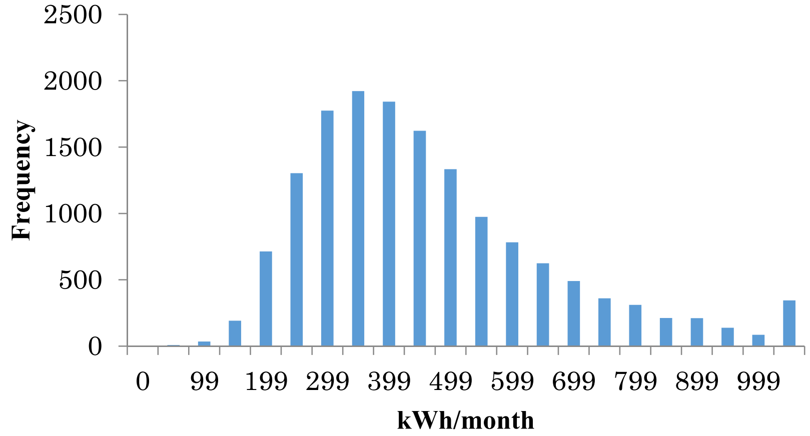


Figure 3a. Monthly electricity expenditure for AC (Income level 25%)

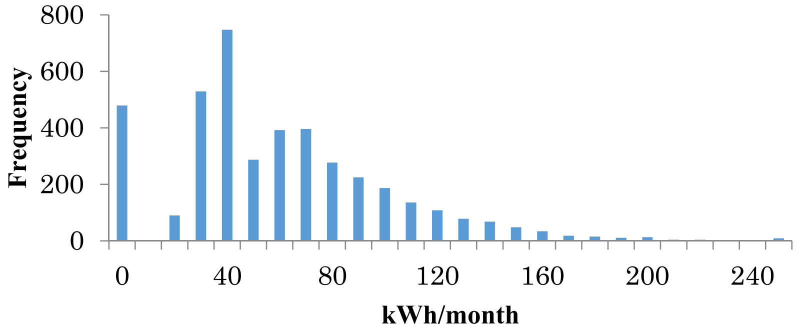


Figure 3b. Monthly electricity expenditure for AC (Income level 25–50%)

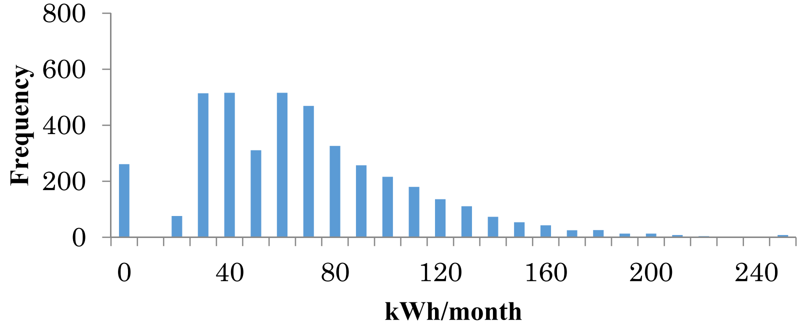


Figure 3c. Monthly electricity expenditure for AC (Income level 50–75%)

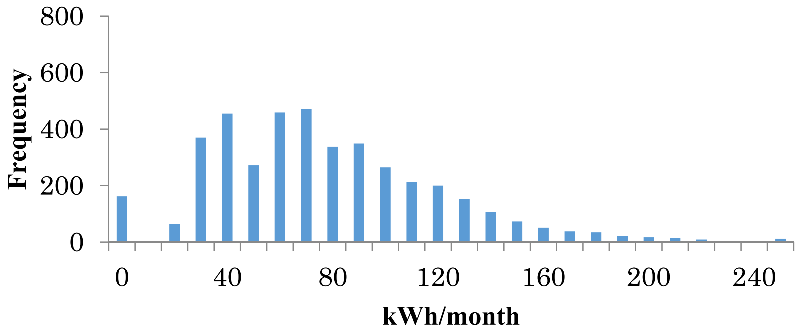


Figure 3d. Monthly electricity expenditure for AC (Income level 70–100%)

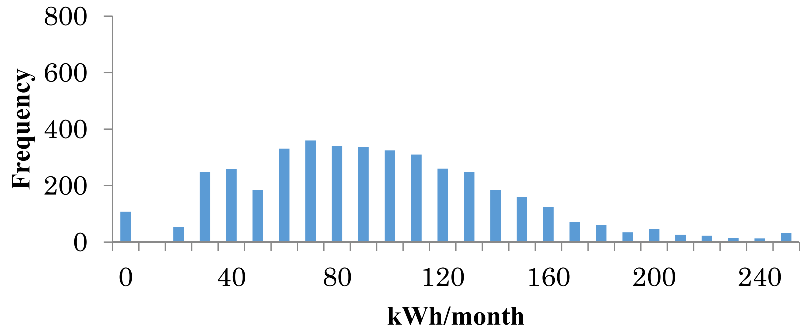


Table 1. Electricity contracts in three metropolitan areas

		Tokyo Electric Power Company (Type B contract[a], 20 amperes[b])	Chubu Electric Power Company (Type B contract[a], 20 amperes[b])		Kanai Electric Power Company (Type A contract[a], 6 kVA)
Basic charge		546.0	546.0	< 15	307.7
	Range	Unit (JPY/kWh)	Unit (JPY/kWh)	Range	Unit (JPY/kWh)
Stage 1	–120	15.56	15.94	15–120	18.66
Stage 2	121–300	20.64	20.98	121–300	24.36
Stage 3	>300	22.19	22.87	>300	26.17
Monthly bill (350 kWh)		7,237.90	7,378.70		7,960.25

Source **Statistical Bureau, Ministry of Internal Affairs and Communications (2015b)**

Note [a] The most popular contract is chosen as the reference.

[b] 20 amperes can be a small amount for a large family.

Table 2. Descriptive statistics

Variable	Unit	All households (N = 16,643) Mean	Std. Dev.	Single-person households (N = 1,357) Mean	Std. Dev.	Multi-person households (N = 15,286) Mean	Std. Dev.
Appliance ownership							
Number of air conditioners	Unit	2.62	1.66	1.30	1.34	2.74	1.64
Number of televisions	Unit	2.18	1.24	1.34	0.79	2.25	1.25
Number of personal computers	Unit	1.08	0.98	0.60	0.83	1.12	0.98
Number of washing machine	Unit	1.05	0.33	0.80	0.42	1.07	0.31
Number of microwaves	Unit	1.02	0.30	0.83	0.42	1.04	0.29
Number of dishwasher	Unit	0.20	0.41	0.05	0.22	0.21	0.42
Number of small refrigerators (<300 L)	Unit	0.41	0.59	0.64	0.52	0.39	0.59
Number of large refrigerators (>300 L)	Unit	0.80	0.51	0.37	0.51	0.84	0.49
Warm water bidet	Unit	0.74	0.70	0.35	0.55	0.78	0.70
Rice cooker	Unit	0.92	0.48	0.68	0.54	0.94	0.47
Cellular phones	Unit	1.82	1.20	0.67	0.56	1.92	1.19
Vacuum cleaners	Unit	1.41	0.66	1.04	0.59	1.44	0.66
Solar water heater	Unit	0.06	0.25	0.02	0.16	0.07	0.25
Other appliance							
Household characteristics							
Electricity use	kWh/month	421.15	219.55	200.85	122.11	440.71	215.57
Floor area	m^2	102.76	47.46	62.65	46.62	106.32	45.87
Wood house	Share	0.63		0.48		0.65	

Table 2. (Continued)

Variable	Unit	All households Mean	All households Std. Dev.	Single-person households Mean	Single-person households Std. Dev.	Multi-person households Mean	Multi-person households Std. Dev.
Detached house	Share	0.67		0.37		0.69	
Number of household members	Persons	3.06	1.27	1	-	3.24	1.15
Number of teenagers (aged 10–19)	Persons	0.35	0.71	0	-	0.38	0.73
Labor income	JPY10,000	29.57	28.59	14.82	16.96	30.88	29.04
Nonlabor income	JPY10,000	4.94	8.65	6.53	9.01	4.80	8.60
Husband's income	JPY10,000	-	-	-	-	24.54	25.07
Wife's income	JPY10,000	-	-	-	-	3.41	8.65
Households with positive labor income only		(N = 10,946)		(N = 701)		(N = 10,245)	
Labor income	JPY10,000	44.96	23.47	28.69	12.60	46.08	23.63
Nonlabor income	JPY10,000	2.79	6.45	0.99	3.86	2.91	6.57
Husband's income	JPY10,000	-	-	-	-	36.61	22.26
Wife's income	JPY10,000	-	-	-	-	5.08	10.15

Table 3. Electricity consumption analysis (Unit: kWh/month)

	Model 1		Model 2		Model 3		Model 4	
Number of records	16,643		16,643		15,286		38,427	
Constant	27.014	***	49.388	***	55.452	***	90.809	***
Floor area	0.091	***	0.083	***	0.084	***	0.085	***
Refrigerator								
Small size (<300 L)								
# New model	52.353	***	52.787	***	54.639	***	46.405	***
# Old model	66.467	***	64.730	***	66.286	***	54.670	***
Large size (>300 L)								
# New model	61.127	***	58.133	***	57.875	***	48.161	***
# Old model	78.298	***	73.762	***	73.574	***	66.820	***
Air conditioner								
# New model	19.182	***	28.996	***	30.284	***	26.833	***
# Old model	22.527	***	32.978	***	34.219	***	33.013	***
Persons			−3.704		−4.855	*	−1.877	
Teens			1.885	***	2.655	***	2.827	***
Labor income			−0.076	***				
Husband’s income					−0.020		−0.042	*
Wife’s income					−0.393	***	−0.191	***
Nonlabor income			−0.333	***	−0.271	***	−0.250	***
Wood			−1.185		−1.276		−0.706	
Detached			−3.910	**	−3.541	**	−1.872	
Television								
# New model	19.300	***	21.912	***	21.393	***	17.710	***
# Old model	14.838	***	17.628	***	17.282	***	13.862	***
Persons			3.446	*	3.315	*	2.236	**
Personal computer								
# New model	12.806	***	15.391	***	16.294	***	13.956	***
# Old model	11.029	***	14.180	***	15.156	***	11.891	***
Persons			1.262		2.028		1.531	

Table 3. (Continued) (Unit: kWh/month)

	Model 1		Model 2		Model 3		Model 4	
Washing machine								
New model	8.234	*	2.662		1.939		12.536	***
Old model	6.984		3.010		1.917		11.376	***
Persons			5.502	**	6.548	**	10.650	***
Microwave								
Model	-3.752		9.017	*	10.146	*	−4.137	
Persons			19.878	***	16.905	***	10.838	***
Labor income			-0.190	**				
Husband's income					−0.402	***	−0.442	***
Wife's income					0.897	***	0.035	
Nonlabor income			0.210		−0.041		−0.011	
Dishwasher								
# Dishwasher	30.236	***	28.117	***	27.558	***	33.857	***
Persons			−7.489	**	−4.363		−5.545	***
Teens			10.099	**	8.760	*	7.335	**
Labor income			0.217	**				
Husband's income					0.151		−0.038	
Wife's income					0.041		0.439	**
Nonlabor income			0.992	**	0.896	**	0.207	
Other appliances								
# Warm water bidet	10.888	***	11.947	***	11.246	***	14.457	***
# Rice cooker	7.213	**	8.388	***	7.320	**	4.435	**
# Cellular phone	39.293	***	23.462	***	22.777	***	20.631	***
# Vacuum cleaner	5.464	**	8.858	***	9.873	***	4.632	***
# Solar water heater	−13.428	**	−17.145	***	−18.732	***	−6.975	**
# Other appliances	1.255	**	0.253		−0.024		−1.293	***
Adjusted R^2	0.404		0.428		0.400		0.403	

Note *, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table 4. Annual electricity consumption (New appliance)

		Minimum			Maximum		Share
Appliances	kWh/year [a]	JPY/year [a]	USD/year [a]	kWh/year [a]	JPY/year [a]	USD/year [a]	
Large refrigerator (>300 L)	577.93	12,824.26	106.87	733.52	16,276.76	135.64	18.83%
Small refrigerator (<300 L)	556.86	12,356.62	102.97	655.67	14,549.38	121.24	
Dishwasher	330.69	7,338.01	61.15	406.29	9,015.55	75.13	1.35%
Cellular phone	247.57	5,493.62	45.78	471.52	10,463.02	87.19	10.11%
Air conditioner	230.18	5,107.65	42.56	363.40	8,063.92	67.20	13.28%
Television	212.52	4,715.93	39.30	262.95	5,834.78	48.62	8.48%
Personal computer	153.68	3,410.06	28.42	195.53	4,338.82	36.16	3.14%
Warm water bidet	130.65	2,899.23	24.16	173.48	3,849.58	32.08	2.11%
Vacuum cleaner	55.59	1,233.49	10.28	118.47	2,628.86	21.91	2.44%
Rice cooker	53.22	1,180.97	9.84	100.65	2,233.45	18.61	1.83%
Washing machine [c]				150.44	3,338.17	27.82	2.95%
Solar water heater	−224.78	−4,987.88	−41.57	−83.70	−1,857.31	−15.48	−0.26%

Note [a] Data pertaining to new appliances are used in the calculation. The price of electricity is assumed to be JPY22.19 (USD0.18)/kWh.

[b] The electricity used for a specific appliance service is divided by the total electricity consumption of the average household.

[c] The variable is significant only in Model 4.