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Did improvement of home appliance energy efficiency lead to a reduction of household electricity consumption? Experience from the Japanese Top Runner Program

INOUE NOZOMU† (Ph.D.Candidate,Aoyama Gakuin University)
MATSUMOTO SHIGERU‡ (Faculty of Economics, Aoyama Gakuin University)

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† Room 1160,Build.11,4-4-25 Shibuya,Shibuya-ku,Tokyo,Japan 150-8366
(*d2215001@aoyama.jp*)
‡ Room 828,Build.8, 4-4-25 Shibuya, Shibuya-ku, Tokyo,Japan 150-8366
(*shmatsumoto@aoyamagakuin.jp*)

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INOUE, Nozomu

Ph.D. Candidate, Aoyama Gakuin University

Address: Room 1160, Build. 11, 4-4-25 Shibuya, Shibuya-ku, Tokyo, Japan 150-8366.

E-mail: d2215001@aoyama.jp

MATSUMOTO, Shigeru

Faculty of Economics, Aoyama Gakuin University

Address: Room 828, Build. 8, 4-4-25 Shibuya, Shibuya-ku, Tokyo, Japan 150-8366.

Email: shmatsumoto@aoyamagakuin.jp

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Abstract

Many countries have introduced various policies to improve the energy efficiency of home appliances. Japan introduced the Top Runner Program in 1998 to set efficiency standards for major home appliances. Although the energy efficiency of home appliances greatly improved after the implementation of the program, household electricity consumption has also increased. Using micro-level data from the National Survey of Family Income and Expenditure, we conduct conditional demand analysis to show how energy savings from the energy-saving program have been lost. We find that the average household began spending more electricity on space cooling and food preservation after the implementation of the program. Although electricity consumption per air conditioner (AC) has decreased, the number of ACs per household has increased. In contrast, electricity consumption per refrigerator (REF) has increased since households have started buying bigger REFs. Our analysis shows that the indirect rebound effect is quite sizable in household appliance usage; households use the electricity saved from the improved efficiency of home appliances almost entirely for other purposes.

Keywords: Conditional Demand Analysis; Energy Efficiency; Home Electrical Appliance; Indirect Rebound Effect; Top Runner Program

JEL Classification: D12, K32, Q41, Q48

1. Introduction

Household energy saving has been at the top of the policy agenda in many countries, and various programs have been introduced to improve the energy efficiency of the residential sector. Through the implementation of energy-saving programs, major improvements have been achieved in the efficiency of energy-consuming durables over the last several decades.

Although the size of homes and the number of appliances have been increasing, the average residential energy consumption in the United States (US) has been decreasing for the last 40 years. The US Energy Information Administration (EIA) claims that energy efficiency improvements in space heating, air conditioning, and major home appliances have led to the reduction of household energy consumption (US EIA 2012).

However, the generalization of this finding from the US requires caution because the daily energy consumption of typical US households is quite substantial compared to households in other industrialized nations. For instance, while the 2015 per capita energy consumption in the EU was 3207 kg (of oil equivalent), in the US, it was 6800 kg (World Bank 2017). Even after controlling for economic development level and weather conditions, the energy consumption of US households is still much higher than that of other countries (Nakagami et al. 2008). Based on the high energy consumption among US households, it is natural to think that US households have more options for energy saving than those in other countries.

Did energy efficiency improvement lead to the reduction of household energy consumption outside of the US? To reduce household energy consumption, will US households need to lower their dependence on home appliances in the near future? We believe it is worthwhile to examine how programs aimed at improving energy efficiency of consumer durables have worked in other energy-efficient countries.

Japan introduced the Top Runner Program in 1998 to set energy efficiency standards for various energy-consuming durables. Since the implementation of the program, the energy efficiency of home appliances has improved significantly. According to a survey by the Ministry of Economy, Trade and Industry (2007), the energy efficiencies of televisions (TVs), air conditioners (ACs), and refrigerators (REFs) improved by 25.7% (1997–2003), 67.8% (1997–2004), and 55.2% (1998–2004). Despite such energy efficiency improvements, the total electricity consumption of the average household increased from 291.2 kWh in 1995 to 304.7 kWh in 2005 (Federation of Electric Power Companies of Japan 2013). Hence, unlike in the US, the technological innovation did not lead to a reduction of household electricity consumption in Japan.

More than 150 years ago, William Stanley Jevons asserted that increased demand for a resource will occur as the result of improved efficiency in using that resource (Jevons 1865). Since then, the so-called “Jevons Paradox” has been extensively studied, mostly in terms of the “rebound effect.” More recently, in the framework of the complex theory, Giampietro and Mayumi (2005) stated that as soon as a series of “technological improvements” is introduced into a social system, more room is generated for further expansion of current levels of activity within the original option space, and an expansion of the option space occurs with the adoption of new possible categories and activities.

Khazzoom (1980) stated that improvement in appliance efficiency increases (1) utilization of that appliance, (2) stock of that appliance, and (3) utilization and stock of other appliances. If the magnitudes of these direct and indirect rebound effects are large enough, the energy savings obtained through the technological innovation can be lost entirely. The experience of the Top Runner Program in Japan suggests that the rebound effect is sizable enough to completely offset the energy savings obtained through significant technological improvement. The purpose of this paper is to show how the energy savings obtained from the Top Runner Program have been lost in Japan. We think that the message from this study is important for countries aiming at energy conservation in the residential sector through technological innovation.

The rest of the paper is organized as follows. In the next section, we review studies that investigated the rebound effect of home appliances. In Section 3, we explain conditional demand analysis (CDA) as developed by Parti and Parti (1980). CDA is a statistical technique for estimating the energy consumption of each appliance by combining survey, consumption, and weather data. In this study, we use micro-level data from the National Survey of Family Income and Expenditure (NSFE) in Japan (Statistical Bureau of Japan 2004). We explain NSFE and summarize the data in Section 4. Based on CDA, we estimate electricity usage for an individual appliance in four sampling years: 1989, 1994, 1999, and 2004. By taking into account the changes in appliances ownership, we show in Section 5 how the energy savings obtained through the technological improvements based on the Top Runner Program have been lost. We conclude the paper in Section 6.

2. Literature Survey

The efficiency improvement of an energy-consuming durable lowers the “effective” price of the service it provides and consequently increases demand for that service. In addition, the efficiency improvement creates financial savings and increases demand for the services of other energy-consuming durable goods. The former effect is called the “direct” rebound effect, while the latter effect is called the “indirect” or “secondary” rebound effect. Finally, demand changes may influence the structure of the country’s economy. This last effect is called the “economy-wide” or “macro-scale” rebound effect (Sorrell and Dimitropoulos 2008).

[Direct rebound effect: Macro-level analysis]

The direct rebound effect has been extensively studied using various economic units. Using energy consumption and efficiency data from the 28 EU countries and Norway between 2000 and 2011, Galvin (2014) estimated the direct rebound effect at the macro-level. Although the rebound effect for senior EU members is 0% to 50%, for new EU members it is estimated to be much higher.

Wang et al. (2014) examined the direct rebound effect using panel data from China’s 30 provincial governments from 1996 to 2010. They estimated that the long-run (LR) rebound effect is 74%, while the short-run (SR) rebound effect is 72%.

Freire-González (2010) used household electricity consumption data from the Catalonia municipalities (Spain). He found the SR rebound effect to be 35% and the LR rebound effect 49%.

These types of macro-level analyses are useful for broadly understanding how energy efficiency is associated with energy consumption. However, they are not able to measure rebound effects precisely, since there are many technical failures that may affect energy consumption in the countries.

[Direct rebound effect: Micro-level analysis]

Many authors have conducted micro-level analysis to estimate the direct rebound effects of various energy-consuming durables including vehicles and home appliances. Below, we summarize the empirical findings about home electrical appliances since we analyze household electricity consumption in the empirical section.

In his pioneering work, Hausman (1979) analyzed air conditioner purchase data of American households and estimated the elasticity of energy service with respect to energy efficiency, which can be interpreted as an estimate of the rebound effect. He estimated the SR and LR direct rebound effects to be 4% and 26.5%, respectively.

Khazzoom (1986) used US data from a residential conservation program and found that approximately 60–70% of the initial savings were eroded by the direct rebound effect.

Dubin et al. (1986) used experimental data from the Florida Power and Light Company to examine how the installation of new energy-efficient appliances and thermal improvement changed household electricity consumption. They found that the rebound rate for space cooling was 13% during non-summer months but 2% during peak summer. The rebound rate for space heating was 8–12% in winter.

[Direct rebound effect: Survey studies]

Sizable variation in the magnitude of the rebound effect has been observed in previous studies since these studies define the rebound effect differently. Several scholars examined whether the choice of research methodology affects the magnitude of the rebound effect.

Haas and Biermayr (2000) estimated the direct rebound effect for space heating in Austria using multiple data sources and multiple empirical methods. Regardless of the empirical methodology chosen, they estimated a fairly moderate direct rebound effect (20–30%).

Greening et al. (2000) reviewed the literature estimating the direct rebound effect and found it to be very low or moderate in the majority of the literature. Nadel (2012) included more recent studies in his literature survey. He reported the direct rebound effect was generally estimated to be 10% or less.

[Indirect and economy-wide rebound effects]

A macro-level analysis is necessary to fully account for both indirect and economy-wide rebound effects. Grepperud and Rasmussen (2004) used a computed general equilibrium analysis to estimate the rebound effect in Norway. Although they found a strong rebound effect for the manufacturing sector, they observed weak or very minor rebound effects for the remaining sectors, including the household sector.

Using an environmentally extended input-output model and the consumer expenditure survey for the US, Thomas and Azevedo (2013) estimated that the indirect rebound effect for primary energy was 5–15% when the direct rebound effect was assumed to be 10%.

Freire-González (2017) estimated the direct and indirect rebound effects of energy efficiency in households for the EU-27 countries (the first 27 Member States of the European Union). According to his estimation, the average value for the overall EU-27 economy is between 73.62% and 81.16% if each individual country's estimates are weighted by its GDP. However, he found that the combined direct and indirect rebound effects exceed 100% in seven countries. This result means that energy efficiency improvement could backfire in those countries.

Freire-González et al. (2017) estimated the indirect rebound effect of an efficiency improvement in electricity use in Catalonian households based on an input-output framework with Leontief production functions. Assuming that the money saved through energy efficiency improvements was reallocated to the purchase of other goods and services, they calculated the upper and lower bounds of the direct and indirect rebound effects. Although the size of the rebound effect changed with the scenario, the rebound effect was lower than 100% under realistic conditions.

[Indirect rebound effect: Micro-level analysis]

To date, only a small number of studies have analyzed the indirect rebound effect for home durables, primarily owing to the lack of data. However, even among the small number of existing studies, there are contradictory findings about the magnitude of the indirect rebound effect. Some studies report that the indirect rebound effect is relatively small, while other studies report that the indirect rebound effect is large.

Yu et al. (2013) conducted a survey of Beijing households and estimated the direct and indirect rebound effects for various energy-consuming durables. They found a small or no rebound effect for REFs, electric fans, gas showers, TVs, and personal computers (PCs). In contrast, they found large direct rebound effects for air conditioners, clothes washers, microwave ovens, and cars. They also found that the indirect rebound effects are small.

Chitnis et al. (2013) estimated the combined direct and indirect rebound effects from seven measures aimed at improving energy efficiency in UK dwellings. Five of these measures targeted heating energy consumption, two of them targeted electricity consumption, and four were eligible for investment subsidies. They found that the rebound effects measured in greenhouse gas terms were modest (5–15%) and arose mostly from indirect effects. According to their estimation, the direct and indirect rebound effects for energy-efficient lighting were 17.3% and 11.3%, respectively.

Chitnis et al. (2014) estimated direct and indirect rebound effects from various types of energy efficiency improvement and behavioral changes by UK households. They found that the rebound effects were modest (0–32%) for measures affecting domestic energy use by UK households, larger (25–65%) for measures affecting vehicle fuel use, and very large (66–106%) for measures that reduced food waste. Few studies investigate how rebound effects vary among socioeconomic groups. They compared the rebound effects between income groups and found that measures undertaken by low-income households are associated with larger rebound effects.

The reduction of the effective price through energy efficiency improvement produces both income and substitution effects. Chitnis and Sorrell (2015) used the almost ideal demand system model to separate these two effects. They estimated total rebound effects at 41% for domestic gas use, 48% for electricity use, and 78% for vehicle use. They also found that these rebound effects were generated primarily by substitution effects.

Although green consumption behaviors have gained popularity in recent years, some of those behaviors involve the purchase of new energy-efficient consumer durables. Consequently, the effectiveness of green consumption is lost because of the rebound effect. By combining household expenditure survey data and greenhouse emission data, Murray (2013) showed that the environmental benefits of green consumer behavior were overestimated by 20% for reduced vehicle use and 5% for reduced electricity use.

[Assessment of efficiency improvement programs]

Various programs have been introduced to improve the energy efficiency of lightings and electrical appliances. Some previous studies have evaluated the effectiveness of those programs.

Howarth et al. (2000) reviewed the Green Lights and Energy Star programs introduced to promote energy-efficient technologies to private sector firms. After reviewing the implementation procedures of the programs, they concluded that the programs would have little effect on energy demand. Demand for the services were highly inelastic, and the firms were less likely to pay attention to the cost savings obtained through energy efficiency improvement.

Sanchez et al. (2008) estimated the amount of energy savings obtained through the US Energy Star Program. They focused on office equipment, appliances, and electronics, and estimated the unit energy saving (UES) when an old non-Energy Star product was replaced with a new Energy Star product. By summing UES across time and products, they estimated the Energy Star Program saved 4.8 Exa Joule (EJ) of primary energy through 2006. They also reported that monitors, printers, residential light fixtures, TVs, furnaces, and computers accounted for 70% of energy savings.

The studies that assessed energy efficiency improvement programs unfortunately have methodological limitations. Howarth et al. (2000) did not conduct any data analysis. Sanchez et al. (2008) assumed that people keep using appliances in the same manner after their replacement, that is, they assumed there was no rebound effect.

The Top Runner Program analyzed in this study was introduced to improve the energy efficiency of home appliances. However, the effective price of energy services decreased as the energy efficiency improved. To discuss the effectiveness of the program, we need to take account of rebound effects. The object of this study is to quantify rebound effects using micro-data for household energy consumption. In the next section, we explain our research methodology, namely, CDA.

3. Conditional Demand Analysis

Parti and Parti (1980) developed CDA to analyze the electricity billing records of households in San Diego. Since then, many scholars have used CDA in various countries. 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 an energy consumption reduction in Quebec. Leahy and Lyons (2010) analyzed data from Ireland and found that vacuum cleaners, tumble dryers, dishwashers, and deep freezers increased households' electricity consumption. Newsham and Donnelly (2013) used data from Canadian households to estimate the expected energy savings achieved by appliance upgrades. Matsumoto (2016) used CDA to show how family structure affects electricity usage in Japan.

We estimate the following empirical model for four sampling years:

$$\ln E_i = \alpha + \boldsymbol{B}\boldsymbol{X_i} + \boldsymbol{\Gamma}\boldsymbol{Y_i} + \boldsymbol{\Theta}\boldsymbol{Z_i} + \varepsilon_i \quad (1)$$

where E_i is household *i*'s electricity consumption, $\boldsymbol{X_i}$ is the vector of sociodemographic variables, $\boldsymbol{Y_i}$ is the vector of housing condition variables, and $\boldsymbol{Z_i}$ is the vector of the number of 12 varieties of appliances. Finally, ε_i is an iid error term with a zero mean.

4. Data

The primary data source of this study is Japan's NSFE for 1989, 1994, 1999, and 2004. The NSFE is a nationwide cross-sectional survey initiated in 1959 and conducted every five years. Although the most recent survey was completed in 2014, neither the 2009 nor 2014 data are publicly available at present.

Insert Fig. 1 Approximately Here

As presented in Equation 1, we use the log of monthly electricity usage (kWh/month) as a dependent variable. Japanese electricity companies have been using block pricing for the last several decades. Information about the electricity rate (yen/kWh) can be found in the Retail Price Survey of the Statistical Bureau of Japan (2017). In Figure 1, the electricity rate during 1989 and 1994 is presented as an example. Since NSFE reports the monthly electricity payment (yen/month) of each household, we can calculate the electricity usage (kWh/month) by combining the electricity payment and the electricity rate.[1]

Insert Figs. 2a and 2b Approximately Here

Figures 2a and 2b show the distribution of monthly electricity usage of single and multiple households in 1989, 1994, 1999, and 2004. Both figures show that the curve shifted to the right as the year passed. This implies that average electricity consumption increased. The average monthly electricity usages of single households were 137.87 kWh in 1989, 171.59 kWh in 1994, 182.41 kWh in 1999, and 209.53 kWh in 2004. Those of multiple households were 305.54 kWh in 1989, 389.93 kWh in 1994, 413.21 kWh in 1999, and 428.32 kWh in 2004. The figures also show that the variation in electricity usage among households grew over time.

Insert Table 1 Approximately Here

[1] The data for electricity price were collected from prefectural capitals and large cities with more than 150,000 inhabitants. We use the average electricity price for the Tokyo metropolitan area, Nagoya, and Osaka as the electricity price for metropolitan areas. We use the average electricity price of the remaining capitals and cities as the electricity price for non-metropolitan areas. We removed households whose electricity payment was lower than the basic charges or the minimum charges from the dataset.

NSFE includes socioeconomic information for each household. Table 1 shows that the average number of household members decreased from 3.62 in 1989 to 3.08 in 2004[2]; this decrease is due to the declining birthrate, aging population, and increasing nuclear families. The table shows that although the number of household members decreased during the sampling period, electricity consumption increased. This suggests that electricity dependence increased among Japanese households.

Household members can share some appliances. For instance, they can watch TV and wash clothes together. Since we expect that electricity usage will not increase proportionally to household income, we use "equivalent income" in the following analysis. The equivalent income of the household is calculated by dividing the household income by the square root of the number of household members.[3] Table 1 shows that equivalent income decreased after 1994 owing to the country's sluggish economy. For the estimation of Equation 1, we include the log of equivalent income (adjusted by the Consumer Price Index).

We include the metropolitan area dummy in order to take account of the geographical

[2] The number of household members is upper-censored at 7 in NSFE.

[3] Income is upper-censored at 25 million yen in NSFE.

variation in electricity demand. The dummy variable takes a value of one if a household is in a metropolitan area. Otherwise, it takes a value of zero. Although 37.52% of households were in metropolitan areas in 1989, 40.57% of households were in metropolitan areas in 2004.

In NSFE, households are asked about the number of appliances they own. In this study, we estimate the electricity usage for 12 varieties of appliances. Table 1 shows that households increased the number of specific appliances during the sampling years. For instance, the number of air conditioners (ACs) in the average household increased from 1.06 units in 1989 to 2.25 units in 2004. Similarly, the number of TVs increased from 1.90 units to 2.21 units. In contrast, the number of washing machines (WMs) decreased from 1.22 units to 1.08 units. NSFE records the number of small REFs (<300 liters) separately from that of large REFs (≥300 liters). Table 1 shows that the number of small REFs decreased, but the number of large REFs increased. This suggests that households increased the size of their REFs during the sampling period.

Finally, we include the floor area as a proxy for lighting equipment. We expect households' electricity demand for lighting to increase as the floor area of the house increases. Table 1 shows that the size of houses increased during the sampling period.

5. Estimation Results

5.1. Summary of CDA

Insert Table 2 Approximately Here

[Fitness of the empirical model]

Table 2 shows the results of CDA analyses. The first column shows the estimation result of the pooled regression model with year-specific dummies, while the remaining four columns present the estimation results of the 1989, 1994, 1999, and 2004 models, respectively. The adjusted R-squares are 0.46 in the pooled model, 0.35 in the 1989 model, 0.44 in the 1994 model, 0.47 in the 1999 model, and 0.46 in the 2004 model. The explanatory values of these models are reasonably high compared to previous studies (Matsumoto 2016; Shiraki et al. 2016). In other words, it is confirmed that monthly electricity usage is highly associated with the number of household appliances. The table also shows that the explanatory power increases from 1989 to 2004; this suggests that household dependence on the service of home appliances increases year by year.

The year-specific dummy variables of the pooled regression model are all positive and statistically significant. Furthermore, the table shows that the size of the coefficient increases as years progress. These results suggest that electricity usage increased during the sampling period.

[Electricity usage for appliances]

The left-hand side of Equation 1 uses the log of monthly electricity usage, while the right-hand side includes the number of appliances owned. We estimated the percentage change in electricity usage caused by the purchase of one additional appliance. Specifically, the percentage change of appliance j is calculated by substituting the coefficient θ_j of Equation 1 into $100 \times \left(exp\left(\theta_j\right) - 1\right)$. The estimated changes are presented in Table 2.

All the appliance variables become positive and statistically significant at the 1% level. The largest coefficient is found for large REFs in all five regression models. The result of the pooled regression model shows that the average household spends about 11.99% of electricity for a large REF. The second-largest coefficient is found for AC. According to the estimation result of the pooled regression model, electricity usage increases by 8.34% if the household purchases an additional AC. Comparing the size of the coefficient of REF and AC with those of other appliances, we can state that typical households spend a large proportion of electricity for these two appliances. We believe this result is reasonable since these two appliances use a large amount of electricity to adjust the temperature.

[Socioeconomic variables]

If the number of family members increases, a household may purchase additional home appliances, which may increase electricity usage. Nevertheless, household electricity usage will not increase proportionally to the number of household members. Some home appliances, such as TVs and REFs, can be shared among family members. In the pooled regression, the coefficient of the number of household members becomes 10.80%; this suggests that household electricity usage increases only by 10.80% after controlling for the number of appliances.

The equivalent income variable becomes positive and statistically significant. In the estimation result in the pooled regression, a 1% increase of equivalent income leads to an 8.11% increase of the monthly electricity usage. In the average household, a 1% increase of equivalent income corresponds to the increase in annual household income of 69,554 yen $(= 3{,}817{,}300 \times (\frac{1.00}{100}) \times \sqrt{3.32})$. On the other hands, the annual electricity payment will increase by 9,012 yen $(= 370.42 \times (\frac{8.11}{100}) \times 25 \times 12)$ if the electricity consumption increases by 8.11% and the electricity rate is 25 yen/kWh. This suggests that the average household allocates about 12.96% of additional income to energy usage.

[Housing conditions]

The floor area variable is positive and statistically significant. The size of the coefficient does not changed substantially. Since the floor area of the average house increased from 1073 to 1150 m^2, electricity demand for lighting increased.

The metropolitan area dummy variable is positive and statistically significant from 1989 to 1999. However, the size of the coefficient decreases during these three sampling periods and becomes statistically insignificant in 2004. This result suggests that the geographical variation became less important.

5.2. Electricity usage for appliances

The Top Runner Program was introduced in 1998, and the energy efficiencies of home appliances have improved substantially since then. In this subsection, we compare electricity usage for major appliances before and after the program and evaluate whether the program successfully reduced their electricity usage.

Insert Fig. 3 Approximately Here

Figure 3 shows the conceptual framework of our exercise. The electricity usage before energy efficiency improvement is shown in the box on the left. In contrast, electricity usage after energy efficiency improvement is shown in the boxes in the middle and on the right. As discussed in Section 2, energy efficiency improvement generates various rebound effects. The electricity usage estimated by CDA contains the rebound effect. Here, we discuss the size of rebound effects associated with the Top Runner Program.

We think that most households had one REF and one WM at home throughout the sampling period. In addition, we think that they did not change the manner in which they used those appliances drastically. However, they replaced their REF and WM during the sampling period. If households purchased a larger REF or WM with new functions, the energy usage for these appliances could increase.

As reported previously, households increased the number of ACs and TVs; they began to purchase second or third ACs and TVs. The intensity of the use of the second and third appliances would be lower than for the first one. Therefore, the coefficient could decrease during the sampling period. However, to discuss the effectiveness of the energy saving program, we need to compare the total electricity used for these appliances, including the second and third units.

Insert Table 3 Approximately Here

Table 3 shows how the electricity usage for four major appliances changed after the Top Runner Program. We obtained interesting results for ACs and REFs. The monthly electricity usage per AC decreased from 32.18 kWh in 1994 to 23.38 kWh in 2004. Yet, owing to the increase in the number of ACs, the average monthly electricity usage per household increased from 34.11 kWh to 53.61 kWh.

In the case of REFs, some households own a large REF, while others own a small REF. Thus, we need to combine the two results. While the average household used 31.78 (= 9.39 + 22.39) kWh of electricity per month in 1989, it used 54.83 (= 15.29 + 39.54) kWh of electricity per month in 2004. Although family size became smaller during the sampling period, the energy usage for REFs increased. This suggests that households purchased larger REFs. This phenomenon may be associated with lifestyle changes among Japanese households; they visit grocery stores less frequently and buy a larger amount of food at one time. Thus, they need additional space for food preservation.

6. Discussion and Policy Implications

The reduction of household electricity consumption has been an important policy agenda for many countries, which have aimed to achieve energy-saving goals through energy efficiency improvement. Using micro-data for household electricity consumption in Japan, we have examined whether the energy efficiency improvement of home appliances has led to the reduction of household electricity consumption. The results of this study show that Japanese households increased their electricity consumption even in the period when the energy efficiencies of home appliances were greatly improved. However, household income has hardly increased owing to a prolonged recession.

The indirect rebound effect is quite sizable for household electricity usage. After the energy efficiency of home appliances improved, households began to purchase larger appliances and/or additional appliances, which entirely exhausted the savings obtained through the improvement of energy efficiency.

Our results also raise questions about an energy efficiency standard. When measuring the energy efficiency of home appliances, regulatory agencies take account of the size of the appliance. For example, they take account of the size of the room when evaluating the energy efficiency of air conditioners, while they take account of the volume when evaluating that of REFs. Even if the market share of appliances with an energy efficiency label increases, electricity usage can increase if households start to purchase larger appliances.

The experience of the Japanese Top Runner Program shows that the reduction of household energy consumption is less likely to be achieved through technological innovation alone. A policy to increase the effective price of energy services is essential.

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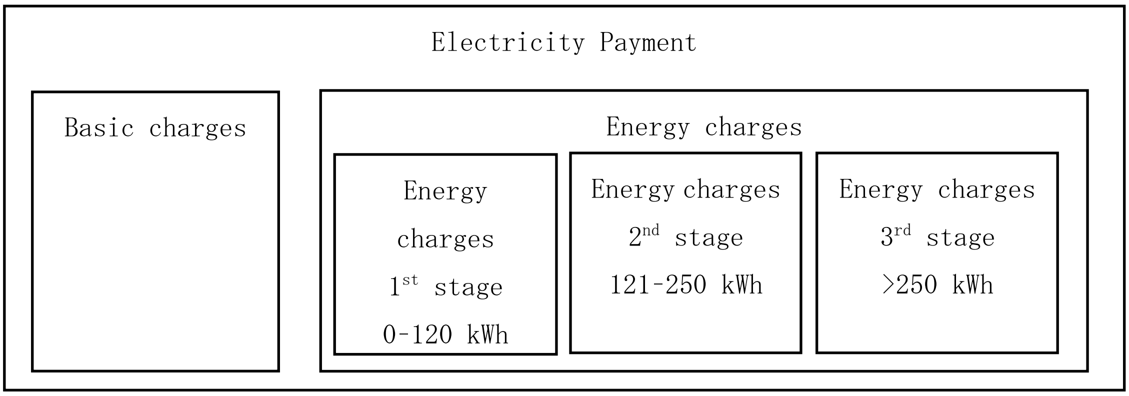


Fig. 1. Block pricing in Japan (1989 and 1994)

Fig. 2a. Electricity usage of single-person households

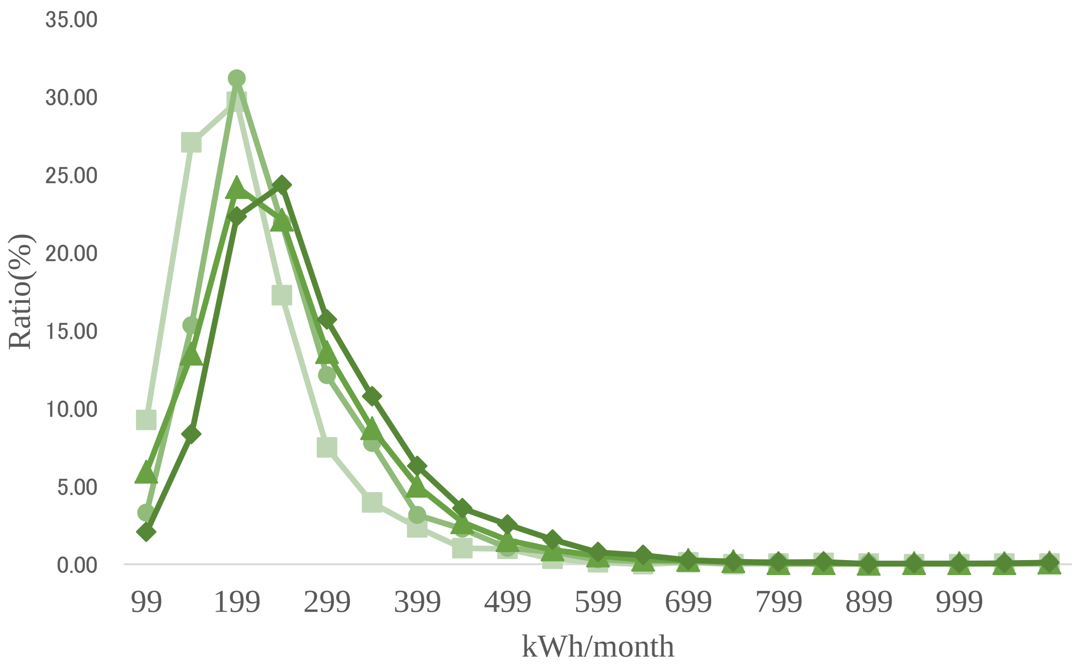
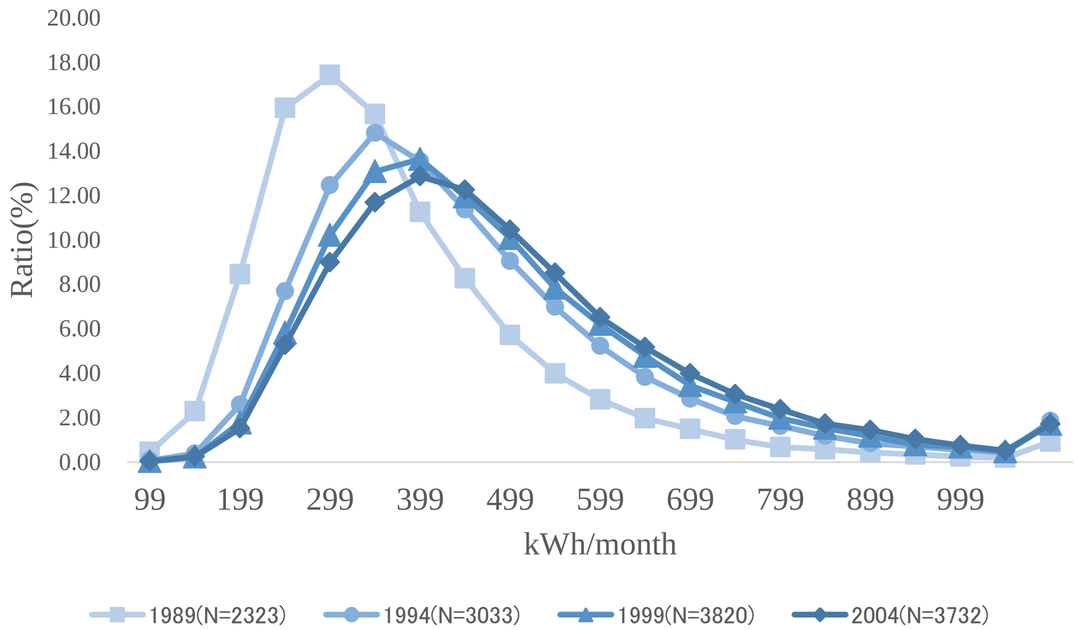


Fig. 2b. Electricity usage of multiple-person households



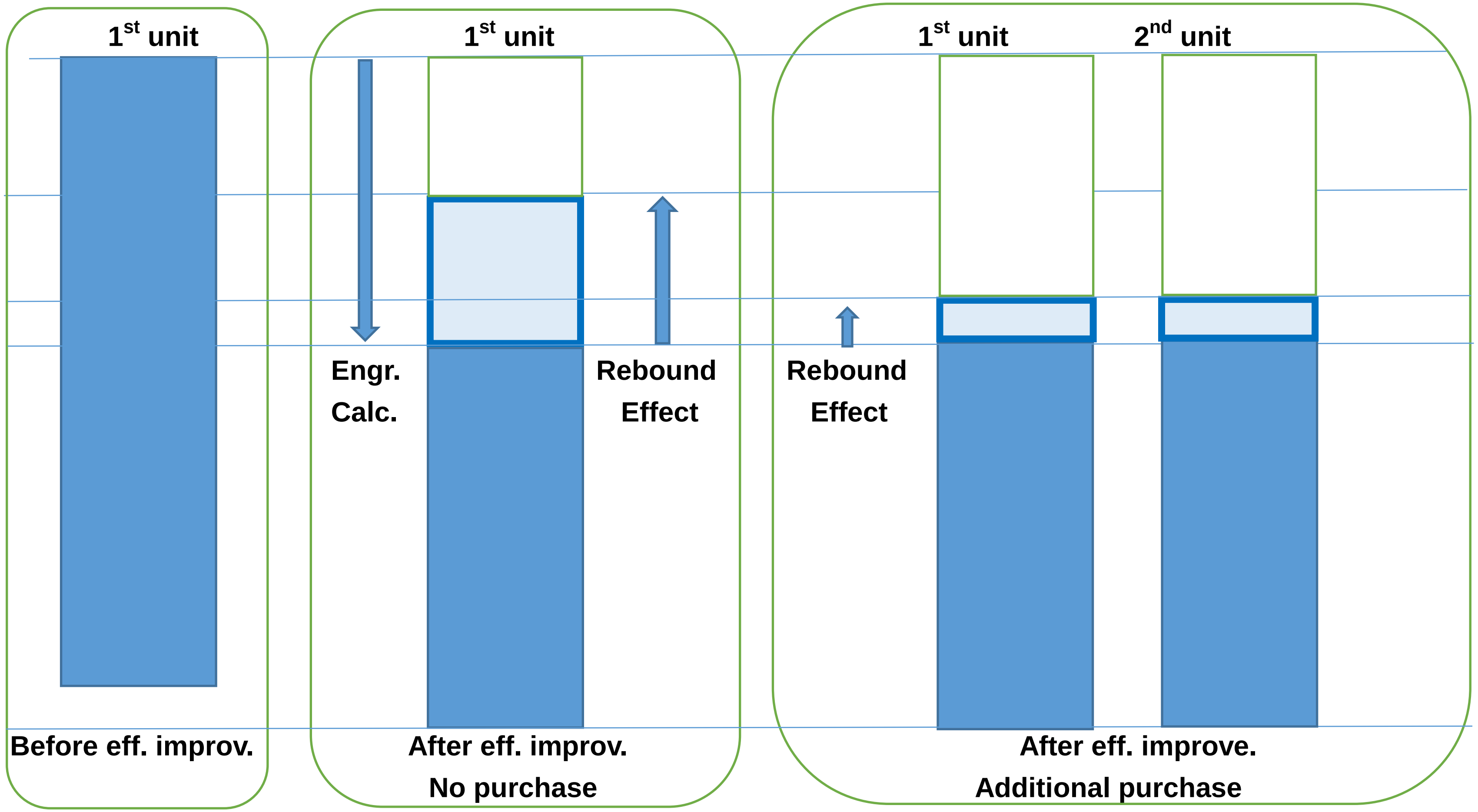


Fig. 3 Change in electricity usage for appliances

Table 1. Descriptive statistics

Variable	Unit	All households for all periods (N = 185,578) Mean	Std. Dev.	All households 1989 (N = 44,740) Mean	Std. Dev.	All households 1994 (N = 46,479) Mean	Std. Dev.	All households 1999 (N = 47,468) Mean	Std. Dev.	All households 2004 (N = 46,891) Mean	Std. Dev.
Number of household members	Persons	3.32	1.41	3.62	1.46	3.41	1.42	3.20	1.38	3.08	1.32
Share of households in the metropolitan area	%	39.96	-	37.52	-	40.20	-	41.44	-	40.57	-
Electricity usage	kWh/month	370.42	204.43	296.83	177.99	375.68	207.73	394.63	204.81	410.91	206.18
Floor area	100 ㎡	11.027	5.12	10.73	5.09	10.78	5.19	11.09	5.16	11.50	5.01
Equivalent income	¥10,000/year	381.73	214.20	362.41	203.70	400.07	220.74	393.1763	217.09	370.41	212.21
Number of air conditioners	Number	1.71	1.57	1.06	1.20	1.57	1.43	1.94	1.61	2.25	1.72
Number of televisions	Number	2.13	1.20	1.90	1.07	2.15	1.16	2.26	1.24	2.21	1.28
Number of video decks	Number	1.09	0.96	0.79	0.70	1.00	0.95	1.16	0.94	1.41	1.11
Number of washing machines	Number	1.17	0.47	1.22	0.52	1.30	0.57	1.08	0.37	1.08	0.35
Number of dishwashers	Number	0.07	0.26	0.04	0.21	0.05	0.22	-	-	0.18	0.39
Number of microwaves	Number	0.92	0.42	0.73	0.51	0.92	0.42	0.99	0.37	1.03	0.32
Number of small refrigerators (<300 L)	Number	0.53	0.63	0.54	0.62	0.59	0.64	0.52	0.64	0.48	0.62
Number of large refrigerators (≥300 L)	Number	0.72	0.56	0.67	0.58	0.65	0.56	0.76	0.54	0.79	0.54
Number of sewing machines	Number	0.72	0.57	0.72	0.57	0.77	0.56	0.73	0.57	0.69	0.56
Number of cellular phones	Number	0.80	1.05	-	-	0.44	0.55	0.99	1.00	1.71	1.21
Number of facsimile machines	Number	0.22	0.43	-	-	0.09	0.29	0.31	0.47	0.48	0.52
Number of rice cookers	Number	0.69	0.63	-	-	0.89	0.60	0.91	0.57	0.94	0.52

Table 2. Household electricity usage (Conditional Demand Analysis)

Sampling year	All four periods		1989		1994		1999		2004	
Number of observations	185,578		44,740		46,479		47,468		46,891	
Constant	4.16***[1]	(376.84)[b]	3.96***	(159.13)	4.39***	(212.59)	4.43***	(215.95)	4.54***	(228.66)
Dummy variable of 1994	18.57***	(52.36)	-	-	-	-	-	-	-	-
Dummy variable of 1999	19.41***	(49.46)	-	-	-	-	-	-	-	-
Dummy variable of 2004	19.43***	(42.84)	-	-	-	-	-	-	-	-
Number of large refrigerators (≥300 L)	11.99***	(48.60)	11.27***	(20.36)	12.35***	(25.75)	12.24***	(25.35)	12.18***	(26.58)
Number of small refrigerators (<300 L)	6.03***	(29.85)	5.87***	(12.00)	6.27***	(16.05)	4.92***	(13.05)	7.75***	(20.90)
Number of air conditioners	8.34***	(105.12)	10.85***	(50.62)	10.32***	(64.46)	8.17***	(56.20)	5.69***	(43.42)
Number of microwaves	5.22***	(20.67)	3.78***	(8.23)	3.81***	(7.99)	7.19***	(12.97)	1.63***	(2.78)
Number of cellular phones	5.13***	(19.40)	na		10.08***	(14.86)	6.05***	(14.72)	4.62***	(12.64)
Number of washing machines	3.79***	(16.62)	2.07***	(4.53)	3.25***	(9.14)	6.14***	(10.79)	1.96***	(3.49)
Number of dishwashers	3.61***	(9.14)	5.18***	(4.91)	4.97***	(5.78)	na		5.36***	(11.13)
Number of televisions	2.32***	(22.74)	2.30***	(9.17)	3.00***	(14.87)	1.57***	(8.17)	2.25***	(12.74)
Number of rice cookers	2.06***	(10.32)	na		1.80***	(5.69)	3.06***	(9.08)	1.86***	(5.33)
Number of facsimile machines	1.85***	(9.47)	na		1.81***	(4.46)	3.05***	(9.38)	3.72***	(12.68)
Number of sewing machines	1.57***	(12.36)	na		3.53***	(9.97)	2.60***	(12.42)	2.14***	(11.15)
Number of video decks	1.01***	(8.84)	3.42***	(9.86)	0.80***	(3.74)	0.61***	(2.82)	0.72***	(3.93)
Number of household members	10.80***	(133.23)	10.02***	(58.62)	10.82***	(73.25)	11.59***	(72.25)	10.17***	(57.76)
Equivalent income	8.11***	(42.08)	11.53***	(24.61)	7.39***	(19.95)	5.23***	(14.46)	6.46***	(18.53)
Floor area	2.09***	(91.30)	2.49***	(49.19)	1.67***	(39.23)	2.08***	(46.02)	2.16***	(48.67)
Dummy variable for metropolitan area	3.01***	(14.35)	5.04***	(10.29)	3.44***	(8.43)	2.48***	(6.20)	−0.35	(-0.94)

Table 2. Continued

Sampling year	All four periods	1989	1994	1999	2004
Adjusted R^2	0.46	0.36	0.45	0.47	0.46

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

b. Numbers in parentheses are standard errors of the coefficient estimates.

na. Data for the corresponding appliances are not available.

Table 3. Change in electricity usage for major appliances

Variable	Year	Average electricity usage	Coefficient	Electricity usage per appliance	Average Ownership	Average electricity usage per household
		kWh/month	%	kWh/month	unit	kWh/month
Air conditioner	1989	296.83	10.84	32.18	1.06	34.11
	1994	375.68	10.31	38.73	1.57	60.81
	1999	394.63	8.17	32.24	1.94	62.55
	2004	410.91	5.69	23.38	2.25	52.61
Small refrigerator (<300 L)	1989	296.83	5.86	17.39	0.54	9.39
	1994	375.68	6.26	23.52	0.59	13.88
	1999	394.63	4.92	19.42	0.52	10.10
	2004	410.91	7.75	31.85	0.48	15.29
Large refrigerator (≥300 L)	1989	296.83	11.26	33.42	0.67	22.39
	1994	375.68	12.34	46.36	0.65	30.13
	1999	394.63	12.24	48.30	0.76	36.71
	2004	410.91	12.18	50.05	0.79	39.54
Television	1989	296.83	2.29	6.80	1.90	12.92
	1994	375.68	2.99	11.23	2.15	24.15
	1999	394.63	1.57	6.20	2.26	14.00
	2004	410.91	2.25	9.25	2.21	20.43
Washing machine	1989	296.83	2.06	6.11	1.22	7.46
	1994	375.68	3.24	12.17	1.30	15.82
	1999	394.63	6.14	24.23	1.08	26.17
	2004	410.91	1.96	8.05	1.08	8.70