Replacement or Additional Purchase: The Impact of Energy-Efficient Appliances on Household Electricity Saving

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May 2015
Discussion Paper No.1520

GRADUATE SCHOOL OF ECONOMICS

KOBE UNIVERSITY

ROKKO, KOBE, JAPAN

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Abstract

This study examined the influence of additional and replacement purchases of energy-efficient air-conditioners on power savings. We used a questionnaire survey and measured electricity use data from 339 Japanese households, collected from two city areas with different level of government-requested electricity-saving rates, namely, Osaka (10%) and Matsuyama (5%). The main findings of our study are as follows: 1) Households that purchased energy-efficient air-conditioners saved more electricity than those that did not. 2) "Additional-purchase households" showed significant energy savings, whereas "replacement households" did not. The rebound effect may negate the energy-saving effects of a new air-conditioner. 3) Altruistic attitude is associated with more active participation in power saving. 4) Households in Osaka saved more electricity than those in Matsuyama, probably because the government call to save electricity was more forceful.

Keywords: electricity demand; energy efficiency; home appliances; electricity conservation directives; carbon dioxide emissions

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1. Introduction

Unlike in Europe and the United States, where central heating and air-conditioning are predominant, houses and apartments in Japan usually use unit cooling and heating in each room.[1] Therefore, Japanese households make frequent purchase and replacement decisions for air-conditioners. Consequently, people in Japan have more energy-efficient investment opportunities (i.e., chances to purchase energy-efficient air-conditioners for replacement or additional use) than those in European countries and United States. These investments have important implications not only for cooling and heating costs but also for total energy demand and the risk of climate change. In Japan, air-conditioners account for 60% of household electricity consumption during peak summer and winter hours (Ministry of Economy, Trade and Industry, 2013).

Several scholars have investigated the relationship between energy-efficient investment and actual energy saving. Halvorsen and Larsen (2001), for example, analyzed the influence of electricity appliance possession on power demand, using Norwegian household panel data. Berkhout et al. (2004) analyzed electricity and gas demand in the Netherland based on possession of several electric appliances. Davis et al. (2014) evaluated the effect of a large-scale electric appliance replacement program in Mexico, using data on 1.9 million households. Rehdanz (2007) analyzed the factors that contributed to

[1] According to EDMC (2014), room air-conditioners have a diffusion rate of 90% in Japan and their average number per household is 2.64 based on 2012 data.

space-heating expenditure, using panel data from 12,000 German households. The results of these studies suggest that high-income, owner-occupier households invest in energy-efficient equipment but tend to not engage in energy-saving behavior.

Extending the scope of previous work, this study compares two modes of energy-efficient equipment investment: replacement and additional purchases. While both investment types seem to contribute to energy saving, we need to perform an empirical analysis to understand how these different appliance-purchase motives actually affect energy saving behavior. For example, an energy-efficient appliance that replaced an old appliance might not contribute to power saving when a rebound effect occurs (Sorrell and Dimitropoulos, 2008). On the other hand, households that purchase additional appliances might be able to reduce their electricity consumption with relative ease because the need of the additional appliances might be low.

Because of its electricity shortage, Japan offers an interesting environment for the investigation of the impact of home appliances on power demand. The shutdown of nuclear power plants after the meltdown at the Fukushima Daiichi Nuclear Power Plant in 2011 urged electricity saving, particularly during the peak summer season. We use a questionnaire survey and electricity usage data from 339 Japanese households in the summers of 2011 and 2012, collected from two city areas with different government-requested electricity-saving rates: Osaka city area (10%) and Matsuyama city (5%).

Approximately 25% of the power supply in Japan was generated by nuclear power

(EDMC, 2014) until the closure of nuclear power plants in Japan after the Great East Japan Earthquake of March 2011 due to safety concerns.[2] The shutdown of the nuclear plants caused power shortage, especially in the summer and winter seasons when electricity demand is high. Therefore, power saving was required in all sectors after 2011. In summer 2012, the Japanese government issued an "electricity conservation directive" for seven of the ten regions of Japan, depending on the expected power shortage[3]. Figure 1 shows the service areas of the ten major electric power companies in Japan.[4]

[Figure 1 here]

This study targeted households in two city areas (Osaka city area in Kansai region and Matsuyama city in Shikoku region) with different electricity-saving goals: a reduction of 10% for Osaka and 5% for Matsuyama from the 2010 level. Therefore, our study can investigate the effect of this policy on household electricity-saving behavior. Moreover, if power demand exceeds power supply, large-scale power failure would occur. Therefore, people might cooperate with each other, saving electricity for themselves and for others. This altruism mirrors the power-saving behavior that aims to mitigate climate change. Thus, we can consider an altruistic attitude as an important determinant of household decisions on saving electricity. We measure the extent of altruism from the responses to five questions

[2] All 54 nuclear power reactors in Japan were shut down by May 2012 and remain closed as of March 2015.

[3] Since many nuclear power plants in Japan were still working in summer 2011, no electricity-saving request was issued during the season, except for the Kanto and Tohoku regions, where electricity demand is tight.

[4] The Japanese electricity market is dominated by ten regional monopolies.

and investigate their relationship to electricity-saving behavior (Clark et al. 2003).

The main purpose of this study can be summarized as follows. It aims to compare the impact on electricity demand from two investment modes for energy-efficient equipment: replacement and additional purchase. Our focus is on the electricity conservation directive during the summer of 2012. The econometric analysis of this study would reveal how energy-efficient appliances helped household responses to power conservation directive. While analyzing power-saving behaviors, we also look at the effect of the strength of electricity conservation directive and the role of the altruistic motive.

This paper is organized as follows: Section 2 discusses previous studies on household energy-saving behavior. In Section 3, the data and the method of empirical analysis are described. Section 4 presents the results of our empirical analysis. Section 5 discusses our findings with a focus on energy-efficient air-conditioner purchase and its effects on the level of power savings. Section 6 concludes the paper and notes some limitations of our study.

2. Literature Review

2.1 Previous Studies

Many scholars have studied energy-saving behaviors of households (for literature review, see Madlener [1996] and Espey and Espey [2004]). These studies focus on two subjects: energy-efficient investment and energy-saving behavior. Energy-efficient investment involves introducing energy-efficient equipment such as household electric appliances, thermal insulation material, and solar panels. When these equipment are installed, households can reduce energy consumption without changing their daily behavior. On the other hand, energy-saving behavior involves decreasing energy consumption without changing equipment. Energy-saving behavior can be analyzed on a discrete-continuous or conditional demand approach. The discrete-continuous approach to estimating energy demand is based on a discrete or continuous choice analysis of energy equipment (Dubin and McFadden, 1984; Nesbakken, 2001; Halvorsen and Larsen, 2001). The conditional demand approach is based on an energy demand analysis given the features of energy equipment (Leth-Petersen and Togeby, 2001; Meier and Rehdanz, 2010).

2-2. Energy-efficient investments

Studies on energy-efficient investments have analyzed the factors (e.g., socioeconomic characteristics and government policy) that influence household investment decisions. Krumm (1983) conducted a pioneering study in this field that used micro data from 1,520 American households. A multinomial logit model was estimated, which distinguished between purchase of room units and installation of central air-conditioning. Household income, housing unit characteristics, and climate conditions significantly affected investment. Cameron (1985) analyzed, also using U.S. household data, the adoption of insulated windows and double-glazed windows with a nested logit model. Cost of investment, energy price, and household income significantly influenced adoption decisions. Scott (1997) studied 1,200 Irish households analyzing three types of investments. Household income, ownership form of house, amount of potential energy savings, and time and effort to find optimal equipment significantly affected energy-efficient investment. Targeting 305 households in Switzerland, Banfi et al. (2008) evaluated the willingness to pay for energy-efficient investment by conducting a choice experiment. Households placed significant value on investment benefits. Grosche and Vance (2009) also found, for German households, that the costs and benefits of energy-saving investments have a significant influence on their willingness-to-pays. Furthermore, Nair et al. (2010) showed, targeting 3,000 households in Switzerland, that households with higher energy consumption tended to make energy-efficient investments. While these studies used discrete dependent variables, other studies used a Tobit model with investment expenditure as the dependent variable (Mendelsohn, 1977; Montgomery, 1992; Mahapatra and Gustavsson, 2008; Charlier, 2013). Using expenditure data, they examined not only the influencing factors but also their impact on investment. Results of these studies suggest that energy-efficient equipment are generally purchased by high-income, high-energy-spending, owner-occupier households. However, the form of purchase of energy-efficient equipment, which may affect the level of energy saving, has received relatively little attention.

2-3. Energy-saving behavior

Most empirical studies on energy-saving behavior have focused on energy price elasticity (Espey and Espey, 2004). For example, Dubin and McFadden (1984) analyzed household electricity demand using micro data on 3,249 U.S. households. A number of studies have examined household electricity demand using micro data or micro panel data across several countries (Garbacz, 1985, 1987; Branch, 1993; Jung, 1993; Nesbakken, 1999; Vaage, 2000; Halvorsen and Larsen, 2001; Wu et al., 2004; Zhang and Kotani, 2012). Meier and Rehdanz (2010) analyzed the determinants of space-heating expenditure using panel data on 5,000 U.K. households. They investigated the effects of many socioeconomic characteristics, types of house, and energy price. Homeowners tended to use more energy than those who rented their houses. This was likely due to poor energy efficiency of detached houses (homeowners) compared to apartments (in many cases, rental households).

2-4. The aim of present study

This study analyzes the factors influencing electricity demand in Japanese households, focusing on their investment in energy-efficient air-conditioners. Several studies have considered past energy-efficient investments. Halvorsen and Larsen (2001) estimated the short- and long-term price elasticity of electricity using Norwegian household panel data. They analyzed the influence of electricity appliance possession on power demand. Using household panel data in the Netherlands, Berkhout et al. (2004) analyzed electricity and gas demand considering possession of several electric appliances. Reiss and White (2005) estimated price and income elasticities of electricity demand based on 1,307 California residents, considering the possession of home electric appliances. Davis et al. (2014) evaluated the effect of a large-scale electric appliance replacement program in Mexico, using data on 1.9 million households. Under this program, households replaced their old refrigerators and air-conditioners with energy-efficient models. They found that households that had replaced refrigerators reduced electricity by 8%, although this reduction was only one-quarter of what they had expected ex ante. Rehdanz (2007) analyzed the factors that contributed to space-heating expenditure, using panel data from 12,000 German households. Energy-efficient heating systems and insulated windows significantly decreased use of heating energy. Moreover, owner-occupiers tended to invest in energy saving more than rental households did. On the other hand, owner-occupiers were more insensitive to changes in energy price than were renters. She reported that owner-occupier households tended to prefer energy-efficient investments to energy-saving behavior.

In summary, previous studies on energy-efficient investments and energy-saving behavior suggest that high-income, owner-occupied households invest in energy-efficient equipment. These households tend to not engage in energy-saving behavior. Thus, we test the hypothesis that households investing in energy-efficient equipment would be more reluctant to practice energy-saving behavior.

This study estimates the electricity demand function, investigating household electricity demand in summer (space cooling). Space cooling is almost always fueled by electricity. Therefore, we do not need to consider possible choices among other energy sources. As discussed previously, most Japanese households use space cooling/heating, and not central air-conditioning but room air-conditioning. Therefore, insulation of air-conditioners is relatively easy. These conditions allow us to examine the effect of energy-efficient air-conditioners on household energy-saving levels. Furthermore, we distinguish between "replacement" and "additional-purchase" households to analyze between-group differences on power saving. We expect a decrease in electricity usage with the replacement of old appliances by new, efficient models. On the other hand, since additional units would be added to existing ones, electricity usage seems to increase. These expectations, nevertheless, might not hold if the rebound effect is invoked by energy-efficient equipment.

3. Data and Model

3-1. Data

We administered a questionnaire survey to households in the Osaka city area and Matsuyama city in the summer of 2012. We requested the Nippon Research Center and Matsuyama Chamber of Commerce and Industry to conduct the survey among Osaka and Matsuyama households, respectively. The surveyors sent the questionnaire to 700 randomly selected households in both cities. The households answered the questionnaire online on the Nippon Research Center's webpage (Osaka) or on paper (Matsuyama). The queries related to the households' socioeconomic characteristics, the nature and extent of their electricity-saving behaviors, air-conditioner usage and number of units, presence or absence of energy-efficient air-conditioners, and form of purchase (replacement or additional purchase).

Aside from the questionnaire, we asked households to send a specification of their electricity usage in August 2012. The specification was dropped in the mailbox by the person in charge of meter reading, hired by the electricity company of each region.[5] The amount of electricity usage and fees for the current month and same month a year ago were included in this specification to calculate the saving rate from the previous year. Table 1 presents the descriptive statistics. The average electricity saving from 2011 to 2012 was 2.5%, while the difference was not statistically significant.

[Table 1 here]

In the questionnaire survey, we asked households whether they purchased a new air-conditioner between May 2009 and March 2011. If yes, the respondent was asked whether it was a replacement or additional purchase and whether it was targeted by the Eco-Points Program (hereafter EPP), a subsidy program for energy-efficient home appliances[6]. Percentage of households that purchased energy-efficient air-conditioners

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[5] There are ten regional-monopoly electricity companies in Japan. The Osaka city area is serviced by the Kansai Electricity Company, and Matsuyama city by the Shikoku Electricity Company.

[6] The Eco-Points Program was implemented by the Japanese government from May 2009 to March 2011 to increase acceptance of energy-efficient solutions. Specifically, those who purchased home electronic appliances with a high energy-saving level (the target products of EPP were air-conditioners, refrigerators, and TVs) received "eco points," which could then be exchanged for money (1 point = 1 yen, where €1 = 128.6 yen as on April 2, 2015) on a prepaid transportation pass, electronic money, gift certificates, regional specialty products, and so forth. According to the Ministry of Economy, Trade and Industry et al. (2010), about 639.1 billion eco points were issued in May 2011.

targeted by the EPP were almost the same between replacement and additional units (9.1 % and 6.8%, respectively, as shown in Table 1). Moreover, several households purchased replacement and additional units that were not targeted by the EPP (4.1% and 3.2%, respectively). The energy-saving performance of these less-efficient air-conditioners are slightly lower than those targeted by the EPP. However, a significant proportion of consumers purchased air-conditioners not targeted by the EPP, even while the program was active, because their prices were in many cases lower than those of the EPP-targeted ones. In our analysis, we consider the combined number of EPP and non-EPP air-conditioners.[7] Actually, modern air-conditioners, even if not targeted for EPP, are highly energy efficient. Due to the Top Runner Program by the Japanese government[8], companies of air-conditioner must continue to upgrade the energy efficiency of their air-conditioners on a yearly basis.

Osaka households comprised about 37% of our sample. The Japanese government requested households in Kansai region, which includes Osaka, to decrease electricity by 10% from the 2010 level.[9] A number of measures were put in place toward this goal. For example, the local government published a booklet and created website on power-saving measures, and the media promoted power-saving behaviors. Electricity companies, too, conducted power-saving promotion measures. For instance, the Kansai Electricity Company

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[7] Only nine households made both replacement and additional purchases of energy-efficient air-conditioners. We excluded these households from our data set.

[8] The purpose of this program is to promote energy-efficient electric appliances and automotive vehicles. Under this program, energy efficiency targets are set based on the value of the most energy-efficient products on the market at the time of the value-setting process, and all machinery and equipment products covered by the program should exceed these targets. If a company continues to sell products that fall below the targets, the company name will be published and penalty charges imposed.
(http://www.enecho.meti.go.jp/policy/saveenergy/toprunner2011.03en-1103.pdf)

[9] A 15% electricity-saving request was issued in July 2012. The request was reduced to 10% after the Ohi nuclear power plant of the Kansai Electricity Company resumed operations. The Ohi nuclear facility was again shut down in September 2013. It remains closed as of March 2015.

implemented an “electricity-saving trial,” a voluntary-based program in which participants that achieved a certain electricity-saving level were given a money coupon. Households in Shikoku region, which includes Matsuyama, were asked to decrease power usage by 5%; however, the power-saving measures implemented were more modest than those of Kansai region.

We use two subjective measures on social preferences of households. One is the New Ecological Paradigm (NEP) scale, representing the environmental attitude of respondents (Dunlap et al., 2000; Kotchen and Moore, 2007). Respondents were asked to rate on a 5-point Likert scale the extent to which they agreed or disagreed with several statements on environmental issues. Our survey included five statements from the NEP scale and combined them into a summated scale that provides a measure of general environmental attitude (that is, the NEP scale can take a value between 5 and 25). Another measure of social preferences is the altruism scale (ALT). Respondents indicated on a 5-point Likert scale the extent to which they agreed or disagreed with five different statements on altruistic motivation (Clark et al., 2003). Then, they were combined into a summated scale that provides a measure of general altruistic attitude (that is, the ALT scale can take a value between 5 and 25).

3-2. Regression model

We estimate a household electricity demand function. The dependent variable is the electricity usage in August 2012. We examine the influence of energy-efficient investments, considering the two types of air-conditioner purchases (replacement and additional units). The regression model for our study is as follows:

$$Y_{2012,i} = \alpha + \beta_1 OSAKA_i + \gamma_{replace} REPLACE_i + \gamma_{add} ADD_i + \beta_2 X_i + \varepsilon_i, \qquad (1)$$

where $Y_{2012,i}$ indicates the logarithmic value of the electricity consumption for August 2012 ($ELEC\_2012$); *OSAKA* represents the dummy variable for household in Osaka city area; $REPLACE_i$ and ADD_i indicate the number of efficient air-conditioners owned, the former by replacement and the latter by additional purchase; X_i represents other variables.

Electricity consumption decreases with replacement if household behavior is unchanged, since the replaced unit is generally less efficient. Therefore, the coefficient of *REPLACE* is expected to be negative. However, as described in Section 3, households that invest in energy-efficient equipment engage in less energy-saving behavior than households that do not. If they increase the usage of air conditioner than before, the coefficient might be insignificant or even positive.

On the other hand, we might expect that electricity consumption of households that purchased a new energy-efficient air-conditioner will increase. The coefficient of *ADD* is expected to be positive. However, households that purchase an additional unit might reduce the usage of their existing air-conditioner, in which case total electricity consumption might decrease or remain the same. In that case, the coefficient of *ADD* can become negative or non-significant.

4. Estimation Results

Table 2 shows the estimation results. Columns (1) and (2) provide the results based on logged electricity consumption in 2012 as the dependent variable, columns (3) and (4) indicate the results based on logged electricity consumption in 2011 as the dependent variable, and columns (5) and (6) show the results based on the electricity-saving rate between 2011 and 2012 as the dependent variable. The result shows that the number of air-conditioners (AIR_N) and the room area (AIR_WIDE) are positive and statistically significant. Thus, household electricity consumption in summer is surely affected by air-conditioner use.

[Table 2 here]

We examine the effect of energy-efficient air-conditioners using different models. First, we examine if the energy-efficient appliances contribute to power saving. The models shown in columns (1), (3), and (5) include the EFFICIENT_AIR variable, which combines REPLACE and ADD. Because the estimation coefficient of EFFICIENT_AIR for 2012 is negative and statistically significant, we can conclude that households which purchased energy-efficient air-conditioners saved more electricity than households that did not. This might demonstrate the effect of the diffusion policy initiated by the EPP, which promoted energy-efficient appliances.

We note different forms of purchase. Columns (2), (4), and (6) show results based on REPLACE and ADD variables. The estimated coefficients of ADD are negative and statistically significant. In contrast, those of REPLACE are not significant. That is, we did not find power-saving effects for the replacement of old air-conditioners. Our result supports Davis et al.'s (2014) finding that households which shifted to energy-efficient air-conditioners increased electricity demand. On the other hand, households that purchased additional energy-efficient air-conditioners tend to save electricity. Results on purchase mode differences will be discussed in more detail in the next section.

The coefficients of other variables are almost in line with the expectation. The 2012 electricity-saving request for the Kansai region (10%), which includes Osaka, is greater than the request for Shikoku region (5%), which includes Matsuyama. Therefore, we can conclude that the social pressure was stronger in Osaka than in Matsuyama. The coefficients of the OSAKA dummy are negative and statistically significant (except for 2011).[10] We can interpret this result to mean that households in Osaka saved more electricity in response to the request. Since the meltdown at the Fukushima Daiichi Nuclear Power Plant, Japanese citizens have become increasingly conscious of power saving. This result may indicate that electricity-saving requests could further encourage households to save power. Our results

[10] In the summer of 2011, the main target of electricity saving was not the household sector, but the industrial and service sectors. In fact, most of the measures targeting households were initiated after 2012. Moreover, since only Kanto and Tohoku regions showed a tight electricity demand in summer 2011, the electricity saving request for Kansai region, where some of the nuclear power plants were still working at that time, was not very serious.

support Reiss and White's (2008) finding that public pressure on households in California could encourage sustained reductions in electricity demand.

One might imagine that electricity prices between the two areas are different. Actually, as shown in Table 3, the electric rate structures of both Kansai and Shikoku regions are almost same. The price structure is stepwise, increasing with electricity usage. Therefore, the current unit price may be difficult to perceive, and consumers may be insensitive to unit price changes.[11] Furthermore, the average electricity price becomes higher when households use more electricity. Since the price variable in our regression is calculated by dividing total electricity expenditure by total power usage, the reverse causality might lead to a positive estimate of the coefficient.

[Table 3 here]

Environmental awareness (NEP) was not significant in many estimated models. Households with strong environmental preferences might use less electricity even before the earthquake and have less room for additional electricity savings. The estimated coefficients for altruism (ALT) are positive and statistically significant for 2012. Thus, we found that households with higher altruistic index save more electricity. Households facing the possibility of a large-scale power outage in summer 2012 saved electricity, possibly not only

[11] The power charge did not change either in 2011 or in 2012. However, with the increase in thermal power generation following the shutdown of nuclear power plants, fuel costs rose sharply. Therefore, electric companies have been increasing prices since 2013. For example, the Kansai Electric Power Co., Inc., increased household power charges by about 9.75% on May 1, 2013. The company increased the price by about 10.23% again on April 1, 2015. Therefore, consumers may be more sensitive to price changes in recent years than before.

for their own sake but also for others’ benefit.

5. Discussion

This section further discusses the results of the regression analysis. First, why did households that replaced old air-conditioners not save more electricity than other households? Davis et al. (2014) suggest some reasons. The first is the change in appliance size and features: the new air-conditioner might be larger than the replaced unit. Furthermore, recent models provide various functions such as rapidity cooling, thermal management, and automatic cleaning. Thus, power consumption might increase even if the new air-conditioner has energy-efficient features. The second reason is the rebound effect: although technological progress can reduce energy usage, reduction in the cost of energy services may lead to an increase in the demand for energy services (Sorrell and Dimitropoulos, 2008). For example, let us consider the replacement of an old air-conditioner with a new energy-efficient one. If the hours of operation and the preset temperature are identical, energy consumption would decrease by the technological improvement. However, improvement of energy efficiency means reduction of operating costs, resulting in additional demand for air-conditioning. Mizobuchi (2008) also found a substantial rebound effect among Japanese households. Last but not least, findings in previous research suggest that households that prefer power-saving investment might not be active in energy-saving behavior but might be insensitive to electricity-saving policy initiatives (Rehdanz, 2007).

Our results show that additional-purchase households are more likely to save electricity. This can be explained by two reasons. The first is the possibility of greater power savings from an additional air-conditioner. Most additional-purchase households, especially those targeted by the EPP, might have purchased air-conditioners for rooms that scarcely need air-conditioning. Therefore, when required, they could save a significant amount of electricity by reducing the use of these rooms in their residence. Compared to households with only the minimum number of air-conditioners, additional-purchase households should be able to readily save power. The second reason is the difference in power-saving consciousness. Households that purchased new air-conditioners in addition to existing units might be well aware of the possibility of an increase in electricity consumption during summer, raising their power-saving consciousness and encouraging their power saving behaviors.

To understand the factors that determine whether to replace an old unit or make an additional purchase, we estimate a model that explains the choice of purchasing mode. Table 4 shows the results of probit models that take REPLACE, ADD, and EFFICIENT_AIR as dependent variables. Regarding the decision to replace a unit, the coefficients of age and altruistic attitudes are positive and statistically significant. On the other hand, additional-purchase households tend to own their house, have a large family, and have higher environmental awareness. Interestingly, households with higher environmental awareness might make additional purchases. This may be one of the reasons that households making additional purchases tend to save electricity, as shown in Table 2.

[Table 4 here]

6. Conclusion

This study investigated the effects of energy-efficient air-conditioners under public electricity conservation directive. Many energy-efficient air-conditioners were purchased during the implementation of the EPP in Japan (May 2009 to March 2011). We divided households that purchased energy-efficient air-conditioners into “replacement” and “additional-purchase” households, and examined the power-saving difference between the two groups. Additional-purchase households attained a significant power-saving, whereas replacement households did not. As discussed in Section 5, (1) a higher potential for power-saving and (2) higher consciousness could possibly neutralize the effects of increased number of appliances. Our results suggest that the degree of power saving might depend on the purchasing form. These differences of purchase mode should be considered for effective policy making.

We should note some limitations of this study. First, whether our analysis appropriately captures the power-saving effect of replacement households is not clear, given the situation in the summer of 2012. The study period is characterized by restricted power usage in most parts of Japan. Thus, most households were probably more conscious of their electricity use during this time. Although we found that replacement households showed statistically insignificant power saving, this might not be true under the usual circumstances. Similarly, the power-saving effect of additional-purchase households might be overestimated. Electricity conservation directive have not been issued since 2013 with a fall in electricity demand and the increase in electricity supply from natural-gas-fired power plants. Therefore, power-saving consciousness might gradually decrease.

The second limitation of this study is the relatively small sample size. Recent studies on energy demand have used large sample sizes (in the thousands or tens of thousands). Our study required actual current and past electricity consumption data (August 2011 and 2012), and respondents were asked to directly send in their power usage data rather than indicate the information on a questionnaire. This limited our sample size raises questions about the generalization of our findings. These limitations remain to be addressed in future research.

Acknowledgements

This research is supported by the Japan Society for the Promotion of Science (Grant-in-Aid for Young Scientists (B) #22730217), which is acknowledged by K. Mizobuchi. K. Takeuchi would like to thank the Department of Economics at the University of Gothenburg for the opportunity provided to him to work as a visiting researcher.

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Table 1. Descriptive statistics of the variables included in the analysis

Variable	Definition	Mean	Std. Dev	Min	Max	No. of Obs
ELEC_2012	Electricity consumption of August 2012（kWh）	438.673	245.662	82.000	1724.000	339
ELEC_2011	Electricity consumption of August 2011（kWh）	437.369	253.888	76.000	1807.000	339
REDUCTION	Power-saving rate of August 2012 (%, year-on-year)	2.473	19.425	-66.500	100.530	339
P_ELEC_2012	Electricity price per kWh in 2012 (yen/ kWh)	22.924	1.937	16.426	26.503	339
P_ELEC_2011	Electricity price per kWh in 2011 (yen/kWh)	23.092	1.850	15.108	26.236	339
EFFICIENT_AIR	Purchased energy efficient air conditioning (yes=1, no=0)	0.233	0.423	0.000	1.000	339
REPLACE	Replaced with energy efficient air conditioning (yes = 1, no = 0)	0.133	0.340	0.000	1.000	339
REPLACE_EPP	Replacement Targeted by the EPP	0.091	0.289	0.000	1.000	339
REPLACE_NO EPP	Replacement Not targeted by the EPP	0.041	0.199	0.000	1.000	339
ADD	Purchased additional energy efficient air conditioning (yes = 1, no = 0)	0.100	0.301	0.000	1.000	339
ADD_EPP	Additional Purchase Targeted by the EPP	0.068	0.252	0.000	1.000	339
ADD_NO EPP	Additional Purchase Not targeted by the EPP	0.032	0.177	0.000	1.000	339
OSAKA	Household in Osaka prefecture (yes = 1, no = 0)	0.372	0.484	0.000	1.000	339
AGE	Age of respondent	44.694	10.827	22.000	75.000	330
INCOME *1	Income level	3.139	1.469	1.000	8.000	317
DETACHED	Single-family house	0.524	0.500	0.000	1.000	336
OWN	Own home (yes = 1, no = 0)	0.664	0.473	0.000	1.000	336
FAM_SIZE *2	Family size	2.868	1.320	1.000	7.000	334
CHILD *3	Number of children under elementary school age	0.198	0.517	0.000	3.000	334
OLD*4	Number of elderly people	0.240	0.556	0.000	2.000	334
NEP	Environmental awareness	16.097	3.129	7.000	25.000	339
ALT	Altruistic character	16.589	2.578	7.000	23.000	339
AIR_N	Number of air-conditions owned	3.525	1.508	1.000	9.000	339
AIR_WIDE	Size of room where main air conditioner installed	10.509	4.406	1.000	25.000	327
TEMP_2012	Average outside air temperature of August 2012（℃）	28.509	0.528	27.680	29.473	339
TEMP_2011	Average outside air temperature of August 2011（℃）	27.830	0.689	26.494	29.038	339

*1: Under 2 million yen = 1, 2–4 million yen = 2, 4– 6 million yen = 3, 6–8 million yen = 4, 8–10 million yen = 5, 10–12 million yen = 6, 12–14 million yen = 7, over 14 million yen = 8.

*2: one = 1, two = 2, three = 3, four = 4, five = 5, six = 6, seven = 7, eight = 8, nine = 9, over ten = 10.

*3: zero = 0, one = 1, two = 2, three = 3, four = 4, over five = 5.

*4: zero = 0, one = 1, two = 2, three = 3, four = 4, over five = 5.

Table 2. Estimation results

	log(ELEC_2012)				log(ELEC_2011)				REDUCTION			
	(1)		(2)		(3)		(4)		(5)		(6)	
OSAKA	-0.129	**	-0.135	***	-0.068		-0.072		-10.039	***	-10.257	***
	(0.052)		(0.052)		(0.057)		(0.057)		(3.390)		(3.412)	
EFFICIENT_AIR	-0.089	*			-0.051				-3.811			
	(0.049)				(0.049)				(2.372)			
REPLACE			-0.012				0.013				-1.904	
			(0.057)				(0.055)				(2.820)	
ADD			-0.202	***			-0.146	**			-6.681	*
			(0.071)				(0.072)				(3.426)	
AGE	0.004	*	0.004	*	0.006	**	0.005	**	-0.099		-0.107	
	(0.002)		(0.002)		(0.002)		(0.002)		(0.106)		(0.106)	
INCOME	0.020		0.018		0.002		0.001		1.480	*	1.436	*
	(0.017)		(0.016)		(0.019)		(0.019)		(0.858)		(0.859)	
OWN	0.089		0.096		0.121	*	0.127	*	-4.327		-4.150	
	(0.058)		(0.058)		(0.065)		(0.065)		(3.166)		(3.178)	
DETACHED	-0.160	***	-0.166	***	-0.140	**	-0.145	**	-3.868		-4.034	
	(0.059)		(0.058)		(0.063)		(0.062)		(3.106)		(3.106)	
FAM_SIZE	0.132	***	0.133	***	0.135	***	0.136	***	-0.047		-0.036	
	(0.024)		(0.024)		(0.026)		(0.026)		(1.089)		(1.082)	
CHILD	-0.096	**	-0.092	***	-0.067		-0.064		-3.400		-3.306	
	(0.047)		(0.047)		(0.048)		(0.048)		(2.513)		(2.491)	
OLD	0.129	***	0.131	**	0.114	***	0.115	***	-0.096		-0.058	
	(0.042)		(0.042)		(0.044)		(0.043)		(1.833)		(1.818)	
NEP	0.000		0.003		0.005		0.007		-0.627	*	-0.570	
	(0.007)		(0.007)		(0.007)		(0.007)		(0.357)		(0.365)	
ALT	-0.016	*	-0.018	**	-0.010		-0.012		-0.709		-0.763	
	(0.008)		(0.009)		(0.009)		(0.009)		(0.504)		(0.509)	

Table 2. (Cont'd)

	(1)		(2)		(3)		(4)		(5)		(6)	
AIR_N	0.137	***	0.138	***	0.128	***	0.129	***	1.113		1.122	
	(0.020)		(0.020)		(0.020)		(0.019)		(0.859)		(0.854)	
AIR_WIDE	0.018	***	0.018	***	0.019	***	0.019	***	-0.034		-0.038	
	(0.005)		(0.006)		(0.006)		(0.006)		(0.239)		(0.240)	
P_ELEC_2011					0.043	**	0.042	**				
					(0.017)		(0.017)					
P_ELEC_2012	0.059	***	0.058	***								
	(0.014)		(0.015)									
DIFF_P_ELEC									-3.050	*	-3.071	*
									(1.646)		(1.648)	
TEMP_2011					-0.014		-0.016					
					(0.0370)		(0.037)					
TEMP_2012	0.052		0.047									
	(0.044)		(0.044)									
DIFF_TEMP									2.257		2.217	
									(2.876)		(2.902)	
Constant	2.153	*	2.350	*	4.142	***	4.249	***	28.537	***	29.069	***
	(1.289)		(1.284)		(1.117)		(1.114)		(10.791)		(10.778)	
Observations	310		310		310		310		310		310	
R-squared	0.552		0.558		0.514		0.519		0.100		0.103	

1. ***, **, and * represent statistical significance at the 1%, 5%, and 10% levels, respectively.
2. Standard errors are in parentheses.
3. DIFF_P_ELEC = P_ELEC_2012 - P_ELEC_2011
4. DIFF_TEMP = TEMP_2012 - TEMP_2011

Table 3. Electric rate structure for the household sector

Kansai Electric Power CO. INC. *1			
Minimum charge	First 14 kWh	333.00	yen
	15 to 120 kWh	19.38	yen
Electric power charge (per kWh)	121 to 300 kWh	24.54	yen
	Above 301 kWh	25.88	yen

Shikoku Electric Power CO. INC. *2			
Minimum charge	First 11 kWh	392.70	yen
	12 to 120 kWh	19.45	yen
Electric power charge (per kWh)	121 to 300 kWh	25.77	yen
	Above 301 kWh	29.12	yen

*1. http://www.kepco.co.jp/

*2. http://www.yonden.co.jp/

Table 4. Probit model for the purchase decision on energy efficient air conditioners

VARIABLES	EFFICIENT_AIR (i) REPLACE		EFFICIENT_AIR (ii) ADD		(iii) EFFICIENT_AIR	
AGE	0.016	*	-0.005		0.010	
	(0.009)		(0.009)		(0.008)	
INCOME	0.096		-0.016		0.061	
	(0.061)		(0.054)		(0.053)	
OWN	0.128		0.421	*	0.274	
	(0.235)		(0.256)		(0.201)	
FAM_SIZE	0.018		0.182	**	0.095	
	(0.082)		(0.0907)		(0.072)	
NEP	-0.040		0.089	***	0.021	
	(0.033)		(0.033)		(0.028)	
ALT	0.067	*	-0.053		0.010	
	(0.037)		(0.040)		(0.033)	
log(ELEC_2011)	0.208		-0.407	*	-0.040	
	(0.181)		(0.219)		(0.167)	
Constant	-4.000	***	-0.085		-2.129	**
	(1.158)		(1.3601)		(1.047)	
Observations	314		314		314	
Log likelihood	-119.558		-89.400		-164.193	

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

2. Standard errors are in parentheses.

Figure 1. Service Areas of the Ten Major Electric Power Companies in Japan