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How much household electricity consumption is actually saved by replacement with Light-Emitting Diodes (LEDs)?

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Abstract

Many countries have promoted the replacement of conventional lamps with next-generation lamps to reduce electricity usage for lighting. In Japan, the majority of the lamps sold at home appliance mass merchant shops have been changed from incandescent lamps to energy-saving lamps. All conventional lamps are planned to be replaced with light-emitting diodes (LEDs) by 2020. Although the energy-saving effect of LEDs has been stressed in many engineering studies, the amount of electricity that is actually saved by the installation of LEDs has not been examined. Using microlevel data from the Survey on Carbon Dioxide Emission from Households (SCDEH), we compare monthly electricity usage between households using conventional lamps and those using LEDs. Our empirical results demonstrate that households have reduced their electricity usage by 1.96% through past LEDization. Households can reduce their electricity usage by an additional 6.99% when LEDization is completed. The empirical results further demonstrate that middle-income households have higher price elasticity of electricity demand and are more likely to receive greater benefit from LED installation.

JEL classification: C23, D12, Q41
Keywords: Energy Saving; Household Electricity Usage; LEDization; Microlevel Data

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1. Introduction

According to an estimation by the International Energy Agency (2016), the residential sector accounted for 21% of the final energy consumption worldwide in 2013. Although there are considerable variations in energy usage across countries, on average, households use 52% of energy for space heating. Compared to the share for space heating, the share of energy consumption for lighting is relatively small and accounts for only 4%.

Therefore, the importance of lighting in energy consumption is relatively small. Nevertheless, countries have undertaken great efforts to reduce electricity usage for lighting. Many countries have introduced a phase-out program of incandescent lamps, and some countries have banned their sales (Dick 2016). The European Commission adopted a regulation on nondirectional household lamps that aimed to replace inefficient incandescent lamps with more efficient alternatives in March 2008 (European Commission 2009). The ban was enforced against almost all types of incandescent lamps in 2017.[5] The US President George W. Bush signed into law the Energy Independence and Security Act of 2007 in December 2007. Although this act does not directly prohibit the sales of incandescent lamps, it requests an increase in the energy efficiency of lamps by 25% from 2012 to 2014 (US Department of Energy 2012; US Environmental Protection Agency 2011). Consequently, the act "effectively" bans the manufacturing and importing of conventional incandescent lamps.

The Japanese government asked domestic manufacturers to stop the production of incandescent lamps in 2008. Since then, the majority of the lamps sold at home appliance mass merchant shops have been changed from incandescent lamps to energy-saving lamps. In November 2015, the Japanese government announced the idea of strengthening the regulation of incandescent and fluorescent lamps and accelerated their replacement with light-emitting diodes

[5] Currently, non-directional halogen lamps, such as standard GLS or candle lamps, are treated as exceptions. However, they will also be banned in September 2018 (Lightbulbs Direct 2018).

(LEDs) to improve the energy efficiency of houses (Nippon Television 2015). In Japan, both incandescent and fluorescent lamps are planned to be replaced with LEDs by 2020.

LEDs are energy efficient and last longer than conventional incandescent lighting. According to the US Department of Energy (2015), residential LEDs use at least 75% less energy and last 25 times longer than incandescent lighting. Therefore, households can reduce their electricity bills by installing LEDs. Despite this cost advantage, LEDs have not been popular technology until recently. Some consumers have complained that LEDs emit a cold, unnatural light compared to conventional lamps. Other consumers complain about the cost of LEDs. Previous studies have repeatedly reported that high upfront costs of energy-efficient products discourage consumers from purchasing them (Poortinga et al. 2003; Gillingham, Newell, & Palmer 2009; Nair, Gustavsson, & Mahapatra 2010; Karlin et al. 2014; Frederiks, Stenner, & Hobman 2015; Matsumoto 2015). In recent years, scholars have investigated household investment in energy-saving lamps (Mills & Schleich 2010; Gram-Hanssen 2013; Ameli & Brandt 2015). These studies confirmed that household income determines the investment decision regarding energy-efficient lamps; in particular, they found that high upfront cost discourages low-income households from purchasing energy-efficient lamps.

Thomas Edison's great invention (the incandescent lamp) has changed our daily life drastically. His invention enabled us to perform tasks at night time that used to be possible only during the day. Will LEDs also change our daily life by lighting homes at a much lower cost?

The replacement of incandescent lights with LEDs is expected to accelerate increasingly in the near future. Though engineers provide estimates of cost savings in an ideal situation, studies have not yet investigated how the electricity usage of households is changed *in reality* by replacement with LEDs. The cost savings from LED installation depend on how consumers behave after they install LEDs. For example, if consumers understand the efficiency of LEDs, they may leave their LED lights on more than before. In this case, the cost savings from LED may not be as large as engineers predict.[6] Is there a difference in the size of the benefits of energy savings across households? Who will receive the greatest benefit from LED installation? We answer these questions in this paper.

The rest of the paper is organized as follows. In the next section, we provide background information about the Japanese lighting market. We also summarize the electricity usage of Japanese households. In this study, we use microlevel data from the Survey on Carbon Dioxide Emission from Households (SCDEH) (Ministry of the Environment of Japan 2016). We provide information about the SCDEH and summarize the data in Section 3. After controlling for dwelling characteristics, socioeconomic characteristics, appliance ownership, and geographical conditions of households, we compare monthly electricity usages between households using conventional lamps and those using LEDs. Section 4 presents the estimation model, and Section 5 reports the empirical findings. The empirical result demonstrates that households can reduce their household electricity usage by 2.3%-2.8% with the installation of LEDs. The empirical result further shows that middle-income households have higher price elasticity and are likely to receive greater benefit from LED installation. Section 6 makes policy recommendations based on the empirical findings.

2. Japanese Lighting Market

According to the statistics from the Agency for Natural Resources and Energy of Japan (2015), the final energy consumptions of the industry, commercial, household, and transportation sectors were 6.14, 2.46, 1.87, and 3.08 $\times$ 10^{18}J, respectively. Thus, the household sector accounted for 13.8% of the final energy consumption in 2015. In terms of the composition of energy sources,

[6] There is an opinion that the banning of incandescent lamps has not achieved as much of a reduction in energy use as was initially hoped. Households increased the number of lamps in the home and switched to halogen downlighters (Hickman 2012).

electricity, city gas, LP gas, kerosene, and solar constituted 16,918, 7,062, 3,519, 5,135, and 260 $\times$ 10^6J, respectively (Institute of Energy Economics of Japan 2015). Therefore, the share of electricity was approximately 52.5% in 2015.

Figure 1 presents the historical change in the monthly electricity usage of the average Japanese household. The electricity usage showed an upward trend until 2010. However, it became a downward trend after the Great East Japan Earthquake in 2011. In 2015, the average Japanese household used approximately 247.8 kWh of electricity per month. Based on an estimation by the Institute of Energy Economics of Japan (2015), the average household uses 708×10^6J of electricity for space cooling, 7,367 $\times$ 10^6J for space heating, 9,495 $\times$ 10^6J for water heating, 3,069 $\times$ 10^6J for cooking, and 12,256 $\times$ 10^6J for lighting and appliances. According to the estimation by the Ministry of Economy, Trade, and Industry (METI) of Japan (2011), the average household allocated approximately 13.4% of electricity for lighting in 2009.

In June 2010, the Cabinet approved the New Growth Strategy and established the installation of next-generation lighting systems as one of the national strategies for creating an environmentally friendly and energy-efficient country through green innovations. According to the target, 100% of LED and organic EL lighting will be realized by 2020 on a flow basis and by 2030 on a stock basis. To accelerate the lighting renovation of factories and business offices, many local governments have introduced various subsidy programs. Due to a series of such promotion policies, LEDs have become popular in Japan.

The Japan Lighting Manufacturers Association (JLMA) conducts a survey on shipping status among its member companies every year. Figure 2 presents the historical change in the share of the shipment of lamps from the JLMA (2017). The figure clearly shows that the market share of LEDs has been expanding while the shares of incandescent lamps (general and micro lamps) and fluorescent lamps have been decreasing. Nevertheless, the market share of LEDs increased from

2.0% in 2010 to 12.7% in 2016 alone. This pace is not sufficient to achieve the LED replacement target by 2020.

3. Data

3.1. Data Source

The data used in this analysis are obtained from the SCDEH (MOEJ, 2016)[7]. The SCDEH is a monthly survey conducted by the Ministry of the Environment of Japan (MOEJ) between October 2014 and September 2015. It uses both in-person and Internet surveys and includes samples of 16,402 households (8,802 households from the in-person survey and 7,600 households from the Internet survey) from all parts of Japan. As the title of the survey suggests, the survey is designed to study the energy usage of households. Information about the monthly electricity usage of individual households is also included. The survey contains household information typically included in the analysis of household electricity usage (Frederiks et al. 2015): socioeconomic characteristics, dwelling characteristics, ownership of home appliances, and geographical conditions. In addition, information about LED installation is included.

3.2. Data summary

3.2.1. Data summary

Table 1 shows the descriptive statistics by household composition and income class. On average, multiple-person households use more electricity, have higher income and more appliances, live in larger houses, and behave in more eco-friendly ways than single-person households. The share of single-person households is large in the lowest income class, comprising approximately half of that income group. Household income affects the amount of time that

[7] This survey was a pilot survey. The actual survey (the Statistical Survey on Actual Carbon Dioxide Emission from Households) began in April 2017.

people stay at home; people in the low income classes spend more time at home and go out less frequently.

The table shows that household electricity consumption increases with higher income classes. The average electricity consumption of the lowest income class is 272.68 kWh per month, while that of the highest income class is 571.67 kWh per month. The survey contains information about the monthly electricity bill. We calculated the average electricity price by dividing the amount of the electricity bill by the amount of electricity consumption. The households in the lowest income class pay 26.90 per kWh on average, while those in the highest income class pay 28.13 per kWh. Hence, households in high income classes pay a higher electricity price. This is because the block pricing scheme is used in Japan.[8] Since high-income households consume more electricity, they face a higher electricity price.

The table also shows that high-income households own more home appliances. The average household in the lowest income class owns 1.51 televisions (TVs), 1.50 air conditioners (ACs), and 0.87 personal computers (PCs), while the average household in the highest income class owns 2.58 TVs, 3.84 ACs, and 2.25 PCs. Households that intend to use more home appliances require a higher circuit breaker amperage capacity.[9] The basic charge for the electricity contract increases as the circuit breaker amperage capacity increases. Since high-income households own more appliances, they make contracts at a higher amperage capacity. Consequently, they face a higher electricity price.

3.2.2. LED installation status

In the survey, households were asked whether they had installed LEDs in the living room,

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[8] The unit price of electricity increases as the amount of electricity consumption increases.
[9] The contracted ampere capacity is an indication of the volume of electricity that can be used at any one time.

dining room, kitchen, and bedroom. Table 2 shows the correlation of installation across rooms. The table suggests that households that install LEDs in the living room tend to install LEDs in other rooms. Due to this correlation, it is difficult to estimate the impact of LED installation for each room separately. In this study, we assume that households have completed LEDization if they answered that they were using only LEDs in all rooms. Alternatively, if households answered that they did not use LEDs in any room, we assume that households were in the zero LEDization stage. In our dataset, 525 households are in the complete LEDization stage while 4,094 households have been in the zero LEDization stage.

The remaining 6,819 households use LEDs in some rooms but not in all rooms. Thus, these households are in the partial LEDization stage. We use Item Response Theory (IRT) to assess the difficulty of installing LEDs for four types of rooms. See Appendix 1 for details. According to the estimation results, LED installation is progressing in the order of living room, dining room, bedroom, and kitchen. Since a typical household starts its LEDization in the living room, we evaluate the electricity savings due to LED replacement in the living room. This estimation shows the amount of energy savings that households experience in the first stage of LEDization.

Previous studies, such as those by Mills and Schleich (2010), Ameli and Brandt (2015) and Das et al. (2018), report that household income determines the likelihood of the installation of energy-efficient technologies. We also find that household income determines the type of lamps installed. Figure 3.a. shows the type of lamps installed in the living room in the SCDEH. Since several varieties of lamps could be installed in the living room, multiple responses are allowed. Households respond “yes” if any corresponding lamp is installed. Therefore, the sum of the shares of incandescent, fluorescent, and LED lamps may be greater than 100% in the survey.[10] The figure shows that the most popular lamp is a fluorescent lamp; 62.3% of households answered

[10] We create a dummy variable, taking 1 for the household using LEDs most frequently in the living room, and use it as an LED installation variable in the following analysis.

that they installed a fluorescent lamp in the living room. In contrast, 34.7% of households installed an incandescent lamp, and only 11.4% of households installed LEDs. The figure further shows that the likelihood of LED installation increases as the income class increases. We observe a similar pattern for incandescent lamp installation; namely, high-income households install incandescent lamps more frequently. In contrast, we find the opposite pattern with regard to fluorescent lamp installation; high-income households install fluorescent lamps less frequently.

Previous studies find that the age of the head of household influences the energy-saving investment. In general, the likelihood of energy-saving investment shows an inverse U shape. Middle-aged households invest in energy-saving technologies most frequently. However, in the case of energy-efficient lamps, Ameli and Brandt (2015) and Das et al. (2018) find that the age of the household head does not affect the likelihood of installation. In Figure 3.b., we compare the type of lamps by the age of the household head. This figure shows that the age of the household head does not determine the likelihood of LED installation. However, we find that the age of the household head determines the likelihood of the other two types of lamps; elderly households tend to use fluorescent lamps, while young households tend to use incandescent lamps.

Figure 3.c. shows the relationship between the type of lamps and the construction age of houses. The figure shows that LEDs are being installed in houses built after 2011 at a rate nearly twice as high as that of houses built previously. Fluorescent lamps are the most popular type of lamp in houses built before 2011. Although the share of incandescent light bulbs has been relatively small, it increased until 2011.

Respondents to the survey were also asked about the type of the lamp most frequently used in the living room. According to the survey results, households that use LEDs most frequently consume 434.5 kWh of electricity per month. Households that use incandescent lamps most frequently consume 408.7 kWh, while households that use fluorescent lamps most frequently consume 399.1 kWh. Not surprisingly, households that consume more electricity tend to install

LEDs. This finding suggests that we need to control the factors that influence household electricity usage before assessing the impact of LED installation.

4. Model

In this study, we employ Conditional Demand Analysis (CDA) to evaluate the determinants of household electricity consumption. CDA is a statistical technique for estimating the household electricity consumption of various appliances by combining survey, consumption, and weather data. CDA was developed by Parti and Parti (1980) and has been used by many scholars, including Aigner et al. (1984), LaFrance and Perron (1994), Leahy and Lyons (2010), Newsham and Donnelly (2013), and Matsumoto (2016). The model used in this study is given by

$$\ln E_{it} = \alpha + \beta LED_i + \boldsymbol{\Gamma}'\boldsymbol{X}_i + \boldsymbol{\Theta}'\boldsymbol{Z}_{it} + \omega_j + \omega_t + \varepsilon_{it} \ , \qquad (1)$$

where E_{it} is household i's electricity consumption in month t. $\boldsymbol{X}_i$ is the vector of control variables composed of the socioeconomic characteristics of households, housing conditions, and the ownership of 11 varieties of home appliances, while $\boldsymbol{Z}_{it}$ is the vector of control variables that vary between sampling months (namely, the electricity price and the vacancy dummy variable). LED_i is a dummy variable that shows the LEDization stage of household i. ω_j and ω_t are variables that measure regional and monthly fixed effects, respectively. Finally, ε_{it} is the error term.

We need to pay attention to the interpretation of the estimated coefficient of a binary explanatory variable in a semilogarithmic model. When dummy variables are included in a semilog model, the resulting coefficients are not equal to percentage changes (Halvorsen & Palmquist, 1980). For the estimated coefficient corresponding to a dummy variable, such as β in Equation 1, the percentage effect on electricity consumption (in our case) is $100 \times (e^{\beta} -$

1) according to Halvorsen and Palmquist (1980). Kennedy (1981) improved upon Halvorsen and Palmquist (1980) with a less biased estimator calculated by $100 \times (e^{\beta - \frac{1}{2}\sigma_{\beta}^{2}} - 1)$. Giles (1982) showed that the estimator suggested by Kennedy (1981) leads to interpretations that are negligibly different from those arising from the minimum unbiased estimator he proposed. Thus, we calculate the less biased estimators, using Kennedy's (1981) approach, from the estimated coefficients implied by the dummy variables in the regression and use these estimators to interpret our results.

5. Results

5.1. Comparison with previous research

The estimation results are presented in Table 3. Although we controlled for both regional and seasonal effects in all the models, we omitted them from Table 3 for the sake of brevity.

Before assessing the impact of LED installation, we verify the validity of our estimation results based on Model 1, which includes the data of all households. First, the sign of all appliance variables becomes positive and statistically significant. METI (2011) estimated the electricity usage of various appliances based on the 2009 data. In Figure 4, we compare the shares of electricity usage for measured appliances estimated from this estimation with those estimated from METI's study. Compared to METI's study, the SCDEH study presents a higher usage share for ACs but presents a lower usage share for refrigerators and TVs. These results seem to be consistent with the fact that from METI's survey in 2009 to the SCDEH survey in 2016, the energy efficiency of refrigerators improved and the watching time of TVs decreased, but the number of air conditioners increased.

In terms of housing variables, we obtained the expected results from previous studies: electricity usage increases as the floor area of houses increases; households living in new houses use less electricity than those living in old houses; and households living in apartment housing use less electricity than those living in detached houses.

The results of the demographic variables are consistent with those of previous studies. Model 1 shows that electricity usage increases as the number of family member increases. Electricity consumption increases as the age of the household head increases. The presence of children between 10-19 years old increases electricity usage, while the presence of elderly persons over 75 years old decreases it.

The survey asked whether all family members spent more than 5 days outside the house. The result shows that electricity usage decreases on vacant days. The survey further asked whether someone usually stayed at home during the day on weekdays. The table shows that electricity usage increases if someone stays at home during the day on weekdays.

The income variable became positive and statistically significant in Model 1. Therefore, we find that electricity usage increases as household income increases even after controlling for appliance ownership and housing conditions. This finding may suggest that wealthy households use appliances more intensively than less wealthy households do. According to our estimation, the income elasticity of demand is approximately 0.07. Espey and Espey (2004) conducted a meta-analysis of 36 studies published between 1971 and 2000. They reported that short-run income elasticities range between 0.04 and 3.48. They further reported that the majority of previous studies estimated low income elasticities, and income elasticities tend to be estimated as lower when appliance stock is controlled. Therefore, our finding is consistent with their finding.

We calculate the (average) electricity price by dividing the electricity bill by electricity consumption. We then estimate the price elasticity of electricity demand. Although there are several studies that have estimated income-specific price elasticities of electricity based on micro data analysis (Baker et al. 1989; Baker and Blundell 1991; Nesbakken 1999; Meier et al. 2013; Schulte and Heindl 2017), none of them controlled for the appliance ownership condition.

Furthermore, all of the studies estimated price elasticities in Western countries. According to our calculation presented in Model 1, the price elasticity of electricity demand is approximately 1.32. Espey and Espey (2014) reported that price elasticities in the previous studies vary between 0.004 and 2.01. Therefore, our estimation result is within the range of the previous studies.

5.2. Energy savings through LEDization

5.2.1 Energy savings through LEDization

In Table 3, we compare the electricity usage of households that have not installed any LED lamps with that of the remaining households. We insert a zero LEDization dummy variable in Equation 1 to estimate the amount of electricity that households have saved through LEDization. The results are presented from Model 1 to Model 3. The zero LEDization variable becomes positive and statistically significant in Models 1 and 2. According to our calculation in Model 1, households have reduced their yearly electricity usage by approximately 102.2 kWh through past LEDization. Similarly, multiperson households have reduced their yearly electricity usage by approximately 123.7 kWh. In contrast, the LED installation variable became insignificant for single-person households in Model 3.

In Models 4 to 6, we compare the electricity usage of households that have already completed LEDization with that of households that have not yet completed LEDization. The complete LEDization variable becomes negative and statistically significant. According to our calculation, the yearly electricity usage of households that completed LEDization is lower by 347.9 kWh than that of the remaining households. The result suggests that households can save approximately JPY 9,393.2 annually by further proceeding with LEDization; thus, the rate of additional electricity savings expected in future is estimated to be approximately 6.99%. Based on the estimation by METI (2013), the expected electricity savings rate is approximately 4.3%.[11] The result suggests that the energy-saving benefit might be underestimated in the present policy debates. Although we focused on multiperson households in Model 5, the LED installation variable becomes negative and statistically significant. According to our calculations, the average multiperson household saves approximately JPY 11,632.4 annually, which is approximately 7.81% of the electricity savings rate.

In Models 7 to 9, we choose zero-LEDization households as the base and compare the electricity savings of partial-LEDization households with that of complete-LEDization households. The result in Model 7 shows that households reduce their electricity usage by 1.52% at the partial LEDization stage and reduce electricity usage by 7.94% at the complete LEDization stage. The estimated impacts of partial and complete LEDization are more or less similar to the findings in Models 1 to 6.

5.2.2. LEDization benefits for different income-class households

As we mentioned previously, a majority of households are in the partial LEDization stage. Based on the result of IRT analysis, we define the households that use LEDs most frequently in the living room as the average household. We then estimate the LEDization effect of this average household. According to the results presented in Table 4, the average household has reduced its yearly electricity usage by 137.5 kWh through LEDization. In contrast, the average multiperson household has reduced its yearly electricity usage by 236.5 kWh.

In addition, we classify households into six income classes and estimate the impact of LEDization for each income class. The LED installation variable became negative and significant in Model 17. This result suggests that middle-income households are likely to benefit from

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[11] See Appendix 2 for the assumptions for this calculation.

LEDization more than low- or high-income households.

Furthermore, we estimate the price elasticity for each income class. Models 14 to 19 in Table 4 show that the price elasticity of the middle income class is higher than that of the low and high income classes. In other words, the middle income class is more sensitive to the price of electricity. This result is consistent with the findings by Baker et al. (1989).

5.2.3. Robustness check: Inclusion of energy-saving activities

If households that installed LEDs paid closer attention to electricity consumption, then the regression of Equation 1 would suffer from omitted variable bias. In the survey, subjects were asked whether they adjusted the brightness of lights and turned lights off frequently. We include the responses for energy-saving activities to solve the omitted bias problem. Specifically, we estimate the following equation:

$$\ln E_{it} = \alpha + \beta LED_i + \boldsymbol{\Gamma}'\boldsymbol{X}_i + \boldsymbol{\Theta}'\boldsymbol{Z}_{it} + \boldsymbol{\Lambda}'\boldsymbol{ESB}_i + \omega_j + \omega_t + \varepsilon_{it}, \tag{2}$$

where $\boldsymbol{ESB}_i$ is a vector of energy-saving activity dummies. These dummy variables take a value of 1 if household i answered that it adjusts the brightness of lamps or switches off lights frequently. Here, LED_i is the dummy variable for households that use the LED most frequently in the living room.

In the survey, 55.3% of households answered that they adjusted the brightness of lights, while 81.6% answered that they turned lights off frequently. Therefore, the latter is more common than the former. Figure 5.a. shows the intensity of the energy-saving activities of different income class households. This figure shows that middle-income households practice two types of energy-saving activities more often than the lowest- or highest-income households do. Figure 5.b. shows that the likelihood of engaging in energy-saving activities generally increases as the age of the household head increases. Finally, Figure 5.c. presents the relationship between housing age and energy-saving activities. This figure shows that households living in new houses are more likely to turn lights off frequently, but no systematic relationship is found between housing age and brightness adjustment.

The estimation result of Equation 2 is presented in Model 11 in Table 3. The parameter value of the LED installation in Model 11 is somewhat smaller than that in Model 10 (2.79% vs. 2.27%). This discrepancy suggests that the energy-saving effect of LED installation is overly estimated in Model 10.

Model 11 shows that electricity usage can be reduced by 3.07% if households adjust the brightness of lights. Furthermore, households can reduce their electricity usage by 6.54% if they switch lights off frequently. These results suggest that energy-saving activities are important for energy saving.

6. Conclusions and Policy Implications

In this study, we analyzed comprehensive data on household electricity usage and evaluated the energy-saving effects of LED installation and energy-saving behaviors. Households have reduced electricity usage by 1.96% through past LEDization, with an annual cost savings of approximately 2,759 JPY. However, households can further reduce electricity usage for lighting by further proceeding with LEDization. According to our estimation, if LEDization is completed, electricity usage will be reduced by 6.99%.

All our empirical results suggest that the energy savings due to LED installation is sizable and that the acceleration of LEDization is beneficial. However, as mentioned earlier, the progress of LEDization is slow. We need to understand the obstacles for LEDization among households and must find effective measures to remove them.

We also found a sizable energy-saving effect through energy-saving activities, as found in other Japanese studies (Arimura et al. 2018). Policies to encourage energy-saving activities are crucial for the energy conservation of the residential sector in addition to policies to promote LED installation. This area is important to energy conservation policy.

Moreover, our estimation results suggest that the price elasticities of electricity as well as the energy savings through LEDization vary across households depending on income level. In particular, the estimation results suggest that middle-income households have a higher price elasticity and would have a larger potential for energy savings. If this is the case, power companies can reduce electricity demand by charging a higher price to this group of households. Therefore, variation in price elasticity across households should be further examined in future research.

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Appendix 1: Order of the LED installation for rooms

We rely on Item Response Theory (IRT) to assess the difficulty of LED installation for four types of rooms. Let Y_{ij} represent the LED installation status for room i by household j. The probability that household j installs LED lamps for room i is given by the following logistic function,

$$\Pr\left(Y_{ij} = 1 \middle| a_i, b_i, \theta_j\right) = \frac{Exp\{a_i(\theta_j - b_i)\}}{1 + Exp\{a_i(\theta_j - b_i)\}}$$

where a_i represents the discrimination parameter for room i, b_i represents the difficulty of installing LED lamps for room i, and θ_j represents the latent level (the LEDization ability) of household j. Let $p_{ij} = \Pr\left(Y_{ij} = 1 \middle| a_i, b_i, \theta_j\right)$ and $q_{ij} = 1 - p_{ij}$. Then, the conditional density of household j is

$$f(\boldsymbol{y}_j|\boldsymbol{\Gamma},\theta_j) = \prod_{i=1}^{4} p_{ij}^{y_{ij}} q_{ij}^{1-y_{ij}}$$

where $\boldsymbol{y}_j$ is the vector of the LED installation of four types of rooms and $\boldsymbol{\Gamma} = (a_1,\cdots,a_4,b_1,\cdots,b_4)$.

The likelihood for household j is

$$L_j(\boldsymbol{\Gamma}) = \int f(\boldsymbol{y}_j|\boldsymbol{\Gamma},\theta_j)\, \phi(\theta_j) d\theta_j$$

where $\phi(\theta_j)$ is the density function for the standard normal distribution. We find the combination of the parameters that maximizes the log likelihood function,

$$log\, L(\boldsymbol{\Gamma}) = \sum_{j=1}^{N} log L_j(\boldsymbol{\Gamma}).$$

Figure A.1. measures θ_j (the ability of LEDization) on the horizontal axis and probability on the vertical axis. Four logistic curves in the figure show the probability of LED installation under a specific ability. The figure shows that a typical household performs LEDization in the order of living room, dining room, bedroom, and kitchen.

Appendix 2: Difference between actual and hypothetical energy savings

This appendix explains the engineering calculation of the impact of LED installation. We impose the following three assumptions in this calculation.

1. The usage of lamps remains the same after LED installation.
2. For the energy efficiencies of lamps, the values in METI (2013) are used.
3. If a household uses multiple types of lamps, we consider the lamp with the longest operating time as the lamp the household uses.

Table A.1 shows the electricity consumption of each type of lamp reported in METI (2013). The wattage of an LED lamp is more than one-fifth of the wattage of an incandescent lamp and three-quarters of the wattage of a fluorescent lamp.

Table A.2 presents the following calculated values for the engineering calculation of the replacement impact of conventional lamps with LED lamps. Electricity consumption will be reduced by 83.41% through the replacement of incandescent lamps with LED lamps, while it will be reduced by 25.35% through the replacement of a fluorescent lamp with an LED. According to the estimation by METI (2011), a typical household uses 13.4% of electricity for lighting. Therefore, the impact of the replacement of an incandescent lamp with an LED lamp on the total household electricity usage becomes $\Delta_1(\%) = 13.4 \times 0.8341$, while the impact of the replacement of a fluorescent lamp with an LED lamp becomes $\Delta_2(\%) = 13.4 \times 0.2535$.

In the SCDEH, 7.77% of households responded that they used incandescent lamps most frequently, while 58.96% of them responded that they used fluorescent lamps most frequently (Table A.1). If these two types of households are combined, approximately 66.73% of households have energy-saving potential. The relative share of incandescent-lamp households is $s_1 = 7.77 \div 66.73$, while the relative share of fluorescent-lamp households is $s_2 = 58.96 \div 66.73$. Consequently, the expected energy savings from LED replacement becomes $4.3\% = s_1\Delta_1 + s_2\Delta_2$.

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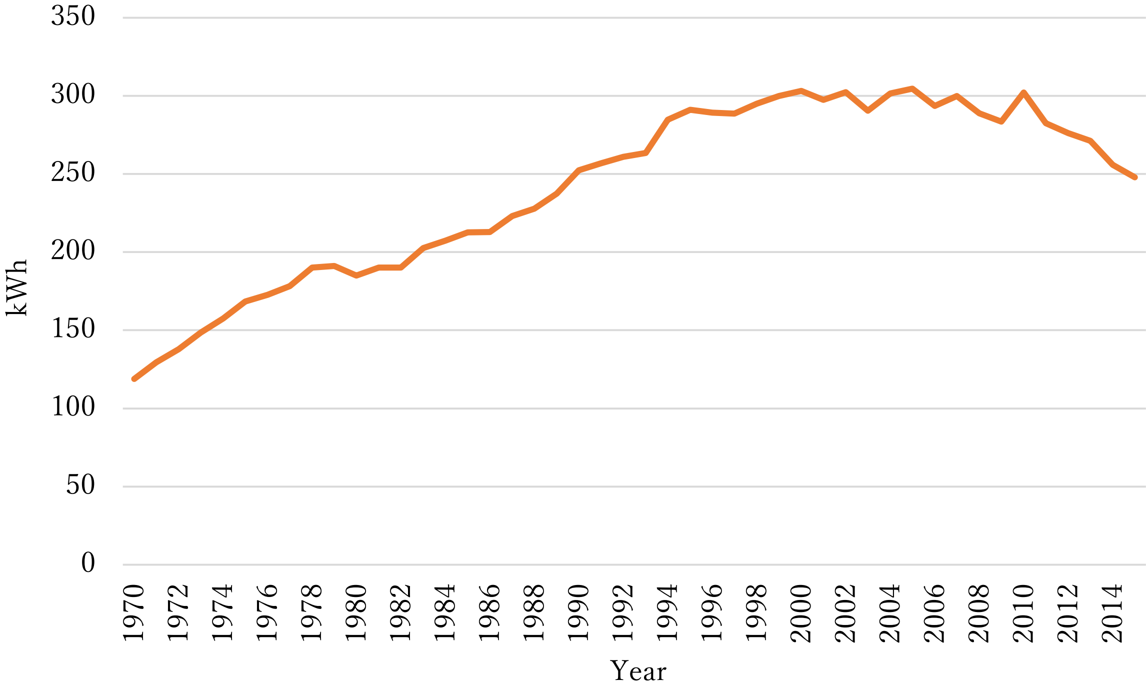
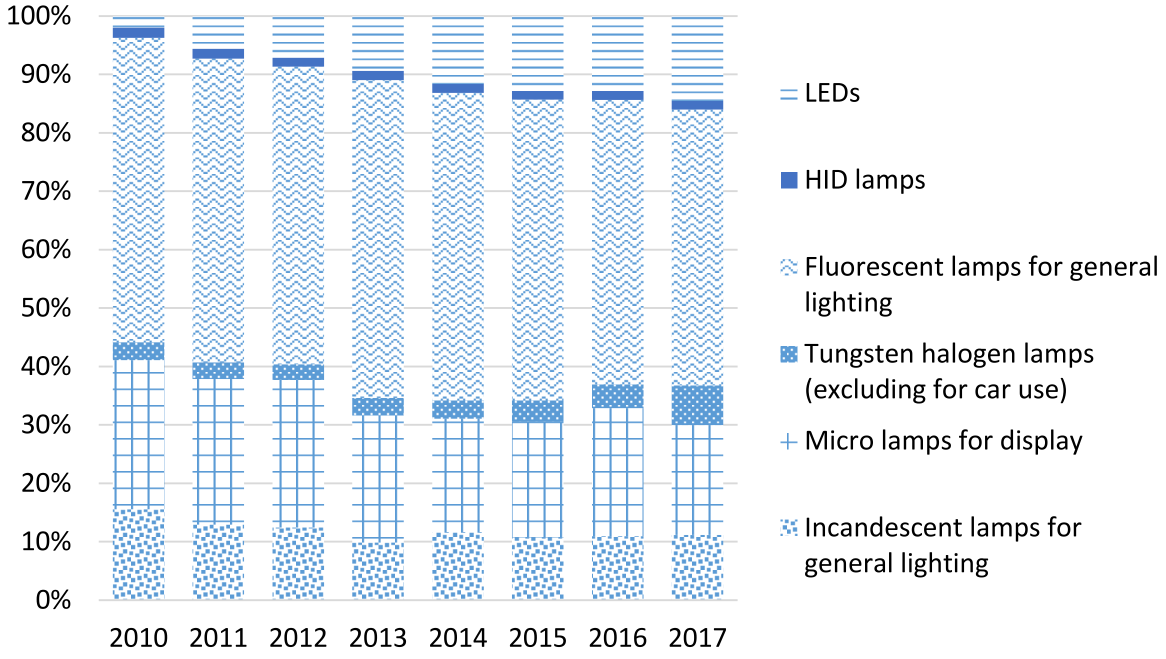
Figure 1. Change in electricity usage of the average Japanese household



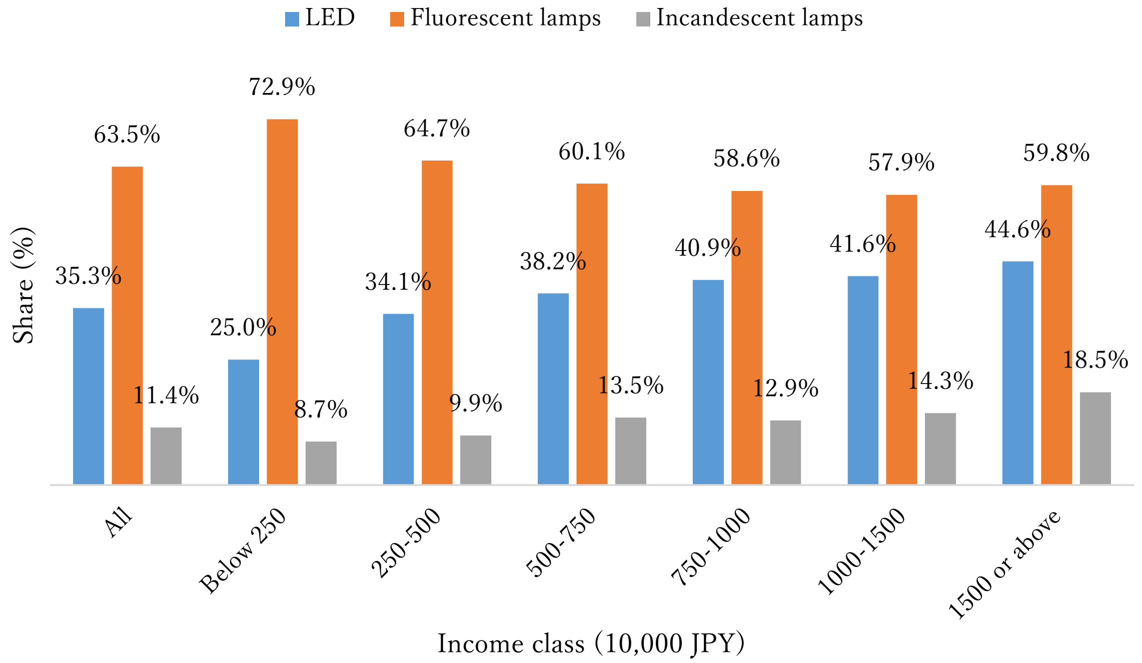
Source: Federation of Electric Power Companies of Japan (2015)

Figure 2. Change in the share of the shipment quantity of lamps



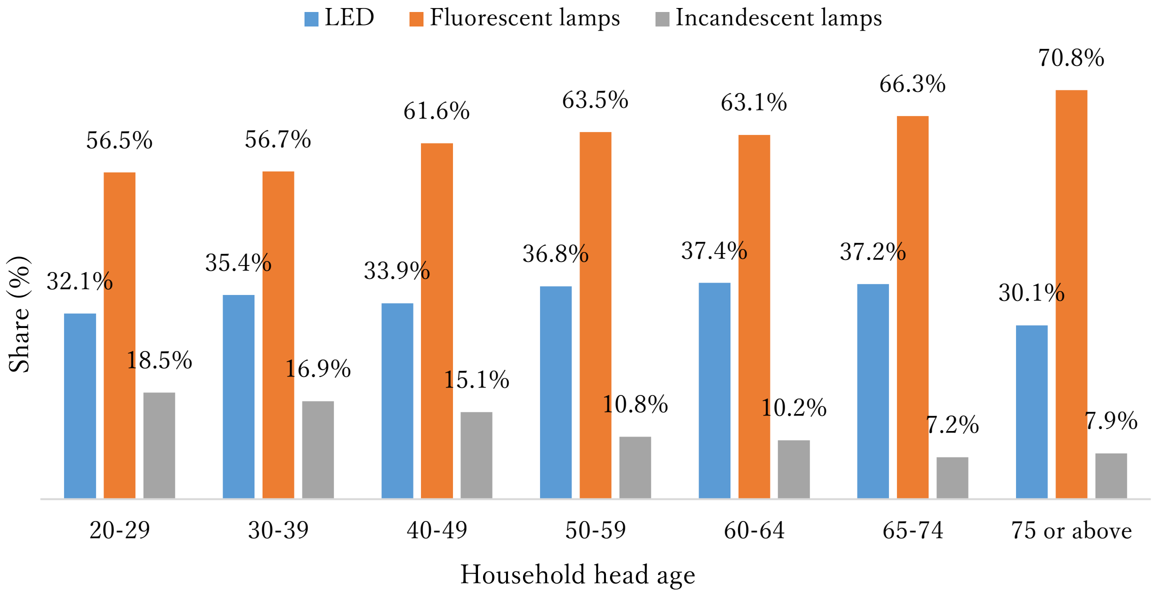
Source: Japan Lighting Manufacturers Association (2017)

Figure 3.a. Type of living room lamps by income class



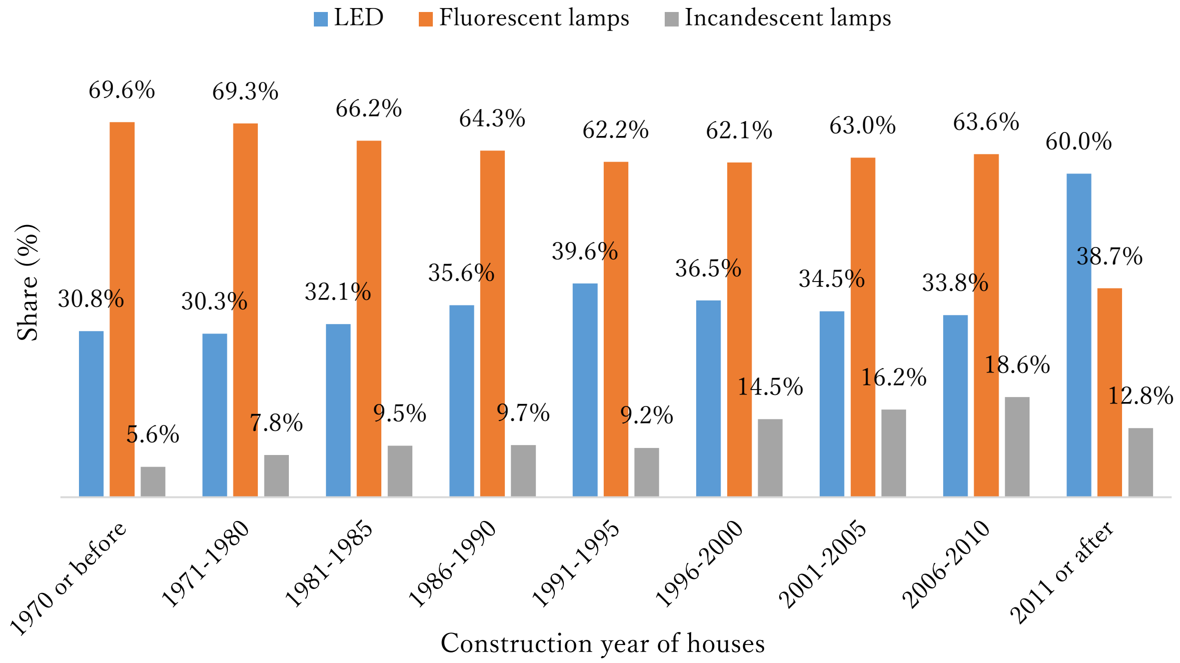
Note. Multiple responses are allowed. Therefore, the total is not 100%.
Data Source: Survey on Carbon Dioxide Emission from Households (Ministry of the Environment of Japan, 2016).

Figure 3.b. Type of living room lamps by household head age



Note. Multiple responses are allowed. Therefore, the total is not 100%.
Data Source: Survey on Carbon Dioxide Emission from Households (Ministry of the Environment of Japan, 2016).

Figure 3.c. Type of living room lamps by construction age of houses



Note. Multiple responses are allowed. Therefore, the total is not 100%

Data Source: Survey on Carbon Dioxide Emission from Households (Ministry of the Environment of Japan, 2016).

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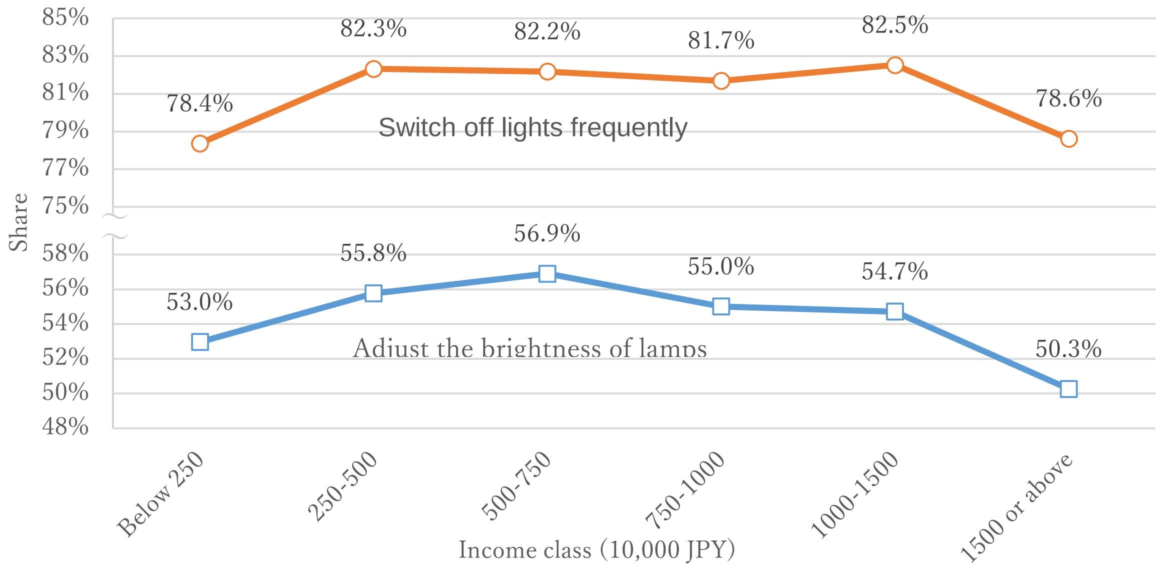
Figure 4. The share of electricity usage of appliances

	Our estimate	2009 estimate*
Air conditioner	13.4%	7.4%
Refrigerator	12.3%	14.2%
Microwave & oven	4.8%	1.8%
Electronic bidet	4.8%	3.7%
Television	4.5%	8.9%
Dishwasher with dryer	3.0%	3.7%
Personal computer	2.9%	2.5%
Electric pot	1.7%	3.2%
Humidifier	1.4%	-
DVD player	1.4%	1.6%
Air cleaner	1.1%	-

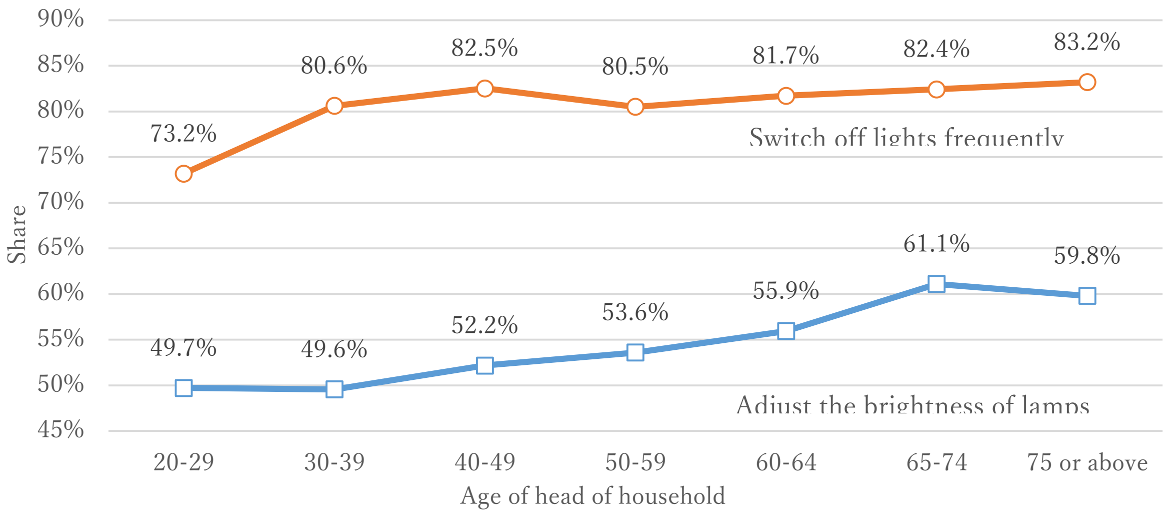
*Source: Ministry of Economy, Trade and Industry (2011)

Figure 5.a. Energy saving activities by income class



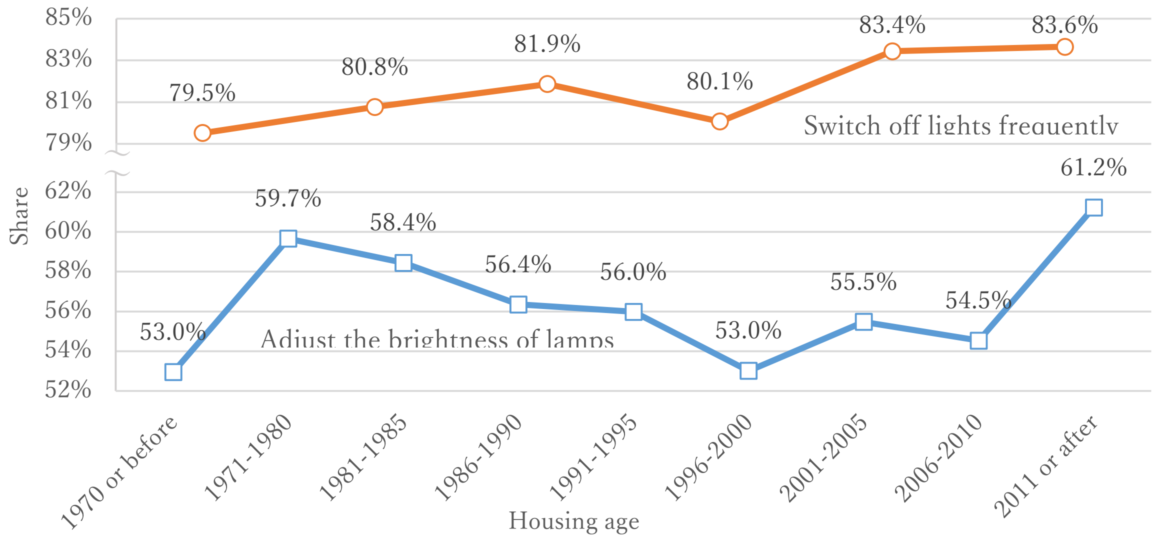
Data Source: Survey on Carbon Dioxide Emission from Households (Ministry of the Environment of Japan, 2016)

Figure 5.b. Energy conservation practices by head of household age



Data Source: Survey on Carbon Dioxide Emission from Households (Ministry of the Environment of Japan, 2016).

Figure 5.c. Energy saving activities by construction age of houses



Data Source: Survey on Carbon Dioxide Emission from Households (Ministry of the Environment of Japan, 2016).

Figure A.1. Difficulty of the LED installation for each room

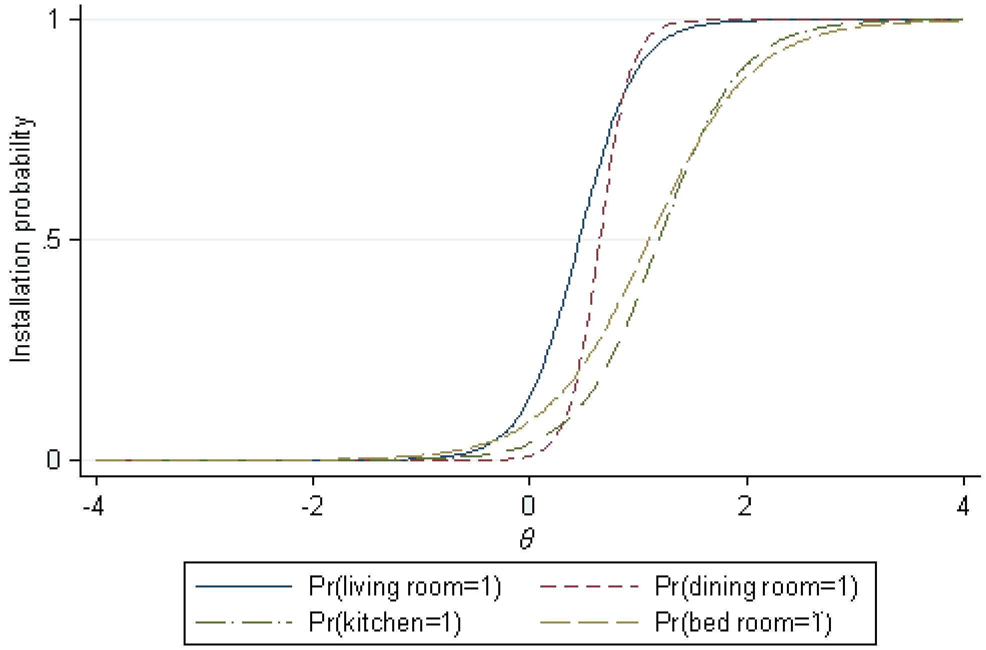


Table 1. Descriptive statistics

Variable	Unit	All households	Single-person	Multiple-person	Income class (10,000 yen) < 250	250-500	500-750	750-1000	1000-1500	> 1500
Electricity usage variables										
Electricity usage per month	kWh	411.07	212.36	454.37	272.68	376.69	452.64	492.43	527.23	571.67
Electricity price	JPY/kWh	26.64	27.04	26.56	26.90	26.74	26.22	26.50	26.72	27.84
Energy-saving behaviors										
Installation of LED light bulbs (living room)	dummy[a]	0.35	0.26	0.37	0.25	0.34	0.38	0.41	0.42	0.45
Switch off lights frequently	dummy[a]	0.55	0.47	0.57	0.53	0.56	0.57	0.55	0.55	0.50
Adjust the brightness of lamps	dummy[a]	0.82	0.77	0.83	0.78	0.82	0.82	0.82	0.83	0.79
Demographic variables										
Income	10^4 JPY	560.04	322.70	611.51						
Number of persons	persons	2.80	1.00	3.20	1.74	2.62	3.19	3.38	3.55	3.57
Share of single-person households	0-1	0.18	1.00	0.00	0.53	0.16	0.09	0.06	0.04	0.06
Age of head of household	years	56.67	56.38	56.73	61.85	57.62	52.75	53.68	54.47	57.20
Presence of children 10-19 years old	dummy[a]	0.21	0.00	0.25	0.07	0.15	0.28	0.33	0.32	0.23
Presence of elderly person over 75 years old	dummy[a]	0.18	0.13	0.19	0.22	0.19	0.14	0.15	0.18	0.19
Stay at home on weekdays in daytime	dummy[a]	0.57	0.39	0.61	0.64	0.60	0.52	0.49	0.51	0.53
Vacancy of house more than 5 days during the month	dummy[a]	0.02	0.01	0.05	0.02	0.02	0.02	0.02	0.02	0.01
Appliance ownership										
Television	unit	1.96	1.24	2.12	1.51	1.88	2.02	2.24	2.30	2.58
Refrigerator	unit	1.24	1.08	1.28	1.17	1.22	1.23	1.28	1.33	1.56
Air conditioner	unit	2.32	1.35	2.53	1.50	2.11	2.42	2.82	3.22	3.84
Dishwasher with dryer	unit	0.28	0.08	0.32	0.10	0.22	0.35	0.40	0.48	0.52
Microwave & oven	unit	1.02	0.95	1.04	0.97	1.01	1.03	1.06	1.06	1.14
Electronic bidet	unit	0.89	0.52	0.97	0.54	0.82	0.97	1.10	1.21	1.39
Electric pot	unit	0.55	0.48	0.56	0.51	0.55	0.54	0.57	0.56	0.61
Humidifier	unit	0.35	0.19	0.38	0.17	0.31	0.41	0.44	0.46	0.65
Air cleaner	unit	0.42	0.24	0.46	0.24	0.38	0.48	0.52	0.57	0.70
Personal computer	unit	1.41	0.96	1.50	0.87	1.28	1.53	1.75	1.94	2.25
DVD player	unit	1.01	0.66	1.09	0.63	0.93	1.14	1.25	1.29	1.54

Housing condition										
Apartment house	dummy[a]	0.31	0.58	0.26	0.40	0.32	0.31	0.28	0.25	0.28
Construction after 2011	dummy[a]	0.08	0.06	0.08	0.04	0.07	0.11	0.10	0.10	0.10
Floor area	m^2	113.54	120.80	80.08	92.75	109.61	112.99	125.70	134.61	154.61
Number of samples (households*months)	Max.	139,584	24,972	114,612	21,636	44,050	29,160	19,068	9,684	2,244
	Min.	138,275	24,779	113,496	21,466	43,655	28,885	18,860	9,602	2,225
Number of household samples	Max.	11,632	2,081	9,551	1,803	3,671	2,430	1,589	807	187
	Min.	10,487	1,728	8,618	1,546	3,377	2,288	1,460	737	164

Note. a. 1 = yes.

Table 2. Correlation of LED installation across rooms

	Living room	Dining room	Kitchen	Bedroom
Living room	1			
Dining room	0.673	1		
Kitchen	0.428	0.549	1	
Bedroom	0.480	0.460	0.432	1

Table 3. The impact of LED installation

Variables	All households 1	Multiple-person 2	Single-person 3	All households 4	Multiple-person 5	Single-person 6	All households 7	Multiple-person 8	Single-person 9
Zero-LEDization	0.0194**	0.0225***	0.00786						
	(0.00825)	(0.00847)	(0.0215)						
Complete-LEDization				-0.0723***	-0.0811***	-0.0252	-0.0825***	-0.0928***	-0.0296
				(0.0207)	(0.0219)	(0.0589)	(0.0214)	(0.0226)	(0.0599)
Partial-LEDization							-0.0153*	-0.0176**	-0.00691
							(0.00832)	(0.00856)	(0.0218)
Ln(Electricity price)	-1.315***	-1.318***	-1.390***	-1.315***	-1.316***	-1.392***	-1.314***	-1.316***	-1.392***
	(0.0337)	(0.0318)	(0.0960)	(0.0337)	(0.0318)	(0.0963)	(0.0337)	(0.0319)	(0.0963)
Apartment house	-0.130***	-0.112***	-0.143***	-0.129***	-0.112***	-0.142***	-0.130***	-0.112***	-0.143***
	(0.0131)	(0.0133)	(0.0343)	(0.0131)	(0.0133)	(0.0341)	(0.0132)	(0.0133)	(0.0343)
Construction after 2011	-0.120***	-0.134***	-0.0393	-0.111***	-0.124***	-0.0381	-0.110***	-0.122***	-0.0374
	(0.0177)	(0.0190)	(0.0410)	(0.0179)	(0.0193)	(0.0417)	(0.0179)	(0.0193)	(0.0417)
Floor area	0.101***	0.0813***	0.0497	0.103***	0.0824***	0.0508*	0.102***	0.0816***	0.0500
	(0.0140)	(0.0142)	(0.0308)	(0.0140)	(0.0142)	(0.0305)	(0.0140)	(0.0142)	(0.0309)
Ln(income)	0.0656***	0.0400***	0.0424**	0.0652***	0.0395***	0.0424**	0.0654***	0.0397***	0.0424**
	(0.00779)	(0.00840)	(0.0175)	(0.00780)	(0.00840)	(0.0175)	(0.00779)	(0.00839)	(0.0175)
Age of head of household	0.00393***	0.00286***	0.00504***	0.00388***	0.00281***	0.00503***	0.00391***	0.00285***	0.00503***
	(0.000441)	(0.000466)	(0.00105)	(0.000442)	(0.000467)	(0.00105)	(0.000440)	(0.000465)	(0.00105)
Presence of children (10-19 years)	0.0276**	0.0427***		0.0287**	0.0439***		0.0283**	0.0435***	
	(0.0126)	(0.0122)		(0.0126)	(0.0123)		(0.0126)	(0.0122)	
Presence of elderly person (> 75 years)	-0.0403***	-0.0187	0.00000645	-0.0395***	-0.0178	0.000773	-0.0402***	-0.0186	0.000471
	(0.0134)	(0.0138)	(0.0434)	(0.0134)	(0.0138)	(0.0434)	(0.0134)	(0.0138)	(0.0435)
Number of persons	0.117***	0.0848***		0.117***	0.0847***		0.117***	0.0846***	
	(0.00513)	(0.00523)		(0.00514)	(0.00525)		(0.00513)	(0.00524)	
Stay at home on weekdays in daytime	0.0469***	0.0237**	0.0500*	0.0467***	0.0236**	0.0496*	0.0469***	0.0236**	0.0500*
	(0.00917)	(0.00948)	(0.0259)	(0.00919)	(0.00952)	(0.0258)	(0.00918)	(0.00950)	(0.0259)
Vacancy of house more than 5 days during the month	-0.219***	-0.177***	-0.201***	-0.218***	-0.173***	-0.201***	-0.217***	-0.174***	-0.201***
	(0.0169)	(0.0185)	(0.0267)	(0.0170)	(0.0185)	(0.0268)	(0.0170)	(0.0186)	(0.0268)
Television	0.0236***	0.0272***	0.0139	0.0238***	0.0275***	0.0138	0.0238***	0.0276***	0.0137
	(0.00518)	(0.00520)	(0.0193)	(0.00516)	(0.00519)	(0.0193)	(0.00516)	(0.00519)	(0.0193)
Refrigerator	0.0995***	0.102***	0.212***	0.0991***	0.102***	0.212***	0.0993***	0.102***	0.213***
	(0.0119)	(0.0124)	(0.0343)	(0.0120)	(0.0124)	(0.0344)	(0.0120)	(0.0124)	(0.0343)
Air conditioner	0.0580***	0.0553***	0.101***	0.0582***	0.0555***	0.101***	0.0581***	0.0554***	0.101***
	(0.00349)	(0.00352)	(0.0130)	(0.00349)	(0.00353)	(0.0131)	(0.00349)	(0.00353)	(0.0130)

Dishwasher with dryer	0.109***	0.109***	0.0528	0.108***	0.108***	0.0521	0.109***	0.108***	0.0530
	(0.0106)	(0.0108)	(0.0369)	(0.0106)	(0.0108)	(0.0368)	(0.0106)	(0.0108)	(0.0369)
Microwave & oven	0.0450**	0.0289	0.130**	0.0462**	0.0311	0.129**	0.0457**	0.0307	0.129**
	(0.0204)	(0.0192)	(0.0541)	(0.0204)	(0.0192)	(0.0548)	(0.0204)	(0.0192)	(0.0546)
Electronic bidet	0.0530***	0.0445***	0.125***	0.0527***	0.0444***	0.125***	0.0532***	0.0449***	0.125***
	(0.00701)	(0.00729)	(0.0219)	(0.00703)	(0.00731)	(0.0219)	(0.00702)	(0.00730)	(0.0219)
Electric pot	0.0317***	0.0337***	0.00747	0.0316***	0.0335***	0.00762	0.0317***	0.0337***	0.00756
	(0.00757)	(0.00764)	(0.0214)	(0.00755)	(0.00763)	(0.0214)	(0.00755)	(0.00763)	(0.0215)
Humidifier	0.0423***	0.0424***	0.0660**	0.0421***	0.0423***	0.0656**	0.0424***	0.0426***	0.0659**
	(0.00688)	(0.00686)	(0.0274)	(0.00685)	(0.00683)	(0.0274)	(0.00687)	(0.00685)	(0.0274)
Air cleaner	0.0251***	0.0158**	0.0635***	0.0257***	0.0164**	0.0640***	0.0259***	0.0166**	0.0642***
	(0.00710)	(0.00718)	(0.0212)	(0.00709)	(0.00719)	(0.0214)	(0.00709)	(0.00718)	(0.0214)
Personal computer	0.0200***	0.0149***	0.0763***	0.0199***	0.0147***	0.0767***	0.0203***	0.0151***	0.0768***
	(0.00448)	(0.00447)	(0.0180)	(0.00447)	(0.00447)	(0.0181)	(0.00447)	(0.00447)	(0.0181)
DVD player	0.0145***	0.00840	0.0443***	0.0143***	0.00815	0.0441***	0.0145***	0.00847	0.0443***
	(0.00541)	(0.00572)	(0.0160)	(0.00539)	(0.00569)	(0.0160)	(0.00539)	(0.00569)	(0.0160)
Constant	7.950***	8.424***	8.204***	7.955***	8.429***	8.211***	7.966***	8.439***	8.217***
	(0.131)	(0.134)	(0.362)	(0.131)	(0.134)	(0.362)	(0.132)	(0.134)	(0.364)
Observations	102,062	85,229	16,833	102,062	85,229	16,833	102,062	85,229	16,833
# of households	8,506	7,107	1,399	8,506	7,107	1,399	8,506	7,107	1,399
Adjusted R^2	0.601	0.548	0.474	0.602	0.549	0.474	0.602	0.549	0.474

Note: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. Regional and monthly dummies are included in the analysis.

Table 4. The impact of LED installation across different income classes

Variables	All households (10)	All households (11)	Multiple-person (12)	Single-person (13)	< 250 (14)	250-500 (15)	500-750 (16)	750-1000 (17)	1000-1500 (18)	> 1500 (19)
Installation of LED light bulbs (living room)	-0.0283***	-0.0229**	-0.0440***	0.0386	0.00250	-0.0451***	-0.0196	-0.0624***	-0.00598	-0.0607
	(0.00893)	(0.00902)	(0.00919)	(0.0258)	(0.0286)	(0.0151)	(0.0171)	(0.0199)	(0.0313)	(0.0691)
Adjust the brightness of lamps		-0.0311***								
		(0.00865)								
Switch off lights frequently		-0.0676***								
		(0.0112)								
Ln(Electricity price)	-1.316***	-1.313***	-1.319***	-1.391***	-1.229***	-1.346***	-1.383***	-1.337***	-1.288***	-1.027***
	(0.0337)	(0.0337)	(0.0319)	(0.0957)	(0.111)	(0.0539)	(0.0491)	(0.0599)	(0.0755)	(0.166)
Apartment house	-0.129***	-0.129***	-0.113***	-0.139***	-0.173***	-0.148***	-0.105***	-0.105***	-0.0503	-0.199**
	(0.0132)	(0.0131)	(0.0134)	(0.0343)	(0.0386)	(0.0210)	(0.0233)	(0.0291)	(0.0455)	(0.0854)
Construction after 2011	-0.115***	-0.115***	-0.126***	-0.0483	-0.0630	-0.0540*	-0.101***	-0.160***	-0.276***	-0.290**
	(0.0179)	(0.0178)	(0.0191)	(0.0415)	(0.0568)	(0.0298)	(0.0306)	(0.0372)	(0.0499)	(0.121)
Floor area	0.104***	0.106***	0.0820***	0.0506*	0.0593*	0.0978***	0.103***	0.0674**	0.149***	0.230**
	(0.0140)	(0.0139)	(0.0142)	(0.0304)	(0.0331)	(0.0208)	(0.0258)	(0.0303)	(0.0504)	(0.0879)
Ln(income)	0.0659***	0.0659***	0.0404***	0.0435**						
	(0.00782)	(0.00780)	(0.00842)	(0.0176)						
Age of head of household	0.004***	0.004***	0.003***	0.005***	0.004***	0.005***	0.005***	0.003***	0.002	-0.001
	(0.000)	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.004)
Presence of children (10-19 years)	0.0270**	0.0264**	0.0418***		0.00494	0.0311	0.0358*	0.0351	0.0294	0.130*
	(0.0127)	(0.0126)	(0.0124)		(0.0611)	(0.0230)	(0.0197)	(0.0259)	(0.0361)	(0.0756)
Presence of elderly person (> 75 years)	-0.0401***	-0.0408***	-0.0192	0.00271	-0.0252	-0.0136	-0.0377	-0.0557	-0.00137	-0.00208
	(0.0134)	(0.0134)	(0.0138)	(0.0433)	(0.0347)	(0.0203)	(0.0250)	(0.0342)	(0.0470)	(0.111)
Number of persons	0.117***	0.118***	0.0849***		0.186***	0.128***	0.101***	0.106***	0.0624***	0.0759***
	(0.00515)	(0.00512)	(0.00525)		(0.0165)	(0.00783)	(0.00824)	(0.0107)	(0.0140)	(0.0268)
Stay at home on weekdays in daytime	0.0472***	0.0503***	0.0240**	0.0504*	0.0597**	0.0404***	0.0333*	0.0573***	0.0516	0.135**
	(0.00923)	(0.00921)	(0.00954)	(0.0260)	(0.0270)	(0.0151)	(0.0171)	(0.0212)	(0.0340)	(0.0593)
Vacancy of house more than 5 days during the month	-0.219***	-0.218***	-0.175***	-0.201***	-0.168***	-0.263***	-0.186***	-0.215***	-0.252***	-0.187*
	(0.0170)	(0.0170)	(0.0186)	(0.0267)	(0.0404)	(0.0305)	(0.0320)	(0.0410)	(0.0684)	(0.106)
Television	0.0232***	0.0218***	0.0268***	0.0143	0.0224	0.00556	0.0377***	0.0300***	0.0310*	0.0154
	(0.00519)	(0.00517)	(0.00521)	(0.0193)	(0.0193)	(0.00843)	(0.00974)	(0.0108)	(0.0184)	(0.0305)
Refrigerator	0.0992***	0.0974***	0.102***	0.212***	0.153***	0.136***	0.101***	0.0927***	-0.00228	0.119**

	(0.0119)	(0.0119)	(0.0123)	(0.0344)	(0.0360)	(0.0144)	(0.0164)	(0.0221)	(0.0532)	(0.0459)
Air conditioner	0.0580***	0.0580***	0.0554***	0.101***	0.0797***	0.0626***	0.0506***	0.0631***	0.0623***	0.0393*
	(0.00351)	(0.00351)	(0.00352)	(0.0131)	(0.0128)	(0.00614)	(0.00734)	(0.00844)	(0.0119)	(0.0212)
Dishwasher with dryer	0.109***	0.110***	0.109***	0.0472	0.112***	0.119***	0.100***	0.0816***	0.134***	0.119**
	(0.0106)	(0.0105)	(0.0107)	(0.0370)	(0.0354)	(0.0181)	(0.0176)	(0.0236)	(0.0287)	(0.0548)
Microwave & oven	0.0468**	0.0477**	0.0311	0.134**	0.0763	0.100***	0.0612	0.0193	0.0405	-0.169*
	(0.0204)	(0.0205)	(0.0192)	(0.0543)	(0.0590)	(0.0359)	(0.0377)	(0.0356)	(0.0632)	(0.0916)
Electronic bidet	0.0537***	0.0549***	0.0458***	0.123***	0.0678***	0.0593***	0.0408***	0.0552***	0.0564**	0.0810*
	(0.00705)	(0.00703)	(0.00730)	(0.0220)	(0.0220)	(0.0122)	(0.0130)	(0.0171)	(0.0251)	(0.0453)
Electric pot	0.0318***	0.0323***	0.0342***	0.00683	0.0214	0.0444***	0.0345**	0.0222	0.00631	0.0565
	(0.00757)	(0.00761)	(0.00763)	(0.0214)	(0.0220)	(0.0125)	(0.0147)	(0.0191)	(0.0252)	(0.0607)
Humidifier	0.0414***	0.0421***	0.0416***	0.0618**	0.0748***	0.0441***	0.0470***	0.0318**	0.0496**	-0.00649
	(0.00688)	(0.00690)	(0.00688)	(0.0273)	(0.0272)	(0.0128)	(0.0128)	(0.0149)	(0.0221)	(0.0307)
Air cleaner	0.0253***	0.0252***	0.0162**	0.0621***	0.0528**	0.0323***	0.0354***	0.00483	-0.0301	0.0224
	(0.00713)	(0.00713)	(0.00721)	(0.0213)	(0.0228)	(0.0113)	(0.0115)	(0.0133)	(0.0193)	(0.0352)
Personal computer	0.0203***	0.0197***	0.0154***	0.0747***	0.0272*	0.0319***	0.0171**	0.0125	0.00980	0.0139
	(0.00452)	(0.00449)	(0.00452)	(0.0181)	(0.0147)	(0.00924)	(0.00822)	(0.0103)	(0.0126)	(0.0213)
DVD player	0.0142***	0.0154***	0.00854	0.0418**	0.0191	0.0135	0.0206**	0.0114	-0.00382	-0.0201
	(0.00541)	(0.00539)	(0.00572)	(0.0163)	(0.0170)	(0.00966)	(0.0105)	(0.0115)	(0.0189)	(0.0419)
Constant	7.958***	8.006***	8.442***	8.193***	7.964***	8.326***	8.593***	8.722***	8.530***	7.613***
	(0.132)	(0.130)	(0.134)	(0.362)	(0.405)	(0.205)	(0.211)	(0.259)	(0.359)	(0.667)
Observations	101,751	101,525	84,978	16,773	15,923	35,128	24,682	16,128	8,058	1,832
# of households	8,551	8,532	7,145	1,406	1,335	2,950	2,076	1,359	677	154
Adjusted R^2	0.601	0.603	0.549	0.475	0.504	0.574	0.613	0.608	0.560	0.674

Note: *** p<0.01, ** p<0.05, * p<0.1. Robust standard errors in parentheses. Regional and monthly dummies are included in the analysis.

Table A.1. Performance of each type of lamp

	Incandescent	Fluorescent	LED*
Wattage (W)	54	12	9.4
Lumens (L)	810	810	850
Efficiency (L/W)	15	67.5	90.4
Share of the most frequently used lamp in the living room (%)	7.77	58.96	31.64

Note. The sum of the shares of incandescent, fluorescent, and LED lamps is below 100% because 1.62% of households responded that they used “other lamps” or “unknown.”

* We report the actual performance values of LEDs shipped in 2011. METI (2013) also provides the target values of more efficient LEDs for 2017. We will conduct somewhat conservative estimates with the actual performance values because we consider that households were using slightly older LED lamps at the time of the survey.

Data Source: Ministry of Economy, Trade and Industry (2013).

Table A.2. Engineering calculation of the impact of replacement by LEDs

	Incandescent – LED	Fluorescent – LED
Reduction rate by replacement (r, %)[a]	83.41	25.35
	Δ_1	Δ_2
Electricity savings rate (Δ, %)	11.18	3.40
	s_1	s_2
Relative share (s)[b]	0.12	0.88
	$s_1\Delta_1$	$s_2\Delta_2$
Potential reduction ($s\times\Delta$)	1.30	3.00
Total potential reduction ($s_1\Delta_1+s_2\Delta_2$)	4.30	

a. Data Source: Ministry of Economy, Trade and Industry (2013)
b. Data Source: Survey on Carbon Dioxide Emission from Households (Ministry of the Environment of Japan, 2016).