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Experimental Study of Electricity Conservation by Social Comparison

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Abstract:

For this study, we conducted an artifactual field experiment to investigate the effects of different social comparisons. Although many previous studies have invited residents to be the subjects of laboratory experiments, the subjects' economic situation has not corresponded to the initial laboratory setting. In our study, we set up experiments based on each subject's actual electricity usage in daily life. The results show that information about other consumers' electricity usage increased the electricity conservation behavior of almost all the subjects. In particular, information provision about the electricity use of "efficient" subjects can improve the total welfare of society after psychological factors (moral utility and moral tax) are considered.

Keywords: Electricity Conservation, Behavioral Economics, Artifactual Field Experiment, Social Comparison

1. Introduction

Many countries aim to increase the share of renewable energy resources to decrease CO_2 emissions. However, the efficient use of renewable energy is associated with technical challenges. A typical example is the adjustment of the gap between electricity supply and demand. Increasing the number of renewable energy installations increases the adjustment cost of electricity companies. At worst, a rapid electricity supply that is unexpected by electricity companies can cause a power outage. On the other hand, if electric vehicles become widespread in large numbers, there is also the possibility of unexpectedly rapid power demand by power companies in the evening and later, when the output of solar power generation becomes smaller. To overcome these problems, economists are proposing the development of demand-side control as a way to curb consumers' energy use. One way to achieve demand-side control is to introduce a dynamic pricing scheme. Some studies have found that dynamic pricing can contribute to decreasing peak demand (Matsukawa et al., 2000; Faruqui and George, 2005; Herter, 2007).

Faruqui and Sergici (2010) conclude that a well-designed dynamic pricing scheme, such as critical peak pricing (CPP), sufficiently reduces electricity usage. However, consumers do not tend to choose the CPP price scheme. Fowlie et al. (2021) show that less than 20% of consumers opt into the CPP price scheme. Furthermore, other studies that focus on different types of price-based policies do not demonstrate adequate cost-effectiveness. For example, Chandra et al. (2010) analyze the cost-effectiveness of an eco-friendly car tax rebate and find that such a price-based policy cannot achieve adequate cost-effectiveness for reducing CO_2 emissions. The cost-effectiveness of such tax rebate programs implemented in other regions and countries also has not achieved satisfactory performance (Beresteanu and Li, 2011; Tanaka and Managi, 2015; Konishi and Zhao, 2017). These problems illustrate the policy limitations of monetary economic incentives. As a result, there has been a dramatic increase in interest in non-monetary energy conservation programs.

In recent years, based on behavioral science, some countries have begun to encourage non-monetary policies that induce voluntary social behavior. Richard Thaler, a behavioral economist, has named such policies "nudge". In an effective nudge experiment to encourage voluntary energy conservation, information is provided based on social comparison. Social comparison is the process of comparing information about another person's position with one's own. For example, Allcott (2011) found that a social comparison scheme using Opower's Home Energy Report (HER) encourages energy saving behavior. This may indicate that untreated households believe that their position is close to the medium value of social norms, and thus treatment tends to cause a decline (rise) in beliefs about the social norms of high-use (low-use) households. Thus, the provision of information about social comparisons on the basis of social norms may encourage voluntary energy conservation for some households.

With this background in mind, this paper examines two research questions that have not been thoroughly examined in previous studies. The first question is the extent to which different types of information provision affect the performance of each intervention. Most social comparison interventions to date have focused only on providing information about "efficient" or "average" electricity users. However, several studies have shown that the provision of information about "inefficient" people also encourages electricity-saving behavior (Kantola, 1984). In addition, experiments such as the Opower HER include up- and downward bi-directional information that influences consumers' electricity use behavior. It is necessary to clarify what kind of social comparison interventions can effectively encourage electricity conservation.

Second, we examine the extent to which the emotional effects of social comparison interventions affect social welfare. While traditional economic models assume that people gain or lose utility only through direct monetary incentives, recent utility models in behavioral economics have begun to take into account non-monetary psychological factors. Levitt and List (2007) define new concepts such as "moral utility" and "moral cost". For example, positive emotions can be generated from appropriate social behavior, such as charitable giving. Such emotions can be viewed as the acquisition of utility through benevolent actions. Nevertheless, people may be compelled by social norms to perform socially desirable actions, and when they do, they develop negative emotions such as guilt and shame. This psychological pressure can be viewed as a loss of utility (DellaVigna et al., 2012; Allcott and Kesller, 2019). These emotional motivations play an important role in people's behavior. Prior research has revealed the existence of such utility gains and losses (Butera et al., 2022; Thunström, 2019), but utility gains and losses vary across regions and countries.

This study aims to quantitatively clarify the comparative social effects of electricity conservation through a laboratory experiment based on a hypothetical decision-making situation regarding electricity use. However, this study is not a simple laboratory experiment. First, the general population with a wide range of socio-demographic characteristics was recruited as the experimental subjects. Second, the experimental setup was based on the actual electricity usage of each subject. The subjects were people who had received HEMS (Home Energy Management Systems) by the power company and who had previously participated in a field study in Yokohama City. For this reason, the initial settings for each subject in this experiment (the amount of electricity used during the summer) were set based on the actual hourly electricity consumption data. Thus, this experiment is an "artifactual field experiment" that captures the approximation of the actual behavior of the subjects as well as a field experiment with subjects participating in the experiment in real life, unlike a conventional laboratory experiment with only a limited number of subjects, such as university students. In this experiment, we also conducted three social comparison interventions, which are described below. By comparing the performance of each intervention, we quantitatively analyzed which type of information was the more cost-effective scheme.

Artifactual field experiments, such as our research method, do not allow for more realistic policy evaluation than framed field experiments (social experiments). However, due to the high cost of conducting framed field experiments, it is difficult to gather enough subjects or to try several different interventions. Therefore, artificial field experiments have the advantage of being able to confirm the "external validity" (generalizability) of multiple interventions in a laboratory experiment. In addition, previous studies have indicated that consumers do not readily perceive electricity costs and benefits in their daily lives (Jessoe and Rapson, 2014; Matsukawa, 2018; Tanaka et al., 2021). It is important to measure the effects of each intervention while controlling for all the information that consumers need to consider. We designed our laboratory experiment to ensure that each subject was fully aware of the costs and benefits of electricity use.

Finally, we obtained several important findings in this study. The first is that, on the whole, information provision schemes based on social comparison encourage electricity-saving behavior. Previous studies have focused only on the impact of social comparison information on average electricity use and on the electricity use of efficient neighbors. However, in the current experiment, social comparison information about the electricity usage of "inefficient" neighbors was added to the experimental design as another type of intervention. The results showed that all the interventions encouraged electricity-saving behavior, although the effects of each intervention were very different.

Second, these results suggest that the effects of social comparison interventions depend on the initial power demand of various individuals. If subjects are aware of the tendency of others to engage in better social behavior, they should attempt to keep up with this behavior and reduce their utility losses because of emotional effects such as social guilt. However, we also found that people tend to give up on social behavior when they know that they cannot take better social action or escape from socially undesirable behavior. In other words, the relative distribution of the initial position and the psychological perception of the information provided influence the effectiveness of the social comparison intervention.

Third, we quantitatively demonstrate that voluntary electricity savings facilitated by the social comparison intervention improve total social welfare. Prior studies have indicated that nudge experiments with social comparison interventions may cause utility losses for some subjects. This is important because such utility losses may partially offset the social welfare gains from social comparison interventions. Thus, this paper demonstrates how the provision of appropriate information based on social comparison interventions can improve the overall welfare of society.

2. Experimental Setting

2.1 Experimental setting and treatments

In this experiment, each subject hypothetically decided the temperature setting of an air conditioner at home. The air conditioner is one of the appliances with the highest power consumption appliances in Japan. The Ministry of Economics, Trade, and Industry in Japan announced that the share of electricity consumption by air conditioners was 58% during the summer. Therefore, the subjects could easily imagine the hypothetical experiment setting. The subjects made decisions based on a hypothetical situation. Each subject decided the temperature setting of the air conditioner between peak hours (from 1 pm to 4 pm) during the summer season in Japan. The electricity price was set at 25 JPY per kWh (25 cents in USD[1]). This price setting was based on general pricing in Tokyo (the residential electricity price of the Tokyo Electric Power Company Holdings, Inc.). The electricity price changes in each period because CPP is implemented when the peak demand approaches the capacity constraints. In this experiment, the total demand for electricity use was decided exogenously; each subject's decision did not affect whether CPP occurred. Each subject could choose a discrete temperature from 25 ℃ (comfortable) to 29 ℃ (uncomfortable). If a subject decided not to use the air conditioner, the room temperature became 30 ℃. For every 1 ℃ higher than 25 ℃, a subject could decrease the total electricity usage by 10% each period (i.e., day).[2] Thus, if a subject chose not to

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[1] In this study, we assume the exchange rate to be JPY 100 = USD 1.

[2] The Energy Conservation Center of Japan (2012) estimates that the temperature change of air conditioners from 27 ℃ to 28 ℃ decreases electricity consumption by 0.03 kWh per hour. This electricity conservation amount is approximately 9.2% of the average total electricity use of the subjects in the summer season.

use the air conditioner, the amount of electricity conserved was approximately 50% of the total electricity use.[3]

Although the subjects could decrease electricity consumption by using a higher temperature setting, they would then have to bear an uncomfortable condition. Thus, we added the preference of comfort. To consider such preferences, we measured the willingness to accept (WTA) higher temperatures via a questionnaire before the first period of the experiment. The questionnaire is presented in Appendix A. In this questionnaire, we asked each subject, "How much money would you require to sustain an increasing room temperature?" The questionnaire included five cases of temperature change from 26 ℃ to 30 ℃ to capture the nonconstant change in WTA temperature increases.[4]

We then applied the results of the questionnaire to the calculation of the payment for this experiment. The payment was calculated as follows:

The payoff
= Initial endowment – Electricity price × Electricity usage
– WTA higher temperature
= Initial endowment – Electricity price × (Initial amount of electricity usage
– Conservation amount of electricity) – WTA higher temperature

In this formulation, the initial amount of electricity usage is based on the actual consumption data of each subject. The subjects of our laboratory experiment were the participants in the field investigation, where the experimenters gathered the HEMS data of each participant during the summer season of 2015. Based on the data, we created the initial setting for each subject in our experiment.[5] The initial amount of electricity usage was the average electricity use in the summer season (from July to September) at the peak time (from 1 pm to 4 pm). The histogram of the initial amount of electricity use is shown in Figure 1. The average value of the initial amount of electricity use was approximately 1.569 kWh, which was similar to the average consumption amount in the Tokyo area. According to the Bureau of Environment of Tokyo metropolitan government (2015), the average consumption amount of household electricity is approximately 369 kWh per

[3] The Agency for Natural Resources and Energy of Japan (2011) reports that 53% of the total electricity use depends on an air conditioner in Japan during the summer peak period (2 pm).
[4] The questionnaire before the experiment is shown in Appendix A.1.
[5] We could not obtain the actual electricity consumption data of other periods due to contractual restrictions. For details about the field investigation, see Ishihara et al. (2019).

month (August) in Tokyo.[6] Based on this report, the total electricity consumption can be calculated as 1.538 kWh in the three peak hours in August.

<Figure 1 Here>

In each period, the subjects could observe the information about electricity usage (i.e., the amount of their electricity usage and the electricity price in the current period). Moreover, each subject received information about the other subjects' electricity usage. Details regarding the electricity usage of other subjects, however, differed based on the treatment. In the control group, the subjects received no information about other consumers' electricity usage.

As the subjects began the next period, they received the information. In treatment group 1, each subject received information about the electricity use of a "nonefficient" person. The electricity usage of "nonefficient" subjects was among the top 10% in the same session. In treatment group 2, each subject received the average consumption amount of the electricity use of all subjects in the same session. In treatment group 3, each subject received information about the electricity use of "efficient" subjects, which was at the bottom 10% in the same session. Allcott (2011) and other related studies with Opower include the effect of treatment groups 2 and 3. If the direction of the social comparison effect is symmetrically the same, the results of our experiments will show the same amount of electricity use reduction in treatment groups 1 and 3. The instructions for the experiment are shown in Appendix A.2 (the case of treatment group 3). Each subject could confirm the amount of electricity consumption and electricity fees due to the air conditioner in each period. Also, they could confirm the amount of the increase or decrease in electricity consumption and fees based on each temperature choice. Therefore, each subject can choose the temperature setting of the air conditioner without the information bias that occurs in actual electric consumption behavior in daily life.

2.2 Experimental details

This study implemented seven sessions to reveal each treatment effect. Table 1 shows details of the experimental sessions (date, number of subjects, and treatment number). These experiments were implemented by z-Tree (see Fischbacher, 2007). We gathered

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[6] The value of electricity consumption is indicated in the case of three members per household.

voluntary participants from a survey sample collected by Kyoto University in Yokohama, Japan.[7] We distributed the call for volunteers to approximately 1,000 people in December 2016. Finally, we obtained a total of 202 subjects. Before the experiment, we sent an invitation letter, as well as a prequestionnaire survey related to electricity use, to the participants in the experiment. The experimental sessions were conducted at the experimental laboratory of Waseda University in January 2017[8].

<Table 1 Here>

First, the subjects took a value orientation test. The value orientation test, which analyzed each subject's preference for cooperation, was developed in the psychological field (e.g., Griesinger and Livingston, 1973; Liebrand, 1984). The test result represents the weight that individuals attach to both their own utility and that of others (Offerman et al., 1996). Our test was based on Park (2000). Adding up the individual's 24 chosen vectors yielded an estimate of the individual's preferred motivational vector. We then classified each subject's characteristics regarding cooperation according to five types ("altruistic," "cooperative," "individualistic," "competitive," and "aggressive"). This study employed the value of the vector as the variable to capture the extent of altruistic preference because the continuous variable captured differences in subjects' preferences.[9] After the value orientation test, the subjects engaged in hypothetical decision making when choosing the temperature of the air conditioner.

3. Main Results

3.1 The choice ratio of the air conditioning temperature

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[7] Appendix B.1 shows the descriptive statistics of the prequestionnaire of our experiment and the questionnaire of the field investigation implemented by Kyoto University.

[8] Climate conditions did not show an apparent difference between the summer season (from July to September) of 2015 and 2016 in the Yokohama area. The Japan Meteorological Agency reported that the average temperature in summer 2015 was 25.2℃, while the average temperature in summer 2016 was 25.8℃.

[9] Some studies employ dummy variables that are classified based on the class of the value orientation results to capture the impact of altruistic preference (e.g., Tanaka et al., 2016). Our calculation results showed that the motivational vectors of all the subjects were within the range of -77.5 to 90. This result implies that the subjects of our experiment did not have special preferences for cooperation (e.g., aggressive and altruistic).

Figure 2 and Table 2 show the selection ratios of air conditioner temperature for each treatment. First, in the control group, the selection ratios of "26°C" and "27°C" were 24% and 25%, respectively, the highest among all groups. Next, in the control group, the ratio of "28°C" was 21%, the lowest among all groups. Finally, in the control group, the ratio of "Do not use" was the lowest among all groups at 5%. Taken together, these results indicate that the control group uses a lower temperature setting for air conditioners.

We also examined the details of the treatment groups. In treatment group 1 (top 10%) and treatment group 2 (average), the selection rates for "25°C", "26°C", and "27°C" were approximately 10% and 10%, 15% and 10%, and 22% and 18%, respectively. These numbers are all higher than the treatment groups (bottom 10%). On the other hand, in treatment group 3 (bottom 10%), the selection rates of "29°C" and "no use" were 25% and 21%, respectively. Both of these figures are higher than those of treatment group 1 (top 10%) and treatment group 2 (average). Summarizing the above results, it can be seen that among the intervention groups, treatment group 3 (bottom 10%) has the highest temperature setting for the air conditioner and has the greatest effect on promoting energy conservation.

A striking and complex trend is observed in the selection rate of 28°C. Treatment group 2 has the highest selection rate of 28°C at 31%. The reason for this may lie in Japan's unique social norms. After the Great East Japan Earthquake, the Japanese government recommended that the temperature of air conditioners be set to 28°C in the summer. Since then, setting the air conditioner at 28°C has become the norm for saving electricity in Japan. In treatment 2, the "average" electricity consumption of the same experimental group was presented to the subjects. Therefore, when the subjects were given the "average," which is a social norm unique to Japan, it was assumed that the subjects behaved in a manner consistent with that norm.

<Figure 2 here>

<Table 2 here>

Our experiment results show some important aspects of the social comparison scheme. However, caution is needed regarding the problems noted in previous studies, such as whether “nudge” implementation, like social comparison schemes, sustain the conservation effect of electricity use in the long run.

In this experiment, each subject repeatedly chose the temperature of the air conditioner between 10 periods. We need to consider the dynamic change in subjects’ behavior by each treatment group because previous studies show the effect of a decrease in information provision over time (Ito et al. 2018). Figure 3 shows the average choice ratio of period 1 and period 9 in each group. The CPP scheme is introduced in period 10. Therefore, the period 9 result includes sufficient learning time and excludes the CPP effect for each group.

<Figure 3 here>

In the control group, some subjects tended to change their temperature choice between the experiments. For example, although almost no subjects chose "no use" in period 1, approximately 10 % of all subjects in the control group chose "no use" in period 9. Despite the lack of information about the consumption amount of other subjects, the subjects in the control group tended to decrease their electricity consumption. This result implies full information provision related to one's own electricity consumption and payment. Houde et al. (2013) and Jossoe and Rapson (2014) reveal that individuals' own electricity usage information on an in-home display reduced household electricity consumption because this information provision encouraged efficient use of electricity. Our experiment results imply that the same information effect occurred as in previous studies.

On the other hand, the subjects in the treatment groups tended to choose relatively higher temperature settings. In particular, subjects who received information about the other subjects' electricity consumption increased the choice ratio of 29℃ in period 9. Furthemore, the subjects in treatment 3 tended to increase the choice ratio of 29℃ and "no use" more than subjects in other treatments between period 1 and period 9. However, the choice ratio of 25℃ and 26℃ increased in treatment 1. Statistical tests show that the subjects in treatment 3 tended to choose higher temperature settings compared to the subjects in the control group and other treatment groups in period 9[10]. With regard to behavior change by period transition, treatment 3 encouraged the most electricity-saving behavior.

3.2 Factor analysis of temperature choice

[10] The results of the t test and Mann–Whitney test show that the subjects in treatment 3 significantly chose higher temperatures in period 9 compared to other groups. The test results also show an insignificant difference between the subjects' choice of temperature between the control group, treatment 1 and treatment 2.

Temperature choices in the experiment may have been affected by several factors, although our experiments controlled for the decision-making situation. To confirm the effect of each treatment, we analyzed the factors that affected the choice of air conditioner temperature by employing ordered logit estimation. The estimation model is as follows:[11]

$$
\begin{aligned}
Choice_{i,t} = a_1 \times Tr_1 + a_2 \times Tr_2 + a_3 \times Tr_3 + b_1 \times price_{i,t} + b_2 \times val_{i,t} \\
+b_3 \times period_{i,t} + b_4 \times initial_{i,t} + c_1 \times initial_{i,t} \times Tr_1 \\
+c_2 \times initial_i \times Tr_2 + c_3 \times initial_{i,t} \times Tr_3 + \varepsilon \qquad (1)
\end{aligned}
$$

In this estimation, *i* represents each subject and *t* shows the number of periods. *a* and *c* show the coefficient parameters of the independent variables that we estimate. The dependent variable (*Choice*) is ordinal and depends on the choice of the temperature of the air conditioner. When the subjects chose 25 ℃, the variable became 0. As the temperature of the air conditioner increased, the dependent variable discretely increased. Finally, *Choice* became 5 when the subject chose “no use” (30 ℃). Therefore, the positive coefficients of the independent variables meant that the variable was a factor that encouraged electricity conservation behavior.

To analyze the effect of each treatment, the model included the dummy variables of each treatment group. Tr_1, Tr_2 and Tr_3 were the dummy variables of treatment groups 1, 2 and 3, respectively. Some previous studies have mentioned the relationship between conservation and altruistic behavior (e.g., Ojea and Loureiro, 2007). We thus added the level of altruism (*val*), which was measured by the value orientation test, to consider the effect of such social preference. In this estimation, *val* was the tangent of the social value orientation circle (the value of the motivational vector). The social value orientation circle consisted of two vectors. The horizontal vector was a summation of the payoff for oneself in all questions. The vertical vector was a summation of payoffs for others (partner) in all questions. If the subject chose the option that increased the partner’s payoff, *val* became larger. We added the number of periods as the independent variable (*period*) to consider the learning effect.

Additionally, we identified the effect of the initial electricity demand (*initial*) on conservation behavior. In this experiment, the initial demand for electricity depended on the real amount of electricity used by each subject. Generally, a person with a larger initial demand was a “nonefficient” person. In each treatment, such persons may have tended to have different behaviors than other persons. To consider such a possibility, we added the

[11] The descriptive statistics of the variables for ordered logit estimation are shown in Appendix B.2.

initial and cross-terms of the *initial* and dummy variables of each treatment group in additional estimations.

The estimation results are shown in Table 3.A. Estimation 1 is the base estimation result of the regression model, and Estimations 2 and 3 consider the effect of the initial electricity demand. In all models, each treatment dummy variable shows a positive correlation. These results indicate that information provisions based on social comparison encourage electricity conservation behavior. In particular, treatment group 3 had the most significant effect on conservation behavior. We tested the difference between the coefficient of each treatment using the Wald test. The test results, which are provided in Table 3.B, show that the coefficient of treatment group 3 differed significantly from that of the other treatments. The test results did not show a significant difference between the coefficients of treatment groups 1 and 2 in Estimations 1 and 2. Although these results imply that all treatments encouraged electricity conservation behavior, treatment group 3 was the most powerful way to encourage such behavior. On the contrary, the effectiveness of treatment groups 1 and 2 to promote electricity conservation behavior was the same and was not more powerful than treatment group 3.

Although the information in treatment group 1 and treatment group 3 was symmetrical, there was a gap in performance between each treatment group. This result suggests a difference in the cognitive process of information. David and Rao (2011) revealed that subjects who received negative feedback did not respect the strength of these signals, were far less predictable in their updating behavior, and were averse to new information. Furthermore, they found that the process of updating with good news conformed more closely to Bayes' rule. In treatment group 1, the subjects were told which subjects were not contributors to electricity conservation. Such information is negative news for subjects who overuse electricity compared to others. On the other hand, the information provision in treatment group 3 was good news for subjects who did not overuse electricity. Therefore, our results indicate that such asymmetric information causes the gap in the outcomes between treatment groups 1 and 3.

<Table 3 here>

The results of Estimation 2 show that *initial* has a negative correlation with the dependent variable. This result means that persons with a larger initial demand discourage electricity conservation behavior. On the contrary, the results of Estimation 3 do not show a significant correlation between *initial* and temperature choice. In Estimation 3, the cross-terms of *initial* and the dummy variables of treatment groups 1 and 3 show a negative correlation with the dependent variable. These results indicate that persons with a larger initial demand discourage electricity conservation behavior under social comparison schemes. After the information was provided, the participants were aware of how much their electricity consumption differed from the standard electricity consumption. Most people tended to decrease their electricity consumption to approximate the referenced consumption amount recommended by the social comparison scheme. However, such a scheme decreases the electricity conservation behavior of the subjects with a larger initial demand. A reason for this result is that those with greater initial demand do not attempt to catch up to more efficient consumers. Moreover, if "nonefficient" consumers cannot catch up in a certain period, they are more likely to give up. To confirm such behavior, we conduct additional regression analysis in appendix C. The additional regression results also indicate that when subjects face a larger gap between the treatments' referenced electricity consumption and the subject's electricity usage in period 1, the gap tends to increase in treatment groups 1 and 3.

3.3 Electricity conservation effects

Based on the ordered logit estimation, we can calculate the conservation effect of CPP and each treatment.[12] Table 4.A shows the electricity conservation amount of CPP and each treatment based on the estimated treatments' coefficient in Estimation 1. Our calculation results show that the CPP scheme encouraged the subjects to decrease their total electricity use by 8.6%. Ito et al. (2018) also estimated the electricity conservation amount of CPP based on field experiments in Japan. They found that increasing the electricity fee by approximately 45 JPY per kWh decreased the total electricity usage in summer peak time by 16.7%. In our experiment, we hypothesized that the electricity fee increased by 25 JPY per kWh when CPP was implemented. If our experiment employed the same set of price changes in CPP, the electricity conservation amount would be approximately 15.5%. In short, our results were similar to those of previous studies.

Additionally, Table 4.A shows that each treatment effect is significant. Treatment group 1 reduced total electricity use by 2.7%, and treatment group 2 decreased total electricity use by 3.3%. The reduction effect of treatment group 3 was particularly remarkable. Our estimation results showed that treatment group 3 decreased total electricity use by 7.5%.

[12] The marginal effect of each independent variable for the choice ratio of temperature choice is shown in Appendix D. The results of Table D.1 are based on the estimation results of Estimation 1. The results of Table D.2 depend on the results of Estimation 3.

We calculated the cross-effects between all treatments and initial demand based on the estimation results of Estimation 3. Table 4.B shows the results of the calculation. The cross-effect between treatment group 1 and initial demand increased by approximately 6.7% of total electricity use. The cross-effect between treatment group 3 and initial demand also increased electricity use by approximately 7.5%. However, we did not obtain a significant correlation of the cross-term between *initial* and Tr_2. Therefore, we excluded the calculation of this effect from the Table 4.B These results imply that the treatment effect depends on the distribution of the initial demand for electricity use. If a social comparison is implemented in a region that has a large deviation in electricity demand, the treatment may not have the expected effect on encouraging electricity conservation behavior.

<Table 4 here>

4. Social Welfare Analysis

4.1 Welfare calculation

We calculated the welfare improvement effect of CPP and each treatment, following Ito et al. (2018). We began with the assumption that the marginal cost of supplying electricity for the critical peak hours was 50 cents per kWh. Ito et al. (2018) use 65 cents per kWh because the optimum price should be set at the electricity wholesale price during peak periods. Note that the electricity price in Japan was higher in 2012 than in other periods. After the Great East Japan Earthquake, Japanese electricity companies suffered from higher electricity generating costs since they relied on old and inefficient electric power facilities to generate electricity. Nearly all nuclear generation plants were shut down by the earthquake. Therefore, the wholesale price of electricity in Japan became higher around the period of the experiment by Ito et al. (2018). However, compared to prices in the aftermath of the earthquake, wholesale prices of electricity have decreased recently. The maximum wholesale spot market price was approximately 51.3 cents in August 2018 (Japan Electric Power Exchange, 2019). Therefore, we assumed that the marginal cost of supplying electricity was 50 cents, which is cheaper than the price used in Ito et al. (2018). The second assumption was the total demand for electricity. We assumed that the peak demand for electricity was 46,800 MWh based on the peak demand for electricity in the summer peak period in Japan.

In this study, we had already calculated the electricity conservation effect created by CPP and each treatment. Based on these calculations, we demonstrated the welfare improvement values. Figures 4.A and 4.B illustrate the welfare analysis of each scheme. Figure 4.A shows the welfare gain from CPP. In this figure, *D* is the demand curve for electricity. On a typical day, electricity companies sell electricity to the consumer for the same price with a usual marginal cost (25 cents per kWh). However, the marginal cost of supplying electricity increases in peak times because electricity companies need to use an additional power plant, which requires a higher marginal cost (50 cents per kWh). When electricity companies change the price of electricity to 50 cents, total demand decreases from D^* to D^c.

However, electricity companies may not change their price rate due to technical or political constraints. In this case, the loss of producer surplus exceeds the increase in consumer surplus. Therefore, there is a total welfare loss. Assuming that technological advancement, such as using a smart grid, can enable electricity companies to monitor real-time electricity use, they can apply the CPP scheme during rapid increases in demand and thus avoid the loss of producer surplus. Then, the total welfare increases compared to the traditional price scheme. In Figure 4.A, the *abc* triangle shows the welfare gain under the CPP scheme.

<Figure 4 here>

In contrast, Figure 4.B shows the welfare gain from the information provision based on social comparison. If the information provision scheme encourages electricity conservation, given that the electricity price does not change, such a scheme can increase the total welfare since the producers do not need to pay the excess marginal cost to satisfy the excess demand. We define this effect as a “direct effect” by the social comparison scheme.

In Figure 4.B, the direct effect is shown as the *acde* trapezoid. In this case, we need to consider the utility of conservation behavior. If people voluntarily decrease their electricity consumption according to the social comparison scheme, then such people will obtain utility functions, including moral utility. Without an electricity price change, decreases in consumption lead to decreases in utilities. However, if people experience pleasant emotions from voluntary electricity conservation, then conservation is considered good societal behavior. We add such emotions to the moral utility term on the utility function. In the case where almost all persons feel good emotions from the altruistic conservation of electricity, the demand curve moves to the lower side to consider the moral term. In Figure 4.B, we define the utility curve to account for the moral term as *D*'. Some studies argue that charitable behavior affects people's utility. In the case of pure altruism, people gain utility from voluntary behavior that contributes to socially desirable things. Thus, utility gain from electricity conservation by social comparison schemes is shown as the *aegf* trapezoid. This study defines such an effect as a moral utility effect (also called "warm glow").

However, some studies have highlighted that nudge schemes sometimes impose a cost by social pressure on the subjects (DellaVigna et al., 2012; Allcott and Kesller, 2019). Thus, social comparison schemes may decrease the utility for each person. Allcott and Kesller (2019) define such utility loss under the social comparison scheme as the moral tax effect. Following Allcott and Kesller (2019), we illustrate the moral tax effect in Figure 4.B (*ebhg* rhomboid).

4.2 Welfare of moral utility

Table 5 shows the calculation results of the welfare gains of CPP and each treatment based on the estimated electricity conservation amount in Table 4.A. The direct effect is the dissolution of deadweight loss by the reduction of electricity use in the peak period of the summer season. The results show that CPP increases the surplus by approximately 22.67 million USD. In a social experiment in Japan, Ito et al. (2018) show that CPP increases welfare by approximately 76.55 million USD. Their study hypothesizes the marginal cost of supplying electricity at 65 JPY per kWh. If we calculate the welfare improvement based on the marginal cost setting of the previous study, CPP increases the surplus to approximately 73.59 million USD[13].

<Table 5 here>

Our results show that the welfare improvement was quite large. The improvement in welfare in treatment group 1 was 11.98 million USD. In treatment group 2, the information provision scheme increased the welfare gain by approximately 13.98 million USD. In particular, treatment group 3 increased the welfare gain by approximately 22.35

[13] Our estimated results show that the elasticity is approximately -0.086. This means that the price impact in this experiment is lower than that in the previous study. If the conservation effect of information provision is large and the price effect becomes small, the moral utility effect becomes relatively important.

million USD. This improvement effect in treatment group 3 showed that it was close to the value of the improvement effect of CPP.

It must be emphasized that each treatment might have had additional welfare gains owing to the desire to do good things for society (moral utility). If such a factor affects the behavior of each subject, we must add the effect of moral utility to social welfare. The calculation results of the moral utility effect in each treatment group are shown in Table 5. The improvement of social welfare by the moral utility effect in treatment group 1 was 4.44 million USD. Moral utility increased welfare by approximately 6.56 million USD in treatment group 2. Moreover, the moral utility effect in treatment group 3 was massively significant in our calculation results (34.92 million USD).

This result relied on the large impact of treatment group 3. In Figure 4.B, if the amount conserved by the treatments increases (distance between D^* and D^s), the demand curve that includes the moral utility term (D') moves to the left. In such a case, the length of *af* (*eg*) increases. As a result, the moral utility effect increases, as the conservation amount is large.

Consequently, total welfare improvement by social comparison becomes large if people gain moral utility from voluntary electricity conservation. In particular, the total welfare improvement in treatment group 3 (57.27 million USD) was more than double the improvement in the control CPP group (22.67 million USD). If we compare only the direct effect between treatment group 3 and the control CPP group, welfare improvement was approximately the same. Although the welfare improvement in treatments 1 and 2 did not exceed the welfare improvement in the control CPP group, the impact of the treatments can be evaluated as a desirable voluntary conservation program. The total welfare improvement in treatment group 1 was approximately 16.42 million USD when we consider the moral utility effect. The welfare improvement achieved 72% of the value in the control CPP group. Total welfare improvement in treatment group 2 was approximately the same as that in the control CPP group. Total welfare improvement in treatment 2 achieved 90% of that of the control CPP group.

4.3 Adjusted welfare of moral utility and moral tax

Our results show that the psychological effect is nonnegligible for consumer surplus. In the calculation in Table 5, we assume that voluntary conservation increases consumer surplus because every person obtains utility from good societal behavior. Note that a nudge sometimes imposes a psychological cost on the subject. Thus, such schemes may have a negative impact on consumer surplus.

To confirm such an effect, we checked the prequestionnaire survey results. The survey included not only basic questions (e.g., number of family members, usual electricity fees and usage, and HEMS usage frequency) about electricity use but also questions about feelings regarding social comparison. The first question was “If your electricity usage exceeds that of the efficient neighbor, do you feel guilty about such information?” For this question, we offered a four-level choice set (strongly feel, feel, do not feel much, do not feel at all). The second question was “If your electricity usage is less than that of the efficient neighbors, do you feel happy?” For this question, we also provided a four-level choice set. If the subjects felt guilty because of the information, then the information provision imposed utility loss on them. In contrast, if the subjects felt happy because of the information, then they received utility from the information provision. Therefore, the answers to the two questions helped our understanding of how much welfare was truly affected by the information provision scheme.

A summary of the questionnaire results is shown in Table 6, which provides the share of each answer for each question. More than half of the participants answered that they felt happy when their electricity use was more efficient than that of their neighbors. On the other hand, more than half of the participants answered that they felt a limited amount of guilt when their electricity usage exceeded that of an efficient neighbor. The total percentage of the number of subjects who answered “strongly feel” and “feel” regarding guilt was approximately 28%.

<Table 6 here>

Based on the questionnaire results, we demonstrate the adjusted moral utility and moral tax effects under the social comparison scheme. We calculate the moral utility effect under the assumption that some subjects feel happy because of electricity conservation. The questionnaire results showed that approximately 42% of the subjects did not feel happy (“do not feel at all” and “do not feel much”) because of voluntary conservation behavior. Therefore, we abate 42% of the total moral utility effect from the total samples. Additionally, we calculate the possible total utility loss under the assumption that other subjects feel the moral tax under the social comparison scheme. The questionnaire results showed that approximately 28% of the subjects felt guilty under the social comparison scheme. Therefore, we abate the remaining 72% of the moral tax effect.

Table 7 shows the calculation results of the adjusted moral utility and moral tax effects that were identified by the questionnaire. The adjusted moral tax effect is not small in all treatments; in particular, it is larger than the moral utility effect in treatment group 1. The total emotional effect (moral utility minus moral tax) caused by the treatment becomes negative (-0.14 million USD). Although the moral utility effect is larger than the moral cost in treatment 2, almost all of the moral utility effect is offset by the moral cost effect. In treatment group 2, the total emotional effect is 0.82 million USD. This result means that we need to pay special attention to the distribution of a person's perception of the social comparison scheme.

<Table 7 here>

Finally, the moral tax effect (1.36 million USD) does not compare with the moral utility effect (20.15 million USD) in treatment group 3, where the subjects received information about the electricity use of "efficient" subjects. In treatment group 3, the total emotional effect amounts to 18.79 million USD. In this regard, Allcott and Kessler (2019) find that the welfare gain of social comparison through the HER was overestimated in previous studies because these studies ignored significant costs incurred by nudge recipients. The study finds that the welfare gain through the HER becomes positive, although it includes psychological costs. However, a difference from our results is the subject's preference for the information provided. Allcott and Kessler (2019) implement a questionnaire about feelings regarding the HER, which is similar to our questionnaire. The questionnaire results show that 63% of the recipients said that the HER made them feel neither "proud" nor "guilty." In particular, the share of the subjects who answered that they felt guilty because of the information provided by the HER was less than 20%. Thus, given our questionnaire results, there are significant differences in how many subjects felt guilty or happy in each region.

5. Discussion and Conclusion

This study analyzes the effect of a social comparison nudge in an artifactual field experiment. The experimental results include some important findings. First, our results show that information provision encourages electricity conservation behavior. Some previous studies have already revealed such an effect of social comparison schemes. However, they have focused only on information about the average trends of people's behavior and good societal behavior. We find that other types of social comparison can also encourage electricity conservation behavior.

Second, our results imply that the effect of the social comparison scheme differs depending on the initial electricity demand of each person. When the subjects know the trend of the good societal behavior of others, they try to catch up since they can obtain utility (moral utility) or decrease their loss of utility (moral tax). However, when they realize that they cannot do better than others or free themselves from undesirable behavior, they tend to give up. This finding means that the effect of the social comparison scheme depends on the distribution of the initial demand for a target good.This finding is in line with findings in other fields. For example, in a laboratory experiment, Gill et al. (2019) identify how individuals respond to the specific rank that they achieve. They find that ranking is particularly effective in incentivizing individuals who perform very well or very poorly. They also find that ranking might demoralize middle-ranked subjects. Therefore, the social comparison scheme needs to consider the relationship between the information and the distribution of consumers' initial electricity demand.

Finally, we emphasize the importance of considering the psychological factors of social comparison. When we calculate the total welfare based on adjustments of these psychological factors (moral utility and moral tax), the moral cost effect may exceed the moral utility effect if each subject receives the average consumption amount of all subjects. Therefore, it is important to consider how people feel about social comparison information.

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Table 1 Details of the experimental sessions

Session No.	Date and time	Number of subjects	Treatment group
1	January 20, 2017 (10:00)	27	Treatment group 2
2	January 21, 2017 (10:00)	25	Treatment group 1
3	January 21, 2017 (14:00)	27	Treatment group 3
4	January 27, 2017 (10:00)	25	Treatment group 2
5	January 27, 2017 (14:00)	23	Treatment group 1
6	January 28, 2017 (10:00)	39	Control group
7	January 28, 2017 (14:00)	37	Treatment group 3

Table 2 The choice ratio of the air conditioning temperature

Temperature	Control	Treatment group 1 (Top 10%)	Treatment group 2 (Average)	Treatment group 3 (Bottom 10%)
25 ℃	5.90%	9.58%	9.62%	6.41%
26 ℃	24.36%	14.79%	10.38%	8.59%
27 ℃	24.62%	22.29%	18.27%	14.06%
28 ℃	20.51%	21.88%	30.77%	25.47%
29 ℃	19.23%	17.92%	18.65%	24.53%
No use	5.38%	13.54%	12.31%	20.94%

Table 3 Factor analysis of the temperature choice

(A) Results of ordered logit estimation

	Estimation 1	Estimation 2	Estimation 3
Tr_1 *(Top 10%)*	0.350*** (0.121)	0.364*** (0.121)	1.261*** (0.290)
Tr_2 *(Average)*	0.425*** (0.119)	0.431*** (0.119)	0.746*** (0.260)
Tr_3 *(Bottom 10%)*	0.991*** (0.116)	0.961*** (0.117)	1.909*** (0.243)
Val *(Altruism)*	-0.005*** (0.001)	-0.006*** (0.001)	-0.006*** (0.001)
price	0.044*** (0.003)	0.045*** (0.003)	0.045*** (13.15)
period	0.008 (0.014)	0.008 (0.014)	0.007 (0.014)
initial		-0.240*** (0.054)	0.067 (0.003)
$Initial \times Tr_1$			-0.556*** (0.162)
$Initial \times Tr_2$			-0.199 (0.144)
$Initial \times Tr_3$			-0.617*** (0.139)
Log likelihood	-3323.3517	-3313.4524	-3301.1918

Note: Values in parentheses are standard errors. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

(B) Wald test results between the coefficient of each treatment

	Estimation 1	Estimation 2	Estimation 3
Treatment group 1 vs. Treatment group 2	0.39	0.30	3.16*
Treatment group 1 vs. Treatment group 3	28.24***	24.27***	4.99**
Treatment group 2 vs. Treatment group 3	22.68***	19.75***	20.00***

Note: Each value shows the chi-square. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table 4 Estimated electricity conservation effects

(A) Estimation 1

	The electricity conservation effect
CPP (+25 JPY per kWh)	0.086
Treatment group 1 (Top 10%)	0.027
Treatment group 2 (Average)	0.033
Treatment group 3 (Bottom 10%)	0.075

Note: Each value shows the rate of electricity conservation effect by each effect.

(B) Estimation 3

	Treatment effect	Cross-effect of treatment group and initial demand	Total electricity conservation effect
Treatment group 1 (Top 10%)	0.094	-0.067	0.027
Treatment group 2 (Average)	0.057	(nonsignificant)	0.057
Treatment group 3 (Bottom 10%)	0.141	-0.075	0.066

Note: Each value shows the rate of electricity conservation effect by each effect. The cross-effect of treatment group 1 and initial demand does not show a significant correlation with temperature choices. Thus, we excluded this effect from the calculation.

Table 5 Moral utility effects and welfare improvements

	Direct effect	Moral utility	Total welfare improvement
CPP	22.67	NA	22.67
Treatment group 1 (Top 10%)	11.98	4.44	16.42
Treatment group 2 (Average)	13.98	6.56	20.54
Treatment group 3 (Bottom 10%)	22.35	34.92	57.27

Note: The values show the converted value based on 1 million US dollars (JPY 100 = USD 1).

Table 6 Feelings about information provision

	Questions	
Answer	Happy	Guilty
Strongly feel	0.050	0.025
Feel	0.527	0.252
Do not feel much	0.294	0.495
Do not feel at all	0.129	0.228
Observations	201	202

Note: Each value shows the rate of response to each item.

Table 7 Moral utility and moral tax effects

	Adjusted moral utility	Adjusted moral tax	Moral utility–Moral tax
Treatment group 1 (Top 10%)	2.56	2.70	-0.14
Treatment group 2 (Average)	3.79	2.96	0.82
Treatment group 3 (Bottom 10%)	20.15	1.36	18.79

Note: The values show the converted value based on 1 million US dollars (JPY 100 = USD 1).

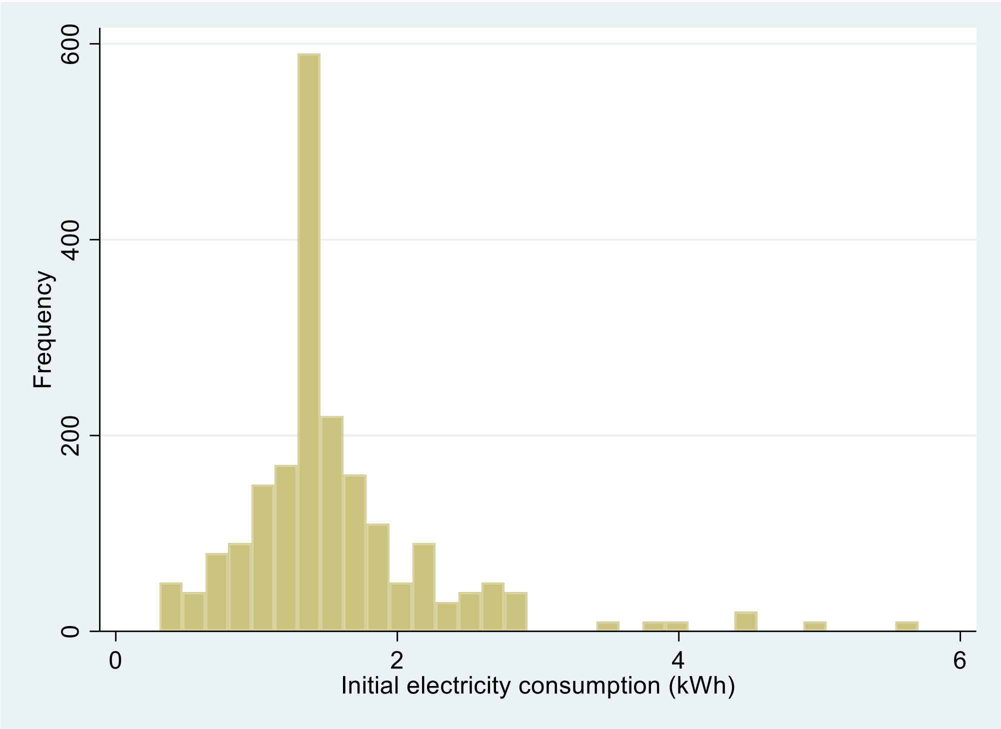

Figure 1 The initial amount of electricity use at the peak of summer

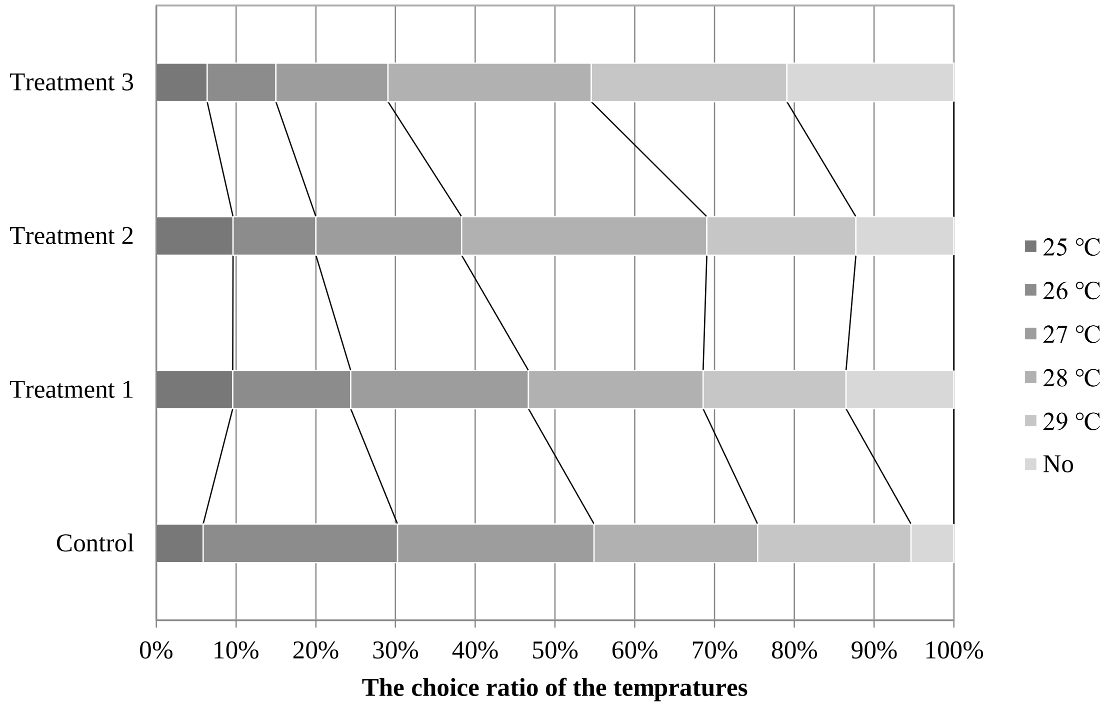

Figure 2 The choice ratio of air conditioning temperatures

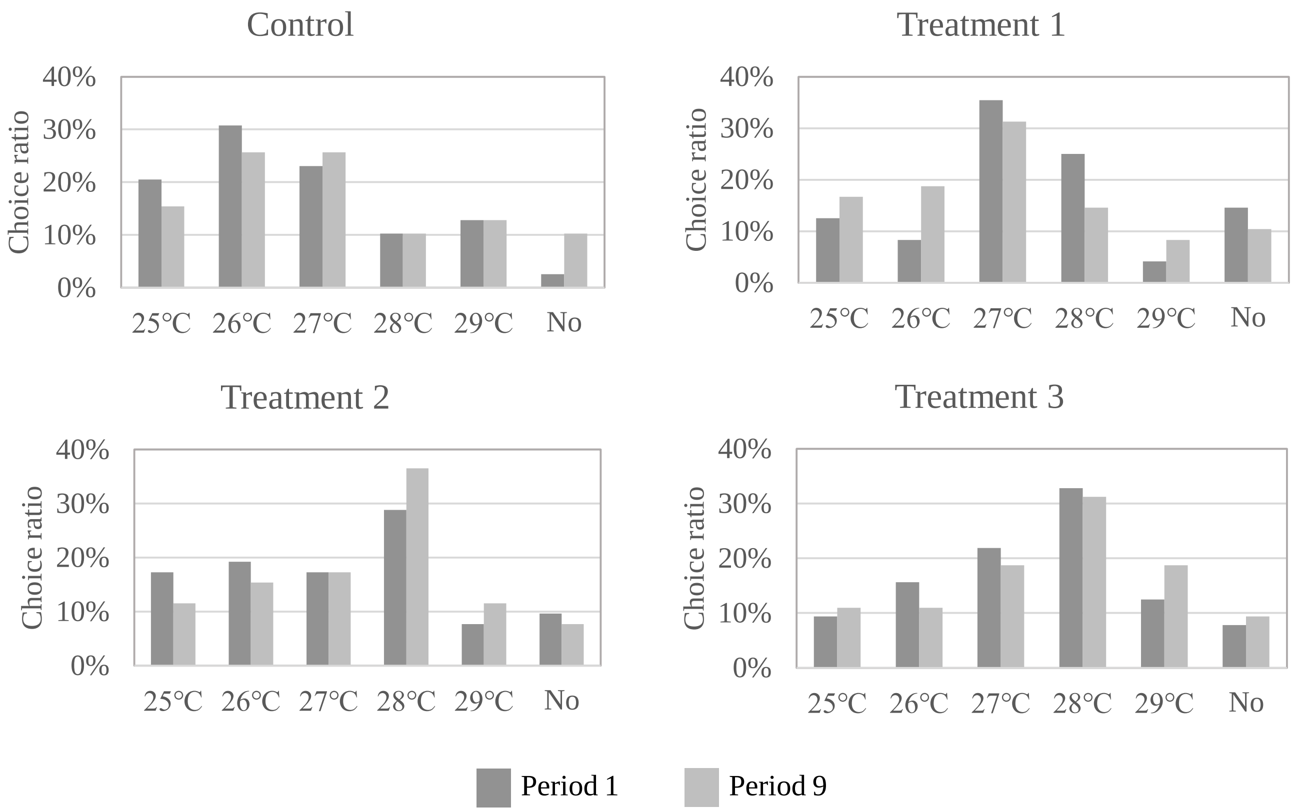

Figure 3 The choice ratio of air conditioning temperatures

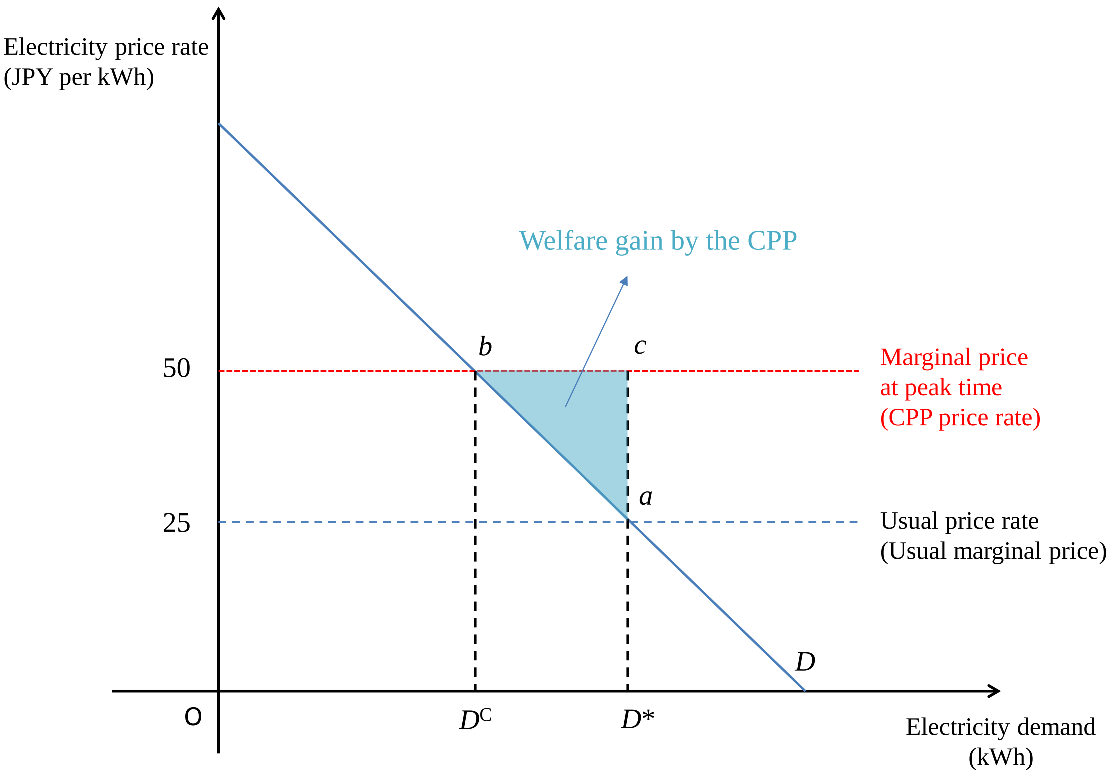

Figure 4 Welfare gain

(A) CPP

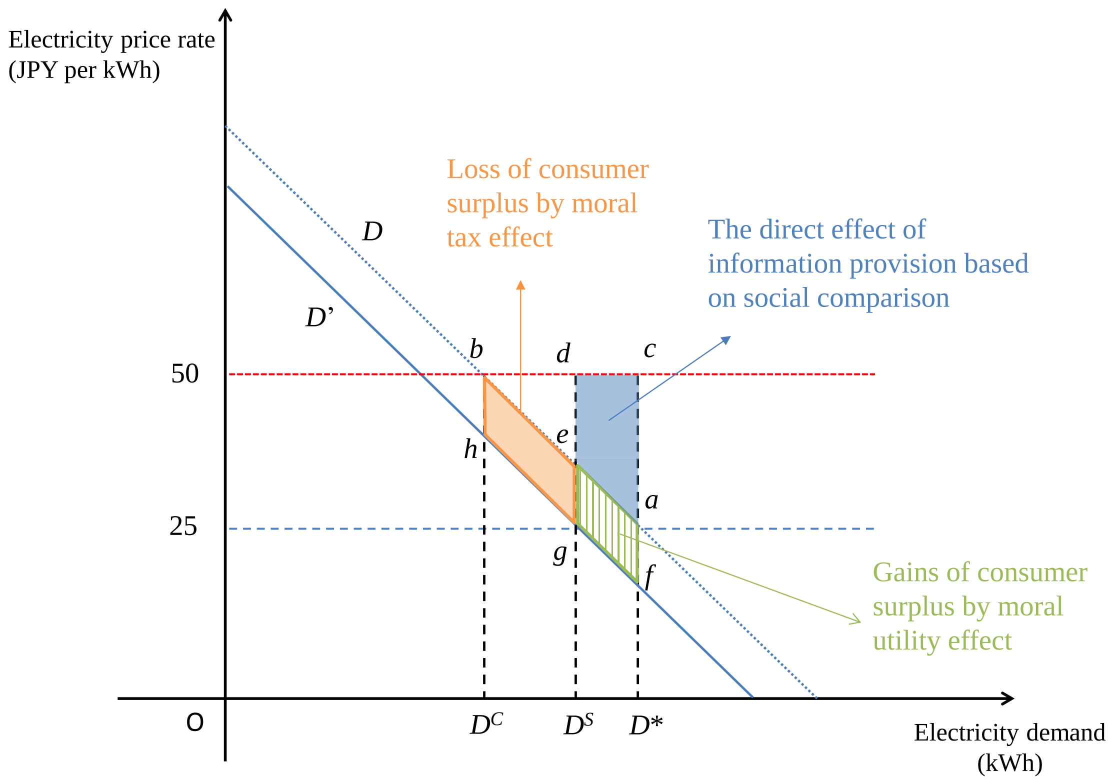

Figure 4 Welfare gain
(B) Moral utility and moral tax effect

Appendix A

Appendix A.1: The questionnaire on electricity use

How much money would you require to sustain an increasing room temperature? Of course, such a cost includes several ways to avoid the uncomfortable condition of high temperature (for example, eating frozen sweets and anything one does to feel cool). Following the situation, please answer the question under the temperature setting of an air conditioner. Please read carefully. Your answers to these questions are reflected in the setting of the experiment. Thus, please give honest answers.

・This is the hottest time in the summer (from 1 pm to 4 pm).

・The comfortable air conditioning temperature setting is 25 ℃.

・In this situation, if you increase the temperature of an air conditioner, you can conserve 10% of your total electricity use with each 1 ℃ increase in your room temperature. Moreover, you can reduce your electricity fee by 〇〇 Japanese yen.

Q1: If you turn up the temperature of the air conditioner to 26 ℃ (Conservation amount of electricity is 10% of your total use in daily life. Moreover, you can reduce your electricity fee by 〇〇 Japanese yen), how much money would you require to sustain the temperature increase?

Q2: If you turn up the temperature of the air conditioner to 27 ℃ (Conservation amount of electricity is 20% of your total use in daily life. Moreover, you can reduce your electricity fee by 〇〇 Japanese yen), how much money would you require to sustain the temperature increase?

Q3: If you turn up the temperature of the air conditioner to 28 ℃ (Conservation amount of electricity is 30% of your total use in daily life. Moreover, you can reduce your electricity fee by 〇〇 Japanese yen), how much money would you require to sustain the temperature increase?

Q4: If you turn up the temperature of the air conditioner to 29 ℃ (Conservation amount of electricity is 40% of your total use in daily life. Moreover, you can reduce your electricity fee by 〇〇 Japanese yen), how much money would you require to sustain the temperature increase?

Q5: If you turn off the air conditioner, your room temperature becomes 30 ℃ (Conservation amount of electricity is 50% of your total use in daily life. Moreover, you can reduce your electricity fee by 〇〇 Japanese yen); thus, how much money would you require to sustain the temperature increase?

Note: In place of 〇〇 is the actual monetary value based on the actual electricity fee of each subject in daily life.

Appendix A.2: Instructions for the experiment (Treatment 3)

Thank you for participating in this experiment. You are required to decide on electricity use. If you have a question about the experiment, please raise your hand. The staff will answer your question. During the experiment, you cannot communicate with other participants. Please decide under the assumption that it is your electricity use in daily life.

1 Summary

In this experiment, you can get the actual money you earn from the experiment. You can earn more money based on the rule of this instruction. Thus, please carefully read this instruction. In this period, you can check your earnings on the computer display.

In this experiment, we will implement several periods. However, no one knows how many periods are contained in this session. Imagine each period as the decision making in a day. Apart from this instruction, you will find another paper. It is a recording sheet. This sheet contributes to your decision making. You cannot share your information with other participants.

2 The decision making of electricity use

In each period, you make decisions about electricity use. Figure 1 is the image of the computer screen regarding decision making. Choose the temperature setting of the air conditioner in each period (day). Please imagine the following situation:

〇Situation of your choice

・This is the hottest time in the summer (from 1 pm to 4 pm).

・The air conditioning temperature setting is 25 ℃.

・If you choose the higher temperature setting, you can save the electricity fee. In short, you can earn money.

・However, you will feel discomfort from the temperature increase. When you choose the higher temperature, you must pay the money indicated in your answer in the previous question of this experiment to avoid the discomfort.

・Finally, your earnings are calculated as follows:

<u>Your earning = Initial endowment － Electricity fee</u>

<u>－ The cost you sustain the higher temperature</u>

Note: Electricity fee = Electricity fee at 25 ℃ － the amount of electricity saved depending on your choice

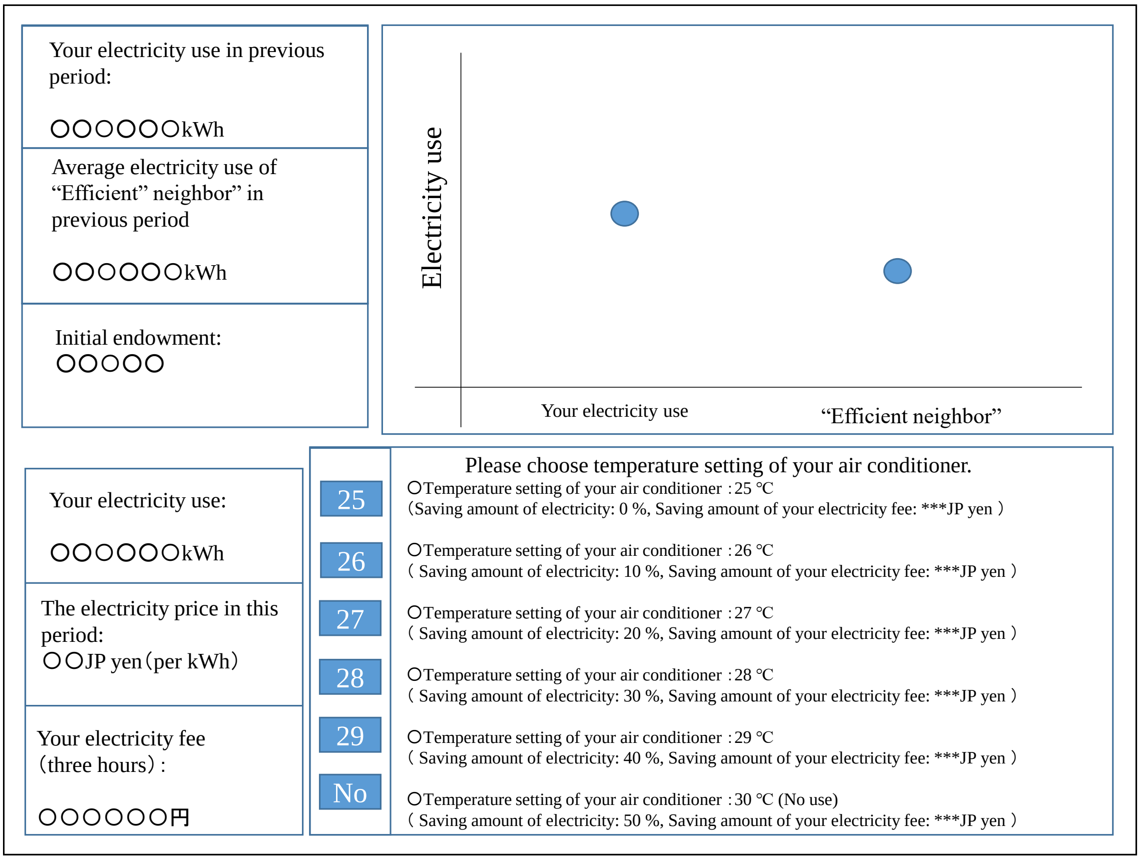

Figure 1 The computer display for your decision making (image)

2.2 Information provision and decision making

In each session, you make a decision on the computer screen, as shown in Figure 1. On the lower left of the screen, you can confirm your electricity use (kWh), electricity fee (Japanese yen), and electricity price (per kWh) at the initial setting (25 °C). After you confirm the initial situation, please choose the temperature setting of the air conditioner. After every participant has finished deciding, you can confirm the results for this period. Please record the results in your record sheet for this period. The next period automatically starts 30 seconds later.

Moreover, you can get other information from the computer screen. In the upper left of the screen, you can see your electricity usage and the average electricity use of "efficient" subjects. Electricity use by "efficient" subjects is at the bottom 10% in the same session. The graph also shows the amount of your electricity use and the average electricity use of "efficient" subjects. Based on this information, please choose the temperature setting.

2.3 The price change regarding electricity

The electricity price is 25 Japanese yen per kWh. However, the total demand for electricity randomly changes. When the peak demand nears capacity constraints, electricity prices become high (CPP scheme). Thus, the electricity price becomes 50 Japanese yen per kWh.

Appendix B Descriptive statistics

Appendix B.1. Descriptive statistics of the questionnaire survey before the experiment

Income class	Frequency	Rate
- No answer	58	0.36478
- < 40,000 dollars	17	0.106918
- 40,000–60,000 dollars	27	0.169811
- 60,000–80,000 dollars	17	0.106918
- 80,000–100,000 dollars	18	0.113208
- 100,000–120,000 dollars	11	0.069182
- 120,000–150,000 dollars	5	0.031447
- 150,000–200,000 dollars	2	0.012579
- Beyond 200,000 dollars	4	0.025157

Other characters	Observations	Average	SD	Min	Max
Number of family members (head count)	168	3.289	1.531	1	12
Monthly electricity fee (Japanese yen)	198	10,008.96	4,899.482	3,100	36,600

Note: The number of family members and income class are based on a field experiment questionnaire by Kyoto University. Data on “monthly electricity fee” were gathered before this experiment.

Appendix B.2. Descriptive statistics of the variables for ordered logit estimation

Variable		Observations	Mean	SD	Min	Max
Dependent variables (Dummy variables of temperature choice)	25 ℃	2,030	0.0803	0.2718	0	1
	26 ℃	2,030	0.1355	0.3423	0	1
	27 ℃	2,030	0.1916	0.3937	0	1
	28 ℃	2,030	0.2502	0.4333	0	1
	29 ℃	2,030	0.2039	0.4030	0	1
	30 ℃ (Turn off)	2,030	0.1384	0.3454	0	1
Independent variables	*initial*	2,030	1.1247	0.6142	0.1551	5.7010
	price	2,030	37.5	12.5031	25	50
	val	2,000	19.5197	32.1677	-77.4712	90

Note: The number of subjects was 203. In this experiment, we implemented 10 periods. Thus, the total number of observations was 2,030. In the value orientation test, the responses of three people showed errors in the calculated value of "*val*."

Appendix C. Effect of giving up or catching up to electricity use recommended by the social comparison scheme

To confirm the extent of the giving-up effect in each treatment, we conduct OLS regression based on the following formulation.

$$\frac{electricity_{9,i,treat}}{ref_{9,i,treat}} = \beta_{treat}\frac{electricity_{1,i,treat}}{ref_{1,i,treat}} + \varepsilon$$

In this formulation, $electricity_9$ and $electricity_1$ are the electricity consumption in periods 9 and 1, while ref_9 and ref_1 are the referenced electricity consumption that is provided in periods 9 and 1, respectively. *treat* shows each treatment group that subject i joined. ε is the error term. In this regression model, we hypothesize a constant term equal to zero. In this formulation, the dependent variable ($\frac{electricity_9}{ref_9}$) indicates how much each subject's electricity consumption differed from the referenced amount of electricity consumption in period 9. The independent variable ($\frac{electricity_1}{ref_1}$) shows how much each subject's electricity consumption differed from the referenced amount of electricity consumption in period 1. The estimated parameter of β shows the giving-up or catching-up effect in each treatment. We can judge whether the information provision causes a giving-up or catching-up effect by showing the estimated value of β as larger or less than 1.

Table C.1 Estimation results of catching-up effect

	β	SD	Adj.R^2	Observation
Treatment 1	1.0225	0.0211	0.9592	48
Treatment 2	0.9878	0.0250	0.9487	52
Treatment 3	1.1258	0.0226	0.9595	64

Note: β has a significant correlation at the 1% level in all regression results.

Table C.1 shows the estimation results of β in each treatment. The estimation results show that the estimated parameter of β in treatment groups 1 and 2 exceeds 1. These results mean that information provision for treatment groups 1 and 2 caused a giving-up effect on subjects who suffered from a gap between their electricity usage and the referenced electricity consumption. On the contrary, the subjects in treatment 2 tended to decrease their electricity consumption in response to the information provided. In short, the catching-up effect occurs in treatment 2.

Appendix D Estimation results of the marginal effect

Table D.1. Estimation results of the marginal effect (Estimation 1)

	25 ℃	26 ℃	27 ℃	28 ℃	29 ℃	30 ℃
Treatment group 1	-0.0190*** (0.006)	-0.0306*** (0.010)	-0.0315*** (0.011)	0.0011 (0.002)	0.0398*** (0.014)	0.0402*** (0.015)
Treatment group 2	-0.0229*** (0.006)	-0.0370*** (0.010)	-0.0383*** (0.011)	-0.0076 (0.002)	0.0482*** (0.013)	0.0493*** (0.015)
Treatment group 3	-0.0508*** (0.006)	-0.0822*** (0.010)	-0.0878*** (0.011)	-0.0079 (0.006)	0.1061*** (0.012)	0.1227*** (0.017)
Val	0.0003*** (0.000)	0.0005*** (0.000)	0.0005*** (0.000)	-0.0001** (0.0000)	-0.0006*** (0.000)	-0.0007*** (0.000)
Period	-0.0005 (0.001)	-0.0007 (0.001)	-0.0007 (0.001)	0.0001 (0.000)	0.0009 (0.002)	0.0008 (0.002)
Price	-0.0026*** (0.000)	-0.0041*** (0.000)	-0.0039*** (0.000)	0.0007*** (0.000)	0.0051*** (0.001)	0.0048*** (0.000)

Notes: Values in parentheses are standard errors. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.

Table D.2. Estimation results of the marginal effect (Estimation 3)

	25 ℃	26 ℃	27 ℃	28 ℃	29 ℃	30 ℃
Treatment group 1	-0.0560*** (0.011)	-0.0954*** (0.018)	-0.1136*** (0.024)	-0.0315* (0.018)	0.1254*** (0.021)	0.1710*** (0.049)
Treatment group 2	-0.0369*** (0.012)	-0.0617*** (0.020)	-0.0685*** (0.024)	-0.0059 (0.009)	0.0827*** (0.026)	0.0902** (0.036)
Treatment group 3	-0.0883*** (0.012)	-0.1424*** (0.016)	-0.1582*** (0.017)	-0.0448*** (0.014)	0.1688*** (0.014)	0.2650*** (0.042)
Val	0.0004*** (0.000)	0.0006*** (0.000)	0.0006*** (0.000)	-0.0001** (0.000)	-0.0007*** (0.000)	-0.0007*** (0.000)
Period	-0.0004 (0.001)	-0.0006 (0.001)	-0.0006 (0.001)	0.0001 (0.000)	0.0008 (0.002)	0.0008 (0.002)
Price	-0.0026*** (0.000)	-0.0041*** (0.000)	-0.0040*** (0.000)	0.0007*** (0.000)	0.0052*** (0.001)	0.0047*** (0.000)
Initial	-0.0038 (0.005)	-0.0061 (0.008)	-0.0060 (0.008)	0.0010 (0.001)	0.0079 (0.011)	0.0071 (0.010)
Initial ×*Treatment 1*	0.0317*** (0.009)	0.0506*** (0.015)	0.0494*** (0.015)	-0.0083** (0.004)	-0.0649*** (0.019)	-0.0585*** (0.017)
Initial ×*Treatment 2*	0.0114 (0.008)	0.0182 (0.013)	0.0177 (0.013)	-0.0030 (0.002)	-0.0233 (0.017)	-0.0210 (0.015)
Initial ×*Treatment 3*	0.0352*** (0.008)	0.0562*** (0.013)	0.0549*** (0.013)	-0.0092** (0.004)	-0.0721*** (0.017)	-0.065*** (0.015)

Note: Values in parentheses are standard errors. *, **, and *** indicate significance at the 10%, 5%, and 1% levels, respectively.