Using Dynamic Electricity Pricing to Address Energy Crises
Evidence from Randomized Field Experiments*

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Abstract
We use field experiments to examine how consumers respond to two different types of policy intervention: social pressure and private incentives. Consumers in our experiment receive social pressure that requests them to reduce electricity usage in hours when the marginal cost of electricity is high. This social pressure does not involve any economic incentive. In addition to the social pressure, our second treatment group receives dynamic electricity pricing, a strong private incentive to save electricity: the hourly marginal price of electricity changes between 15 to 150 yen (15 to 150 cents) per kWh. We find that the social pressure itself reduces electricity consumption by 3% to 4%. However, the reduction is much larger when consumers are exposed to the dynamic pricing, in which the highest marginal price results in a reduction up to 15%. Third, consumers in our experiment, who are well-informed about their hourly electricity price, actually respond to the change in hourly marginal price: higher hourly marginal prices produce larger reductions in consumption. Fourth, we investigate the heterogeneity in response to the social and private incentives. Compared to low-income consumers, high-income consumers respond to the social pressure more. Conversely, the response to the dynamic pricing is less for high-income consumers. Finally, we find that the response to the dynamic pricing is also larger for high-electricity users.

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1 Introduction

Economists have long argued that the economic gain from shifting peak electricity demand to off-peak periods is substantial (e.g. Boiteux, 1960; Williamson, 1966; Kahn, 1988). In general, the marginal cost of generating and distributing electricity is extremely high in limited hours of each year (Joskow, 2012 and Joskow and Wolfram 2012). Moreover, this economic benefit can be much larger when the economy is on the verge of energy crises, because large-scale blackouts can result in enormous cost to the economy.\footnote{For example, the California electricity crisis in 2000-2001 and the Japanese electricity crisis after the earthquake in 2011 and after the shutdowns of nuclear power plants in 2011-2012 lead to the risk of large-scale blackouts.}

To address this inefficiency, policy makers generally take two different types of policy intervention: social pressure and private incentives. In theory, regulators can provide dynamic electricity pricing that reflects the time-varying marginal cost of electricity. Such private incentives can be effective if consumers actually respond to the hourly marginal price of dynamic electricity pricing with relatively short notice. Technologically, dynamic pricing is a feasible option for regulators in many counties including the U.S. because a growing number of consumers have smart electricity meters. However, policy makers are often reluctant to use the private incentive. Many of them suspect that electricity consumers do not respond to hourly electricity price and it is politically unfavorable to increase electricity price. As an alternative, social pressure is frequently used to provide an incentive for consumers to reduce electricity consumption. Such policy was implemented in energy crises in the U.S. (2000-2001), Brazil (2001), and Japan (2011).\footnote{See Reiss and White (2008) for the California electricity crisis and Gerard (2013) for the electricity crisis in Brazil.} While many newspaper articles report that such social pressure resulted in significant reductions in peak hour demand, there is limited empirical evidence of the relative effectiveness of the two types of policy intervention.
In this paper, we use field experiments to examine how consumers respond to social pressure and private incentives. We present two field experiments. In the first experimental location, we examine how consumers respond to dynamic electricity pricing, which provides a strong private incentive to save electricity in peak-hours: the hourly marginal price of electricity changes between 15 to 150 yen (15 to 150 cents) per kWh. In the second experimental location, we focus on the comparison between the effects of dynamic pricing and social pressure by creating two different treatment groups. Consumers in the experiment receive social pressure that requests them to save electricity in hours when the marginal cost of electricity is high. This social pressure does not involve any economic incentive. In addition to the social pressure, the second treatment group receives dynamic electricity pricing similar to the first experimental location.

Results from our experiments provide several findings. First, consumers reduce consumption significantly in response to the changes in hourly marginal price. That is, in contrast to the common belief by regulators and power companies, consumers actually respond to the marginal price of hourly electricity if they are well-informed about the price. Second, higher hourly marginal prices produce larger reductions in consumption. Third, the social pressure itself without private incentive also reduces peak-hour consumption by about 3% to 4%. However, the magnitude of the reduction is much larger when consumers are exposed to dynamic pricing, which results in the reduction by 6% (with the lowest marginal price) to 15% (with the highest marginal price). Fourth, we find that the effect of social pressure is larger for high-income households, while the effect of private incentives is larger for low-income households. These findings imply that the price elasticity is larger for low-income households, but the elasticity with respect to our social pressure treatment is larger for higher-income households.

To our knowledge, this paper is the first study to use a randomized field trial to examine the
relative effectiveness of social pressure and private incentives.\footnote{For quasi-experimental studies on a related policy, see Reiss and White (2008) in the California electricity crisis and Gerard (2013) in the electricity crisis in Brazil.} Our field experiment provides three key features to answer the question. First, it allows us to separately identify the two effects by using random assignment of treatment. As Reiss and White (2008) describe, it is challenging to separate these effects in quasi-experimental data during energy crises, because many policy intervention goes on simultaneously or in very close time periods. Second, we take advantage of the technology of smart meters to gain access to 30-minute interval data of household electricity use. It is especially important to analyze consumer behavior in such detailed time intervals for energy policy because the key policy goal is to reduce consumption in peak-hours. With monthly or annual data, it is not possible to provide evidence on whether a certain policy results in a reduction in peak-hour electricity demand. Finally, the detailed household-level demographic and housing information enables us to investigate the heterogeneity in the treatment effects of the two incentives. Our findings in the heterogeneity in the treatment effects provide important policy implications.

Another important policy implication from our experiments is that the dynamic pricing schedule that we propose in this study potentially provides some advantages to the two common dynamic pricing schedules: 1) real-time pricing and 2) critical peak pricing (CPP).\footnote{For example, Alcott 2011 examines real-time pricing and Wolak (2006, 2010, 2011); Faruqui and Sergici (2011); Jessoe and Rapson (2012) provide empirical evidence of critical peak pricing. Faruqui and Sergici (2010) provides a survey of several dynamic pricing experiments.} In real-time pricing, consumers face time-variant prices that are often a function of real-time wholesale electricity prices. An advantage of real-time pricing is that it directly reflects the marginal cost of electricity. A potential disadvantage that is often argued for real-time pricing is that retail customers, especially residential customers without having an automated demand response devices, may not be able to respond to too much of price fluctuation. As an alternative dynamic pricing schedule, previous
studies implement CPP, in which consumers face a high marginal price only during critical peak hours on CPP event days, which are typically about five to fifteen days per summer and winter. A potential disadvantage of CPP is that a single critical peak price can reflect the marginal cost of electricity in limited amount and regulators or cannot send a different price signal to consumers. In this regard, we address these challenges by introducing variable critical peak pricing (VCPP) in which the peak-hour rate changes depending on the marginal cost of electricity. Our finding suggests that consumers well respond to such pricing given that they receive clear information about the price change.

This paper proceeds as follows. The second section provides a simple conceptual framework to consider the consumer problem in response to social and private incentives. In the third section, we briefly explain the background of our field experiment, experimental design, and data. The fourth section presents our empirical strategy and results. The fifth section provides welfare analysis based on our estimates from the third section, and we conclude in the last section.

2 Conceptual Framework

We here discuss a simple theoretical framework of social pressure and private incentives in the context of electricity demand based on the model by DellaVigna, List, and Malmendier (2012). Suppose that a household consumes electricity $x$ at price $P$, and contributes to voluntary conservation of electricity, $g$. The saved amount $Pg$ in monetary term is added to the numeraire $y$, which totals $Y = y + Pg$. Alternatively, $Y = M - Px$ from the budget constraint of a household with income $M$. Let $G_{-i}$ denote the contributions to voluntary conservation by other households. Each household
then maximizes a differentiable and strictly quasi-concave utility function $U$:

$$\max_{x,g} U = u(x, g, G_{-i}, M - Px) - s(g), \quad (1)$$

where $s(g) = S \cdot (g^* - g) \cdot 1_{g < g^*} \geq 0$ as in DellaVigna, List, and Malmendier (2012). They called $s(g)$ a utility cost of social pressure for not contributing or only contributing a small amount of $g$. The cost is highest for the case of no contribution ($s(0) = Sg^*$), and it decreases linearly in $g$. $S \geq 0$ can be regarded as the strength of social pressure for electricity conservation, implying that the pressure increases as $S$ becomes greater. $g^*$ can be interpreted as a required reduction in power consumption.

The first element of utility, $u$, is similar to the general utility of charitable contributions in Kingma (1989). Kingma argues that there are several competing theoretical models of charitable contributions, ranging from the models that consider charity as a pure public good, to the most general ones that model agents as receiving utility from charity. $u$ in (1) allows for both pure altruism (pure public good) and impure altruism (warm glow). In the case of pure altruism, a household cares about the total contributions to voluntary conservation, $g + G_{-i}$, as in Bergstrom, Blume, and Varian (1986).\(^5\) In the case of impure altruism, a household cares about warm glow $g$, which can be viewed as a private good as in Andreoni (1989).

Assuming that $g < g^*$, the first order condition for the problem (1) with respect to $g$ yields

$$\frac{\partial u}{\partial g} = -S,$$

which implies that a household chooses $g$ such that its marginal utility of conservation is equal to (the negative value of) the intensity of social pressure. It is assumed that $\frac{\partial^2 u}{\partial g^2} < 0$, i.e., marginal utility of conservation is decreasing. If there is no social pressure, a household chooses $g$

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\(^5\)Kotchen (2006) and Kotchen and Moore (2007) extended the framework to examine impure public goods such as a green tariff mechanism.
such that $\frac{\partial u}{\partial g} = 0$. With $S > 0$, a household would feel pressured to further contribute to voluntary conservation of electricity. Thus, an increase in the strength of social pressure would have upward pressure on electricity conservation:

$$\frac{\partial g}{\partial S} > 0.$$  \hspace{1cm} (2)

One interesting question is whether social pressure has different impact on households with different levels of income. That is, the sign of $\frac{\partial^2 g}{\partial M \partial S}$ is of interest. If a household with higher income responds more to social pressure, the sign will be positive, i.e., $\frac{\partial^2 g}{\partial M \partial S} > 0$, which will be examined in the empirical section of the paper.

On the other hand, households also face price incentives expressed as:

$$\frac{\partial x}{\partial P} < 0.$$  \hspace{1cm} (3)

Another interesting question is whether price incentives differ among households with different levels of income. That is, the sign of $\frac{\partial^2 x}{\partial M \partial P}$ is of interest. Reiss and White (2005), among many other existing work, show empirical results that households with lower income are more sensitive to electricity prices than households with higher income. This implies $\frac{\partial^2 x}{\partial M \partial P} > 0$, which we will investigate later in the empirical section.
3 Experimental Design and Data

3.1 Background of the Field Experiment

The Ministry of Economy, Trade, and Industry (METI) launched the Smart Grid Pilot Project in 2010 to investigate the impact of advanced metering and communication technologies on the Japanese energy markets. Using several field experiments in four cities: Yokohama, Toyota, Kyoto, and Kitakyushu, the project aimed to examine dynamic electricity pricing, home and building energy management, and renewable energy management.

The project became a particularly important policy experiment after the Great East Japan Earthquake in March, 2011. The shutdown of nuclear reactors in Fukushima and thermal power plants in many locations led to short-run electricity shortage. Moreover, the electricity shortage became a long-run problem. All of the 50 nuclear reactors, including reactors that were not directly affected by the earthquake, stopped operation in 2011 and 2012 because of safety concerns and opposition from local governments that are responsible for providing an approval for re-operation. Japan lost 46,148 MW capacity, which resulted in Japan’s energy crisis in 2011 and 2012. As a result, reducing peak-hour electricity demand became a central policy goal in Japanese energy policy.

In this paper, we present two field experiments in two cities, Kitakyushu and Kyoto, in the summer of 2012. We collaborate with the Japanese Ministry of Economy, Trade and Industry, the prefecture of Kyoto, Kansai Electric Power Company, Mitsubishi Heavy Industries, the city of Kitakyushu, Fuji Electric, and IBM Japan to design and run the field experiments. We describe details about the experimental design in the next section.
3.2 Data

The sample of our experiment consists of 182 households in for the Kitakyushu experiment and 681 households for the Kyoto experiment. Note that our participants are self-selected samples in the same manner to the previous studies in electricity pricing experiments (Wolak (2006, 2010, 2011); Faruqui and Sergici (2011); Jessoe and Rapson (2012)). That is, our samples are households who agree to participate in the experiment. By participating in the experiment, households receive a smart meter and in-home display for free as well as a participation reward of 12,000 yen ($120) per year in the Kitakyushu experiment and 14,000 yen ($140) per year in the Kyoto experiment.\(^6\)

The primary data for this study come from the 30-minute interval electricity consumption records. In this study, we use consumption data on the weekdays excluding holidays in July, August, and September 2012. In addition to the electricity consumption data, we collects a survey of demographic and housing information. In the Kitakyushu experiment, households are randomly assigned to two groups: 1) 124 households in the dynamic pricing treatment group, 2) 56 households in the control group. In the Kyoto experiment, households are randomly assigned to three groups: 1) 381 households in the dynamic pricing treatment group, 2) 150 households in the conservation request only treatment group, and 3) 150 households in the control group. All groups including the control group receive an in-home display, with which households can observe the information about their electricity price and consumption (Figure 1).

Table 1 presents summary statistics of electricity consumption data and demographic information for samples in Kitakyushu. Column 1 and 2 shows the mean and standard deviation of each variable for the treatment and control groups. In column 3, we present the difference in the mean value of

\(^6\)The participation reward is slightly higher for the Kyoto experiment because the participants are asked to complete a more detailed survey than the survey in the Kitakyushu experiment
each variable between the treatment and control group. Because the treatment group is randomly assigned, the difference is expected to be statistically insignificant given that the randomization is correctly enforced. In the last column, we report the p-value for the null that there is no difference in the mean between the two groups. Overall, the observable variables are well balanced.

Table 2 shows summary statistics for samples in Kyoto. Samples in the Kyoto experiments use slightly more electricity and are more diverse than the samples in the Kitakyushu experiment. The means of electricity use, square meters of residence, household size, and number of AC are slightly larger than those in the Kitakyushu experiment. Because of the random assignment of the groups, all of the means are not statistically different between the three groups.

Figure 2 compares the monthly average high and low temperature between Kyoto and Washington D.C. to understand the climate conditions for households in our experiments. The average low and high temperature are very similar between the two cities. The average high and low temperature in summer months are slightly higher in Kyoto than Washington D.C.. In addition, the air tends to be very humid in the summer in Japan. As a result, the electricity demand from air conditioner usage creates peaky demand in the afternoon of hot summer days in Japan.

3.3 Variable Critical Peak Pricing in the Kitakyushu Experiment

The policy goal of our experiment is to reduce electricity consumption in the system peak load hours. In typical summer days in Japan, the peak hours of the system load are between 1 pm to 4 pm or 5 pm. Therefore, the marginal cost of electricity is generally high for these hours. Moreover, in particularly hot days, the extensive use of air conditioner further increases the system load, which leads to potential rolling blackouts because of the lost capacity due to the shutdown of

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7The average high and low temperature in Kitakyushu are very similar to the ones in Kyoto.
nuclear reactors. In the Kitakyushu experiment, we investigate how dynamic pricing, a private incentive, affect electricity consumption of residential customers.

Among several versions of dynamic electricity pricing, critical peak pricing (CPP) is a commonly used price schedule in the US. When a CPP event day is announced, consumers face a high marginal price for critical peak hours. Previous studies such as Wolak (2006, 2011) find evidence that consumers reduce their consumption significantly in response to CPP. In most of the previous studies, however, CPP schedules have a single critical peak price. A single critical peak price creates two limitations. First, regulators can use only one price as a price signal for an emergency day although the marginal cost of electricity depends on the degree of the emergency. For example, even among really hot summer days, the marginal cost of generating and distributing electricity could vary depending on the demand and available generating units. Second, evidence from previous studies cannot tell whether consumers actually respond to the change in the marginal price of electricity or respond to an announcement of the emergency. Finally, in an experiment with a single critical peak price, one cannot tell whether consumers would reduce their consumption more or less if the critical peak price was higher or lower than the price implemented in the experiment.

In the Kitakyushu experiment, we propose Variable Critical Peak Pricing (VCPP) as shown in Figure 3. In non-event days, consumers in the treatment group have a time-of-use price schedule in which the marginal price equals 6 yen/kWh for the night time, 10 pm to 8 am and 15 yen per kWh for other hours. A CPP day is announced one-day ahead if 1) the forecast maximum temperature exceeds 30°C (86°F) and 2) the day is not a weekend or holiday. When a CPP day is announced, consumers are also notified about the critical peak price that is either of five prices: 15, 50, 75, 100, or 150 yen per kWh in Kitakyushu. Consumers receive the day-ahead notice through their in-home display shown in Figure 1. Using randomly assigned 124 treatment households and 56 control
households, we examine whether consumers respond to the hourly marginal price of electricity.

3.4 Social Pressure vs. Private Incentives in the Kyoto Experiment

The objective of the Kyoto experiment is to examine how consumers respond differently to the two types of policy intervention: social pressure and private incentives. In this experiment, households are randomly assigned into three groups: 1) the control group, 2) the social pressure group, and 3) the dynamic pricing group. All groups including the control group receive an in-home display, with which they can observe the information about electricity price and consumption. We define "peak-hours" as the three hours between 1 pm to 4 pm on weekdays. In addition, we call these three hours by "critical peak-hours" when the day-ahead forecast of the maximum temperature exceeds 30°C (86°F).

Our first treatment group is the social pressure group. In non-event days, they do not receive any treatment. Their price is the same as the control group and they do not receive any notice. In the critical peak event days, they receive a message of social pressure via text messaging and on the in-home display. Figure 5 shows the exact message in Japanese and its translation into English. The exact message is, "Subject: Notice of demand response. In the following hours, please reduce your electricity use. 8/21 (Tuesday) 13:00-16:00". Note that this treatment does not involve any economic incentive.

Our second treatment group is the dynamic pricing group. In non-event days, their hourly marginal price for the peak hours (1 pm to 4 pm) are increased by 20 yen/kWh. However, in these non-event days, they do not receive any message of social pressure. In the critical peak days, they receive a message of social pressure via text messaging and on the in-home display in exactly
the same way as the social pressure group. In addition, their message includes that their hourly marginal price for the peak hours will be increased either by 40, 60, and 80 yen/kWh. Figure 5 shows the exact message in Japanese and its translation into English. The exact message is, "Subject: Notice of demand response. In the demand response hours, your electricity price will be very high. In the following hours, please reduce your electricity use. 8/21 (Tuesday) 13:00-16:00, 1 kWh: +80 yen."

Similar to the dynamic pricing experiment by Wolak (2011), most households in our experiment usually face increasing block pricing. However, the increasing block price schedule is relatively flat compared to the increasing block price schedules commonly used in the US. The marginal price is 19.38 yen/kWh for the first 120kW monthly use, 24.54 yen/kWh for the next 180 kW, and 25.88 yen/kWh for the rest of monthly use. Since this is a relatively flat block price schedule, we use the average marginal price over our sample, 25 yen/kWh, when we calculate the arc price elasticity.\(^8\).

4 Empirical Analysis and Results

4.1 Estimation Strategy in the Kitakyushu Experiment

In the Kitakyushu experiment, consumers in the treatment group face a higher marginal price during the peak hours, 1 pm to 5 pm when CPP days are called. The primary interest is how consumers change their consumption during the peak hours in response to the changes in hourly marginal price. Second, consumers may also change consumption outside the peak hours. If they shift consumption from the peak hours to off peak hours, we may observe an increase in

\(^8\)Alternatively, we can calculate the price elasticity by using the actual marginal rate or average rate that each customer is facing. Such adjustment leads to only slight changes in the elasticity because the difference in the three block rates is relatively very small compared to the large changes in price by the dynamic pricing treatment.
consumption during off peak hours. On the other hand, there may be spillover of the treatment effect in off peak hours. For example, consumers may leave home in response to a CPP event. To investigate the effect on different ranges of hours of the day, we define three time periods: 1) peak hours, 1 pm to 5 pm; 2) shoulder hours, 8 am to 1 pm and 5 pm to 10 pm; and 3) off peak hours, 10 pm to 8 am, and estimate the treatment effect separately for each time period.

Let \( y_{it} \) denote household \( i \)'s electricity consumption during a 30-minute interval period \( t \). First, we estimate the following model to estimate the average treatment effect of all CPP events by having a single dummy variable for all CPP days:

\[
\ln y_{it} = \beta \cdot D_{it} + \theta_i + \lambda_t + \eta_{it}, \tag{4}
\]

where \( D_{it} \) equals one if household \( i \) is in the treatment group and a pricing event occurs for \( i \) in interval \( t \). We estimate this model by peak-hours, shoulder hours, and peak-hours, separately. \( \theta_i \) is a household fixed effect that controls for persistent differences across households in their consumption, \( \lambda_i \) is a time fixed effect for each 30-minute interval \( t \) that accounts for weather and other shocks specific to \( t \). Finally, \( \eta_{it} \) is an unobserved mean zero error term that is uncorrelated with any of the regressors in this model because of randomization.

The second model allows for different average treatment effects for different critical peak prices:

\[
\ln y_{it} = \sum_{p \in \{50,75,100,150\}} \beta_p \cdot D_{it}^p + \theta_i + \lambda_t + \eta_{it}, \tag{5}
\]

where \( D_{it}^p \) equals one if household \( i \) is in the treatment group and a pricing event with price \( p \) occurs for \( i \) in interval \( t \).
Finally, we estimate the third model to examine heterogeneity in the treatment effect. We consider three variables to be interacted with the treatment variable. The first variable is an indicator variable for consumers with higher ex-ante consumption. We calculate mean ex-ante consumption for each consumer by using their consumption data in June 2012, in which the experiment has not started. The indicator variable equals to one if consumer $i$’s mean ex-ante consumption is higher than the sample mean of the ex-ante consumption. The second interaction term is the air conditioner age. Older air conditioners tend to use more electricity to cool rooms. Thus, there might be larger savings of electricity when the CPP is applied to consumers with older air conditioners. Let $x_i$ denote either of the three variables to be interacted with the treatment variable and we run,

$$\ln y_{it} = \beta \cdot D_{it} + \gamma \cdot D_{it} \cdot x_i + \theta_i + \lambda_t + \eta_{it}.$$  

(6)

Note that high-frequency data on household-level electricity consumption are likely to contain serial correlation and cannot be treated as independent data points. To account for the serial correlation, we cluster standard errors at the consumer level.

### 4.2 Estimation Strategy in the Kyoto Experiment

We use a similar estimation strategy in the Kyoto experiment. Remember that in the Kyoto experiment, we have the second treatment group, who receives the conservation request treatment only. The dynamic pricing treatment group receives both conservation request and price incentive when they receive the 40, 60, 80 yen price increases. When they receive the 20 yen price increase,
they do not receive conservation request. We estimate,

\[ \ln y_{it} = \alpha \cdot D_{it}^c + \sum_{p \in \{20, 40, 60, 80\}} \beta_p \cdot D_{it}^p + \theta_i + \lambda_t + \eta_{it}, \]  

(7)

where \( D_{it}^c \) equals one if household \( i \) receives the conservation request in interval \( t \) and \( D_{it}^p \) equals one if household \( i \) receives the price increase by \( p \) in interval \( t \). When the dynamic pricing group receives the 40, 60, 80 yen price increases, their conservation request dummy variable also equals one. Therefore, for example, \( \alpha + \beta_{80} \) provides the combined effect of the treatment effects of conservation request and the 80 yen price increase.

In addition to estimating the average treatment effect, we estimate potential heterogeneity in the treatment effects by including interaction terms between the treatment variables and a variable of interest, \( x_i \) such as household annual income. We estimate,

\[ \ln y_{it} = \alpha \cdot D_{it}^c + \phi \cdot D_{it}^c \cdot x_i + \sum_{p \in \{20, 40, 60, 80\}} (\beta_p \cdot D_{it}^p + \gamma_p \cdot D_{it}^p \cdot x_i) + \theta_i + \lambda_t + \eta_{it}, \]  

(8)

where \( \phi \) and \( \gamma_p \) provides estimates for interaction effects of the treatments and a variable of interest \( x_i \).

### 4.3 Graphical Analysis

An advantage of randomized controlled trials is that simple comparison between the mean outcome values of treatment and control groups provides a way to examine preliminary evidence of the treatment effect. Figure 6 uses data from the Kitakyushu experiment to provide graphical evidence that consumers reduce consumption in response to CPP. We calculate the mean of log consumption.
per 30-minute interval for the control and treatment consumers for each of the five peak hour prices. We use data from all CPP event days to calculate the means. The vertical lines show the critical peak time period, 1 pm to 5 pm. The first figure shows that in non-event days, the mean consumption is essentially the same for the control and treatment groups. That is, this figure provides evidence that there is no systematic difference between the control and treatment group in their consumption in the absence of the intervention of the treatment. When consumers in the treatment group face the marginal price of 50, 75, 100, and 150 yen, they start to reduce consumption at 1 pm. The figures also show that their consumption returns to the control group’s consumption level almost right after the end of the critical peak hours. Finally, the reduction in consumption is smallest when the critical price is 50 yen and largest when the price is 150 yen.

Figure 7 uses data from the Kyoto experiment to compare reductions in consumption in response to the warning-only treatment (no price incentive) and the dynamic pricing treatment. We use data from all CPP event days to calculate the means. The vertical lines show the critical peak time period, 1 pm to 4 pm. We subtract household fixed effects. In hours before the critical peak hours, the consumption between the three groups are not statistically different. During the critical peak hours, both the warning-only group and the dynamic pricing group reduce their consumption. The plots also show the evidence that the magnitude of the reduction is substantially larger for the dynamic pricing treatment. The next section provides estimation results from the econometric models to quantify the treatment effect with standard errors.
4.4 Estimation Results

Table 3 shows the estimation results of the treatment effects of the variable critical peak pricing for the Kitakyushu experiment. Column 1 shows that the average treatment effect of the CPP events is 12.2 percent. In column 2, we estimate the average treatment effect by the critical peak price. The CPP with 50 yen produces a 8.9 percent reduction in consumption. The treatment effect increases with the critical peak price and it is largest with the critical peak price of 150 yen. Although the increase in the treatment effect is monotonic, it diminishes when consumers face 100 yen and higher.

Columns 3 and 4 shows the average treatment effects for the shoulder hours, which are from 8 am to 1 pm and from 5 pm to 10 pm. Consumers may increase consumption during the shoulder hours if they cool their homes right before or right after the peak hours. We do not find significant pre-cooling or post-cooling effects during the shoulder hours. In contrast, we find a slight increase in consumption in off-peak hours, from 10 pm to 8 am. Columns 5 and 6 show that consumers increase consumption by 4% to 5% during the off-peak hours.

Table 4 shows the estimation results for the Kyoto experiment. Column 1 shows that the treatment effect of the conservation request itself is 3.3%. The treatment effects of the dynamic pricing are about 6%, 12%, 14%, and 15% when consumers receive the price increase by 20, 40, 60, and 80 yen per kWh. That is, the dynamic pricing effect increases monotonically with the increases in price. Note that households receive both conservation request and dynamic pricing treatments when they get the price increase by 40, 60, and 80 per kWh. That is, our estimates imply that the combined effect of the two treatments are about 15, 17, and 18%. The p-value of the difference in the effect of the 40 yen increase and the 80 yen increase is 0.03. However, the
effect of the 60 yen increase is not statistically different from the effect of the 40 yen increase and
the effect of the 80 yen increase. In addition, the conservation request effect is also not statistically
different from the effect of the 20 yen increase. If we calculate the arc price elasticity with the
base marginal price of 25 yen per kWh, the price elasticity estimates are -0.102, -0.124, -0.113,
and -0.105 for the 20, 40, 60, and 80 yen price increases. Column 2 implies that the treatments
result in a slight decrease in consumption for shoulder hours, although the estimate is statistically
significant from zero only for the case with the 80 yen price increase. Finally, column 3 provides
evidence of consumption shifting to off-peak hours when consumers have high hourly prices. The
increase in off-peak consumption is about 1% to 2%.

In Figure 8, we plot our estimates to show our estimated demand curve for peak-hour electricity
consumption. Remember that our dynamic pricing group receive the message of conservation
request when they receive the 40, 60, and 80 price increases, while they do not receive the message
of conservation request when they get the 20 yen price increase. To draw the demand curve, we
assume that the effects of conservation warning and dynamic pricing are additive. Note that we
need this assumption only for the point at 45 yen (25 yen base price plus 20 yen) because our
estimate of this point comes from the days when consumers do not receive conservation request.
The demand curve shows that the conservation effect itself lowers consumption 3% and there is a
monotonic relationship between the increase in price and the further decrease in consumption.

To compare the two types of policy intervention, social pressure and private incentives, another
important question is whether households with different income or different electricity usage levels
respond differently to the two incentives. We estimate heterogeneity in the treatment effects in
Table 5 and 6. In Table 5, we use our Kyoto experiment to investigate heterogeneity in the response
to the conservation request and the dynamic pricing. We use two variables for interacting with the
treatment variables. The first variable is the annual household income in 1 million yen ($10,000). The second variable is the mean hourly electricity usage in 100 Wh calculated by using electricity consumption before the beginning of the treatment period. Out of 681 samples, 588 samples report their annual income. First, we investigate the treatment effects interacted with income. The estimates on the effect of conservation request imply that an increase in income by 1 million yen ($10,000) increases the effect of conservation request by 0.6 percentage point. On the other hand, the estimates are positive for the interaction terms with the dynamic pricing treatment. The positive estimates imply that an increase in income by 1 million yen ($10,000) decreases the effect of the 20 yen, 40 yen, 60 yen, and 80 yen increases by 0.9, 1.9, 1.8, and 1.9 percentage point. In summary, the results imply that the effect of our social pressure treatment is larger for higher income households, while the effect of our dynamic pricing treatment is smaller for higher income households.

The next question we ask is whether the treatment effects are different between low- and high-electricity users. Low- and high-electricity users may respond to the treatments differently because high-electricity users are more likely to have more discretionary consumption. Column 2 shows that the interaction effect for the social pressure treatment is not statistically significant from zero. In contrast, the interaction effects are negative and statistically significant for the dynamic pricing treatments. For example, the treatment effect of the 80 yen increases by 4.1 percentage point with an increase in average hourly consumption by 100 kW.

Similarly, Table 6 examines heterogeneous treatment effects by using data from the Kitakyushu experiment. First, we interact the treatment variable with the indicator variable for consumers.

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9We examine whether the miss-reporting is correlated with the assignment of our treatment. The miss-reporting rate is similar in the control, and the two treatment groups. The regression of the miss-reporting dummy variable on the treatment group dummy variables produce insignificant coefficients on the group dummy variables.
whose ex-ante consumption is above the sample mean. Column 2 shows that consumers with higher consumption have a larger treatment effect than those with lower consumption by 8 percentage points. Because older air conditioners tend to use more electricity to cool rooms, there might be larger savings of electricity when the CPP is applied to consumers with older air conditioners. To test this hypothesis, we interact the air conditioner age demeaned by the sample average with the treatment variable in column 3. The result implies that the treatment effect increases by 1.1 percentage point for one-year increase in the air conditioner age.

Finally, we ask whether households in the two treatment groups invested more on their durable goods because of our treatment intervention. In the follow-up survey right after the summer 2012 experiment, we asked households whether they purchased new appliances. Table 7 presents the estimation result of linear probability models, in which the dependent variable is the dummy variable that equals one if the consumer purchased a new appliance in the summer 2012. From this 2012 summer survey, we find that both of the conservation request treatment and the dynamic pricing treatment made households to purchase electric fans, which is relatively low cost of investment to cool their rooms in hot days. We do not find significant effects for other appliances: air conditioner, refrigerator, and washer.

5 Welfare Analysis

5.1 Who Benefits and Loses from the CPP?

Opponents of dynamic pricing often argue that it allows for power companies to raise their peak price and results in a sharp increase in electricity bills for most consumers. The statement is
incorrect because dynamic pricing schedules are typically designed with a revenue neutrality condition. In our experiment, for example, the off peak price of the CPP schedule is set to be lower than the TOU schedule of the control group. To be more precise, we set the peak and off peak price of the treatment group, which guarantees that average consumers would have exactly the same bill between the two price schedules if they have zero price elasticity. However, it is true that some consumers may see a higher bill when they have the CPP schedule because the revenue neutrality guarantees the neutrality only in the mean. For example, consumers with really peaky demand are likely to see a higher bill. The question is what ratio of consumers in the distribution sees an increased bill and how much the increase is.

We use data from the Kitakyushu experiment to investigate this question. In Table 8, we show the difference between the actual bills of consumers in the treatment group and the counterfactual bills that they would have paid if they had the control group’s TOU schedule. For each consumer in the treatment group, we first calculate the bills for the two price schedules. Then, we calculate the difference and percentage difference between the two bills, and show the mean and percentiles in the table. On average, consumers in the treatment group saved 306 yen per month, which is 4.4 percent of their bill. Consumers up to 75th percentile saved money with the CPP in the experiment. About 10 percent of consumers lost money, but the loss is not large. This result is context-specific because the difference between the actual bill and counterfactual depends on how a dynamic pricing schedule is constructed and the shape of each consumer’s load curve, but this results implies that the dynamic pricing schedule used in this experiment benefits most of consumers in the treatment group.
6 Conclusion

This paper presents results from two field experiments on the effects of social pressure and private incentives. We find that the social pressure itself reduces electricity consumption by 3% to 4%. However, the reduction is much larger when consumers are exposed to the dynamic pricing, in which the highest marginal price results in a reduction up to 15%. Consumers in our experiment, who are well-informed about their hourly electricity price, actually respond to the change in hourly marginal price: higher hourly marginal prices produce larger reductions in consumption. Finally, we investigate the heterogeneity in response to the social and private incentives. Compared to low-income consumers, high-income consumers respond to the social pressure more. Conversely, the response to the dynamic pricing is less for high-income consumers.
References


Notes: This figure shows an example screenshot of the in-home display that are installed for both control and treatment consumers in the experiment.
Figure 2: Average High and Low Temperature in Kyoto, Japan and Washington D.C.

Notes: This figure compares the average high and low temperature (°F) in Kyoto, Japan and Washington D.C. in the US.
Figure 3: Variable Critical Peak Pricing (VCPP) in the Kitakyushu experiment

Notes: This figure shows the price schedule of the variable critical peak pricing in the Kitakyushu experiment. Consumers receive one-day ahead notice about their price through their in-home display presented in Figure 1. The marginal price in peak-hours (1 pm to 5 pm) is either 15, 50, 75, 100, or 150 yen. Note that one Japanese yen is nearly equal to one U.S. cent under the current exchange rate (July 2013).
Notes: This figure shows the price schedule of the variable critical peak pricing in the experiment. Consumers are informed about their price one-day ahead through their in-home display presented in Figure 1. Consumers in the dynamic pricing group receive a price increase by 20, 40, 60, and 80 yen/kWh for peak-hours (1 pm to 4 pm). Usually, average consumers pay about 25 yen/kWh so that their marginal price for the peak-hours is either 25, 45, 65, 85, or 105 yen. Note that one Japanese yen is nearly equal to one U.S. cent under the current exchange rate (July 2013).
Figure 5: Messages sent to the Two Treatment Groups in the Kyoto Experiment

1) A message sent to “Conservation request only” treatment group:

Subject: Notice of Demand Response
Main text: *Notice of Demand Response**
In the following hours, please reduce your electricity use.
8/21(Tuesday)13:00-16:00

2) A message sent to “Dynamic pricing” treatment group:

Subject: Notice of Demand Response
Main text: *Notice of Demand Response**
In the demand response hours, your electricity price will be very high.
In the following hours, please reduce your electricity use.
8/21(Tuesday)13:00-16:00
1 kWh: +80 yen

Notes: This figure shows the messages sent to the two treatment groups in the Kyoto experiment. Households in each treatment group receive this message via text messaging to their cell phone and through their in-home display. They receive this message in a day ahead and also in the morning of the day.
Figure 6: Mean Log Consumption by Peak-hour Price in the Kitakyushu experiment

Notes: This figure shows the mean of log consumption per 30-minute interval for the control (○) and treatment (◇) consumers. We use data from all CPP event days to calculate the means. The vertical lines show the critical peak time period, 1 pm to 5 pm.
Figure 7: Mean Log Consumption by Peak-time Price in the Kyoto experiment

Notes: This figure shows the mean of log consumption per 30-minute interval for the control, warning-only, and dynamic pricing groups. We use data from all CPP event days to calculate the means. Household fixed effects are subtracted. The vertical lines show the critical peak time period, 1 pm to 4 pm.
Figure 8: Demand Curve for Peak-Hour Electricity based on the Estimates in the Kyoto experiment

Notes: This figure shows our estimates for the conservation request treatment and dynamic pricing treatment.
Table 1: Summary Statistics of Samples in the Kitakyushu experiment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control</th>
<th>Treatment</th>
<th>Difference (S.E.)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity use (kWh/day)</td>
<td>14.13 (4.57)</td>
<td>13.86 (4.21)</td>
<td>-0.27 (0.54)</td>
<td>0.62</td>
</tr>
<tr>
<td>Number of rooms</td>
<td>3.62 (0.49)</td>
<td>3.61 (0.49)</td>
<td>-0.01 (0.08)</td>
<td>0.89</td>
</tr>
<tr>
<td>Square meter (m²)</td>
<td>90.66 (13.03)</td>
<td>91.33 (13.24)</td>
<td>0.67 (2.02)</td>
<td>0.74</td>
</tr>
<tr>
<td>Number of AC</td>
<td>2.25 (1.10)</td>
<td>2.46 (0.99)</td>
<td>0.21 (0.16)</td>
<td>0.20</td>
</tr>
<tr>
<td>Number of refrigerators</td>
<td>1.03 (0.30)</td>
<td>1.05 (0.26)</td>
<td>0.02 (0.04)</td>
<td>0.57</td>
</tr>
<tr>
<td>Number of TVs</td>
<td>1.72 (0.86)</td>
<td>1.56 (0.76)</td>
<td>-0.16 (0.12)</td>
<td>0.20</td>
</tr>
<tr>
<td>Number of washers</td>
<td>1.00 (0.17)</td>
<td>1.01 (0.09)</td>
<td>0.01 (0.02)</td>
<td>0.65</td>
</tr>
<tr>
<td>Number of dryers</td>
<td>0.31 (0.50)</td>
<td>0.36 (0.48)</td>
<td>0.05 (0.07)</td>
<td>0.52</td>
</tr>
<tr>
<td>Number of dishwashers</td>
<td>0.28 (0.45)</td>
<td>0.30 (0.46)</td>
<td>0.02 (0.07)</td>
<td>0.73</td>
</tr>
<tr>
<td>Number of water heaters</td>
<td>0.18 (0.38)</td>
<td>0.21 (0.41)</td>
<td>0.03 (0.06)</td>
<td>0.64</td>
</tr>
<tr>
<td>Household size</td>
<td>2.87 (1.05)</td>
<td>3.02 (1.06)</td>
<td>0.15 (0.16)</td>
<td>0.36</td>
</tr>
<tr>
<td>Mean age of the household</td>
<td>32.98 (13.17)</td>
<td>31.55 (13.46)</td>
<td>-1.43 (2.07)</td>
<td>0.49</td>
</tr>
<tr>
<td>Income (&lt;=JPY3M)</td>
<td>0.06 (0.24)</td>
<td>0.07 (0.26)</td>
<td>0.01 (0.04)</td>
<td>0.78</td>
</tr>
<tr>
<td>Income (JPY3M to JPY5M)</td>
<td>0.26 (0.44)</td>
<td>0.25 (0.43)</td>
<td>-0.02 (0.07)</td>
<td>0.81</td>
</tr>
<tr>
<td>Income (JPY5M to JPY7M)</td>
<td>0.34 (0.48)</td>
<td>0.25 (0.44)</td>
<td>-0.08 (0.07)</td>
<td>0.24</td>
</tr>
<tr>
<td>Income (JPY10M to JPY15M)</td>
<td>0.23 (0.42)</td>
<td>0.26 (0.44)</td>
<td>0.03 (0.07)</td>
<td>0.63</td>
</tr>
<tr>
<td>Income (&gt;=JPY15M)</td>
<td>0.08 (0.27)</td>
<td>0.14 (0.34)</td>
<td>0.06 (0.05)</td>
<td>0.23</td>
</tr>
<tr>
<td>Education (Junior high school)</td>
<td>0.05 (0.21)</td>
<td>0.03 (0.16)</td>
<td>-0.02 (0.03)</td>
<td>0.52</td>
</tr>
<tr>
<td>Education (High school)</td>
<td>0.29 (0.46)</td>
<td>0.38 (0.49)</td>
<td>0.09 (0.07)</td>
<td>0.22</td>
</tr>
<tr>
<td>Education (College)</td>
<td>0.48 (0.50)</td>
<td>0.40 (0.49)</td>
<td>-0.09 (0.08)</td>
<td>0.25</td>
</tr>
<tr>
<td>Education (Graduate School)</td>
<td>0.05 (0.21)</td>
<td>0.11 (0.31)</td>
<td>0.06 (0.04)</td>
<td>0.15</td>
</tr>
<tr>
<td>Education (Others)</td>
<td>0.14 (0.35)</td>
<td>0.09 (0.29)</td>
<td>-0.05 (0.05)</td>
<td>0.34</td>
</tr>
</tbody>
</table>

Notes: This table shows the summary statistics of electricity consumption and observable characteristics of consumers. Column 1 and 2 shows the mean and standard deviation of each variable for the treatment and control groups. In column 3, we present the difference in the mean value of each variable between the treatment and control group. In the last column, we report the p-value for the null that there is no difference in the mean between the two groups. We use consumption data in the absence of the treatment intervention to calculate the mean consumption for each group. Note that the income and education variables are categorical variables and therefore the mean of these variables implies the ratio of households in each of the income and education categories.
Table 2: Summary Statistics of Samples in the Kyoto experiment

<table>
<thead>
<tr>
<th>Variable</th>
<th>Control Group</th>
<th>Warning-Only Group</th>
<th>Dynamic Pricing Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity Use (kWh/day)</td>
<td>Mean (S.D.)</td>
<td>Mean (S.D.)</td>
<td>Mean (S.D.)</td>
</tr>
<tr>
<td></td>
<td>15.7 (8.64)</td>
<td>15.3 (8.95)</td>
<td>15.6 (7.56)</td>
</tr>
<tr>
<td>Age of Building</td>
<td>13.5 (9.4)</td>
<td>13.7 (8.3)</td>
<td>13.1 (8.1)</td>
</tr>
<tr>
<td>Square meter (m²)</td>
<td>140.8 (45.6)</td>
<td>139.3 (54.9)</td>
<td>134.6 (49.4)</td>
</tr>
<tr>
<td>Household Size</td>
<td>3.3 (1.2)</td>
<td>3.2 (1.2)</td>
<td>3.2 (1.2)</td>
</tr>
<tr>
<td>Mean Age of Household</td>
<td>39.8 (16.5)</td>
<td>41.7 (16.8)</td>
<td>40.3 (17.5)</td>
</tr>
<tr>
<td>Household Income</td>
<td>7350 (3301)</td>
<td>7303 (3467)</td>
<td>7278 (3263)</td>
</tr>
<tr>
<td>(unit: 100yen ≈ $1)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of AC</td>
<td>3.7 (1.6)</td>
<td>3.5 (1.9)</td>
<td>3.6 (1.7)</td>
</tr>
<tr>
<td>Number of Refrigerators</td>
<td>1.1 (0.4)</td>
<td>1.2 (0.5)</td>
<td>1.1 (0.3)</td>
</tr>
</tbody>
</table>

Notes: This table shows the summary statistics of electricity consumption and observable characteristics for the control, warning-only, and dynamic pricing groups. We use consumption data in the absence of the treatment intervention to calculate the mean consumption for each group. All of the means are not statistically different between the three groups.
Table 3: Effects of Dynamic Pricing in the Kitakyushu experiment

<table>
<thead>
<tr>
<th>Time of the day:</th>
<th>Peak (1pm to 5pm)</th>
<th>Shoulder (8am-1pm &amp; 5pm-10pm)</th>
<th>Off-peak (10pm to 8am)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dynamic Pricing (pooled)</td>
<td>-0.122*** (0.022)</td>
<td>-0.005 (0.022)</td>
<td>0.049** (0.024)</td>
</tr>
<tr>
<td>Dynamic Pricing (+35 yen)</td>
<td>-0.089** (0.026)</td>
<td>-0.001 (0.024)</td>
<td>0.042* (0.025)</td>
</tr>
<tr>
<td>Dynamic Pricing (+60 yen)</td>
<td>-0.127*** (0.028)</td>
<td>0.007 (0.026)</td>
<td>0.052** (0.025)</td>
</tr>
<tr>
<td>Dynamic Pricing (+85 yen)</td>
<td>-0.132*** (0.027)</td>
<td>0.014 (0.025)</td>
<td>0.048* (0.026)</td>
</tr>
<tr>
<td>Dynamic Pricing (+135 yen)</td>
<td>-0.146*** (0.027)</td>
<td>-0.042 (0.025)</td>
<td>0.055** (0.025)</td>
</tr>
<tr>
<td>Household Fixed Effect</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time Fixed Effect</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>61273</td>
<td>61273</td>
<td>133813</td>
</tr>
<tr>
<td>Number of customers</td>
<td>181</td>
<td>181</td>
<td>181</td>
</tr>
</tbody>
</table>

Notes: This table shows the main estimation results on the treatment effects of the variable critical peak pricing. The dependent variable is log of electricity consumption. We estimate the treatment effects separately for three time periods: 1) peak hours, 1 pm to 5 pm; 2) shoulder hours, 8 am to 1 pm and 5 pm to 10 pm; and 3) off peak hours, 10 pm to 8 am. Standard errors in parentheses are clustered at the household level to adjust for serial correlation. *, **, and *** show 10%, 5%, and 1% statistical significance from zero.
Table 4: Effects of Conservation Request and Dynamic Pricing in the Kyoto experiment

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak</td>
<td>Shoulder</td>
<td>Off-peak</td>
</tr>
<tr>
<td>Conservation Request</td>
<td>-0.0328**</td>
<td>-0.0091</td>
<td>-0.006</td>
</tr>
<tr>
<td></td>
<td>(0.0132)</td>
<td>(0.0101)</td>
<td>(0.023)</td>
</tr>
<tr>
<td>Dynamic pricing (+20 yen)</td>
<td>-0.0597***</td>
<td>-0.0261</td>
<td>0.0003</td>
</tr>
<tr>
<td></td>
<td>(0.0211)</td>
<td>(0.0160)</td>
<td>(0.0064)</td>
</tr>
<tr>
<td>Dynamic Pricing (+40 yen)</td>
<td>-0.1186***</td>
<td>-0.0288</td>
<td>0.0151*</td>
</tr>
<tr>
<td></td>
<td>(0.0236)</td>
<td>(0.0182)</td>
<td>(0.0081)</td>
</tr>
<tr>
<td>Dynamic Pricing (+60 yen)</td>
<td>-0.1392***</td>
<td>-0.0299</td>
<td>0.0186**</td>
</tr>
<tr>
<td></td>
<td>(0.0250)</td>
<td>(0.0189)</td>
<td>(0.0086)</td>
</tr>
<tr>
<td>Dynamic Pricing (+80 yen)</td>
<td>-0.1517***</td>
<td>-0.0328*</td>
<td>0.0246***</td>
</tr>
<tr>
<td></td>
<td>(0.0249)</td>
<td>(0.0194)</td>
<td>(0.0080)</td>
</tr>
<tr>
<td>Observations</td>
<td>181017</td>
<td>546352</td>
<td>733554</td>
</tr>
<tr>
<td>Number of customers</td>
<td>681</td>
<td>681</td>
<td>681</td>
</tr>
</tbody>
</table>

Notes: This table shows the main estimation results on the treatment effects of the variable critical peak pricing. The dependent variable is log of electricity consumption. We estimate the treatment effects separately for three time periods: 1) peak hours, 1 pm to 4 pm; 2) shoulder hours, 8 am to 1 pm and 4 pm to 10 pm; and 3) off peak hours, 10 pm to 8 am. Standard errors in parentheses are clustered at the household level to adjust for serial correlation. *, **, and *** show 10%, 5%, and 1% statistical significance from zero.
Table 5: Heterogeneity in the Treatment Effects in the Kyoto experiment

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Coefficient</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservation Request</td>
<td>-0.043***</td>
<td>(0.013)</td>
</tr>
<tr>
<td>Dynamic pricing (+20 yen)</td>
<td>-0.066***</td>
<td>(0.020)</td>
</tr>
<tr>
<td>Dynamic pricing (+40 yen)</td>
<td>-0.115***</td>
<td>(0.024)</td>
</tr>
<tr>
<td>Dynamic pricing (+60 yen)</td>
<td>-0.132***</td>
<td>(0.025)</td>
</tr>
<tr>
<td>Dynamic pricing (+80 yen)</td>
<td>-0.149***</td>
<td>(0.025)</td>
</tr>
<tr>
<td>Conservation Request * Income</td>
<td>-0.006**</td>
<td>(0.003)</td>
</tr>
<tr>
<td>Dynamic pricing (+20 yen) * Income</td>
<td>0.009*</td>
<td>(0.005)</td>
</tr>
<tr>
<td>Dynamic pricing (+40 yen) * Income</td>
<td>0.019***</td>
<td>(0.006)</td>
</tr>
<tr>
<td>Dynamic pricing (+60 yen) * Income</td>
<td>0.018***</td>
<td>(0.006)</td>
</tr>
<tr>
<td>Dynamic pricing (+80 yen) * Income</td>
<td>0.019***</td>
<td>(0.006)</td>
</tr>
<tr>
<td>Conservation Request * Electricity Usage</td>
<td>0.0056</td>
<td>(0.0043)</td>
</tr>
<tr>
<td>Dynamic pricing (+20 yen) * Electricity Usage</td>
<td>-0.042***</td>
<td>(0.006)</td>
</tr>
<tr>
<td>Dynamic pricing (+40 yen) * Electricity Usage</td>
<td>-0.036***</td>
<td>(0.008)</td>
</tr>
<tr>
<td>Dynamic pricing (+60 yen) * Electricity Usage</td>
<td>-0.042***</td>
<td>(0.008)</td>
</tr>
<tr>
<td>Dynamic pricing (+80 yen) * Electricity Usage</td>
<td>-0.041***</td>
<td>(0.007)</td>
</tr>
<tr>
<td>Observations</td>
<td>156432</td>
<td></td>
</tr>
<tr>
<td>Number of customers</td>
<td>588</td>
<td></td>
</tr>
</tbody>
</table>

Notes: This table shows the results of the regression in equation (8). The scale of the annual income variable is in 1 million yen ($10k). The scale of the mean hourly electricity use is in 100 kWh per hour. Standard errors in parentheses are clustered at the household level to adjust for serial correlation. *, **, and *** show 10%, 5%, and 1% statistical significance from zero.
Table 6: Heterogeneity in the Treatment Effects in the Kitakyushu experiment

<table>
<thead>
<tr>
<th>Time of the day:</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment*I(CPP day)</td>
<td>-0.112***</td>
<td>-0.064**</td>
<td>-0.106***</td>
</tr>
<tr>
<td></td>
<td>(0.038)</td>
<td>(0.034)</td>
<td>(0.033)</td>
</tr>
<tr>
<td>Treatment<em>I(CPP day)</em></td>
<td></td>
<td>-0.081**</td>
<td></td>
</tr>
<tr>
<td>I(Higher consumption)</td>
<td></td>
<td>(0.038)</td>
<td></td>
</tr>
<tr>
<td>Treatment<em>I(CPP day)</em></td>
<td></td>
<td></td>
<td>-0.011*</td>
</tr>
<tr>
<td>Air Conditioner age</td>
<td></td>
<td></td>
<td>(0.006)</td>
</tr>
<tr>
<td>Household Fixed Effect</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Time Fixed Effect</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Observations</td>
<td>61273</td>
<td>61273</td>
<td>61273</td>
</tr>
<tr>
<td>R-squared</td>
<td>0.021</td>
<td>0.0187</td>
<td>0.021</td>
</tr>
</tbody>
</table>

Notes: This table shows the results of the regression in equation (6). The indicator variable of higher consumption equals one if a consumer’s consumption in June 2012 is higher than the sample mean. The indicator variable of higher income is constructed in the same way. Standard errors in parentheses are clustered at the household level to adjust for serial correlation. *, **, and *** show 10%, 5%, and 1% statistical significance from zero.
Table 7: Linear Probability Model: Appliance Replacement Rates in the Kyoto experiment

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Room AC</td>
<td>Refrigerator</td>
<td>Washer</td>
<td>Electric Fan</td>
</tr>
<tr>
<td>1(Conservation Request Group)</td>
<td>0.006</td>
<td>-0.000</td>
<td>-0.007</td>
<td>0.041*</td>
</tr>
<tr>
<td></td>
<td>(0.029)</td>
<td>(0.023)</td>
<td>(0.019)</td>
<td>(0.022)</td>
</tr>
<tr>
<td>1(Dynamic Pricing Group)</td>
<td>-0.012</td>
<td>-0.004</td>
<td>-0.001</td>
<td>0.036**</td>
</tr>
<tr>
<td></td>
<td>(0.024)</td>
<td>(0.019)</td>
<td>(0.016)</td>
<td>(0.018)</td>
</tr>
<tr>
<td>Constant</td>
<td>0.069***</td>
<td>0.041**</td>
<td>0.028**</td>
<td>0.007</td>
</tr>
<tr>
<td></td>
<td>(0.020)</td>
<td>(0.016)</td>
<td>(0.013)</td>
<td>(0.016)</td>
</tr>
<tr>
<td>Number of households</td>
<td>661</td>
<td>661</td>
<td>661</td>
<td>661</td>
</tr>
</tbody>
</table>

Notes: This table shows the result of the linear probability model, in which the dependent variable equals one if a household purchased a new appliance. *, **, and *** show 10%, 5%, and 1% statistical significance from zero.
Table 8: Difference between Actual and Counterfactual Bills of Consumers in the Treatment Group in the Kitakyushu Experiment

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Mean</th>
<th>p1</th>
<th>p5</th>
<th>p10</th>
<th>p25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference in monthly bill</td>
<td>-306</td>
<td>-1433</td>
<td>-845</td>
<td>-674</td>
<td>-455</td>
</tr>
<tr>
<td>Percentage difference</td>
<td>-4.4%</td>
<td>-13.7%</td>
<td>-9.7%</td>
<td>-8.9%</td>
<td>-7.4%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Distribution</th>
<th>p50</th>
<th>p75</th>
<th>p90</th>
<th>p95</th>
<th>p99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference in monthly bill</td>
<td>-306</td>
<td>-150</td>
<td>45</td>
<td>246</td>
<td>618</td>
</tr>
<tr>
<td>Percentage difference</td>
<td>-4.8%</td>
<td>-2.1%</td>
<td>1.0%</td>
<td>3.8%</td>
<td>7.4%</td>
</tr>
</tbody>
</table>

Notes: This table uses data from the Kitakyushu experiment to show the difference between the actual bills of consumers in the treatment group and the counterfactual bills that they would have paid if they had the control group’s TOU schedule. For each consumer in the treatment group, we first calculate the bills for the two price schedules. Then, we calculate the difference and percentage difference between the two bills, and show the mean and percentiles of the values.