Evaluating a Behavioral Demand Response Trial in Japan: Evidence from a One-year Experiment

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ABSTRACT

This paper presents the latest results of a trial experiment, implemented from August 2013 to November 2014, to evaluate the impact of the following four interventions on home electricity consumption: (1) a tiered rate with increasing prices applied to usage during each 30-minute period, (2) real-time feedback on electricity usage via an in-home display (IHD), (3) weekly reports that provided neighbor usage comparisons and peak savings information, and (4) an email alert appealing to households to reduce peak usage. In particular, we developed a prototype report-generating system that analyzes electricity usage data of each resident and automatically chooses a potentially most-preferable report from among multiple prepared templates. Each template contained four different modules, some that visualize electricity usage and others that suggest ways to effectively reduce usage. The four modules were ordered to construct a “story” to strengthen the impact on resident awareness and behavior during peak times.

Through a randomized experiment targeting almost 500 participant households of a condominium in Japan’s Chiba Prefecture, we found that the total average treatment effect of the four interventions in the first summer, the first winter, and the second summer from the beginning of treatments was around 10% at peak times, some of which were statistically significant with a panel data regression analysis. The peak saving effects were likely to be higher than the electricity conservation effects, implying that people were more responsive in peak times. Furthermore, the 30-minute tiered rate plus IHD was more effective at reducing residential peak demand during winter than grid peak demand during summer, and weekly reports stabilized the impact of peak savings for households with 30-minutes tiered rates plus IHD. We also investigated variations in treatment effects and found that households with larger consumption were likely to have larger potential for peak savings. Survey data suggest that households accept the information-based interventions well.

Introduction

Since the Great East Japan Earthquake and Tsunami in 2011 and the subsequent summers when the nation experienced severe electricity supply shortages, the importance of effective demand reduction and energy conservation measures have become widely recognized in Japan. The Ministry of Energy, Trade and Industry (METI) launched the Smart Grid Pilot Project in 2010 to investigate benefits and issues of energy-related advanced technologies and services, and field experiments were implemented in Kyoto and Kitakyushu to evaluate the impact of critical peak pricing (CPP) in the Japanese electricity market. According to a recent government document, the results of the experiments suggested an approximate 20% reduction in peak demand through the CPP events (METI, 2014). This is a Japanese case of a large body of field experiments that evaluates the impact of demand response (Faruqui and Sergici, 2010; Allcott, 2011).

Electricity consumption information is essential to practical implementation of peak reduction and energy conservation measures. A field experiment in the U.S. suggested that households with an in-home display (IHD) are more responsive to temporary price increases than price-only households (Jessoe and Rapson, 2014). In the Kyoto experiment, IHDs were installed in participants’ homes to inform residents of energy consumption reduction during CPP events. As to energy conservation, many researchers have investigated the impact of informational feedback on household energy use (Abrahamse, et al., 2005; Fischer 2008; Faruqui, et al., 2010). A well-known recent example is Opower's "home energy report," which provides personalized energy use feedback, social comparisons, and energy conservation information (Allcott and Rogers, 2014). This is typical of a "nudge," a stimulus that promotes better decision-making conditions (Thaler and Sunstein, 2008). The home energy report is also used for peak savings through behavior change (Lich, et al. 2014).

Other applications of electricity consumption information is explored in Japan, where advanced metering technologies are being installed in the residential sector across the nation. For example, in July 2014 the Tokyo Electric Power Company (TEPCO) began installing advanced meters for low-voltage (mainly residential) customers over its whole grid, and plans to complete installations by the end of March 2021. Since the nationwide installation plan appeared, government, utility firms, and engineers have discussed ways to effectively use high-frequency electricity consumption data from advanced metering.

Since the summer of 2013, the authors have implemented a demand response and energy conservation trial to evaluate the impact of behavioral interventions, including a weekly report that provides a comparison of neighbors' peak usage and peak savings information (Mukai, et al. 2014). Trial participants were residences of a condominium in Funabashi, a city in the Greater Tokyo Area. Apartments were furnished with electricity usage meters that took measurements at 30-minute intervals, allowing the following four interventions: (1) a three-tiered rate applied to usage as measured for each 30-minute period during the month, (2) real-time feedback on electricity usage provided via an IHD, (3) a weekly report on peak savings, and (4) an email alert to prompt reduced usage during peak times. In the present paper, we show the latest results of this trial.

Experimental Design

The Funabashi trial had three main evaluation periods: (1) 31 days from August 7 to September 6, 2013, (2) 45 days from January 15 to February 28, 2014, and (3) 31 days from August 6 to September 5, 2014. In this paper, we call these three periods S13, W13 and S14, respectively. These periods were selected because peak demand on the TEPCO grid occurs at 1–4 pm on weekdays from August to September. This condominium also has demand peaks at 7–10 pm in January and February.

Intervention Assignment Strategies

To evaluate the impact of peak saving and electricity conservation, we established four categories of price- and information-based interventions, and randomly assigned them to households (Figure 1). The control group (group D) comprises participants assigned a conventional tiered rate without information-based interventions, representing customers of the standard TEPCO service. The conventional tiered rate is identical to TEPCO's "Meter Rate Lighting B" billing plan, which becomes increasingly expensive as electricity usage on a monthly bill cycle increases (Figure 2).

In the following, we describe the packaged interventions for the three treatment groups with detailed explanations of four interventions. Of the four, a 30-minute tiered rate and IHD are persistently assigned to target households from the starting day of trial participation, while weekly reports and email alerts were provided during the evaluation periods (S13, W13, and S14) only.

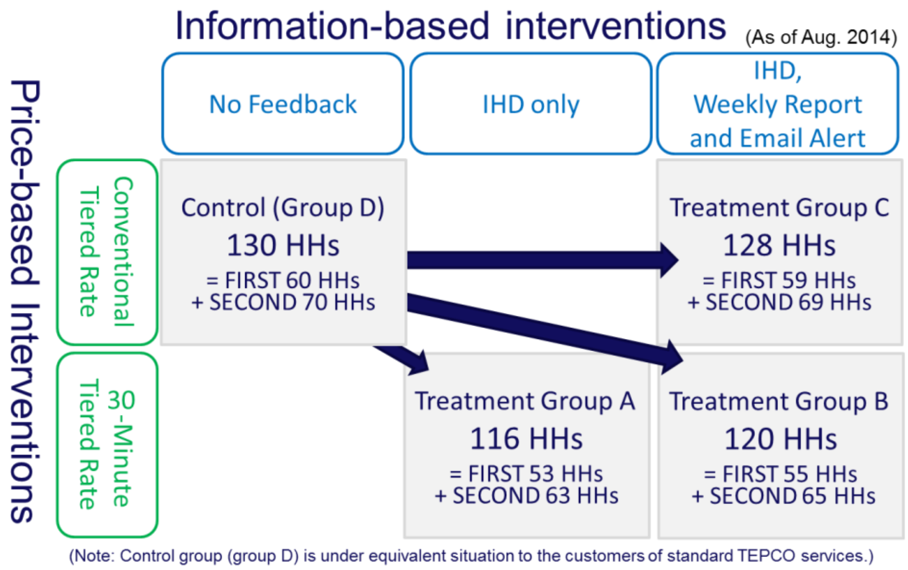

Figure 1. Four types of packaged interventions and sample sizes (Note: The total number of participating households is 494. The "FIRST" was households who moved into the condominium before S13 and were recruited to this trial. The "SECOND" was households who moved into the condominium and were recruited between S13 and W13.)

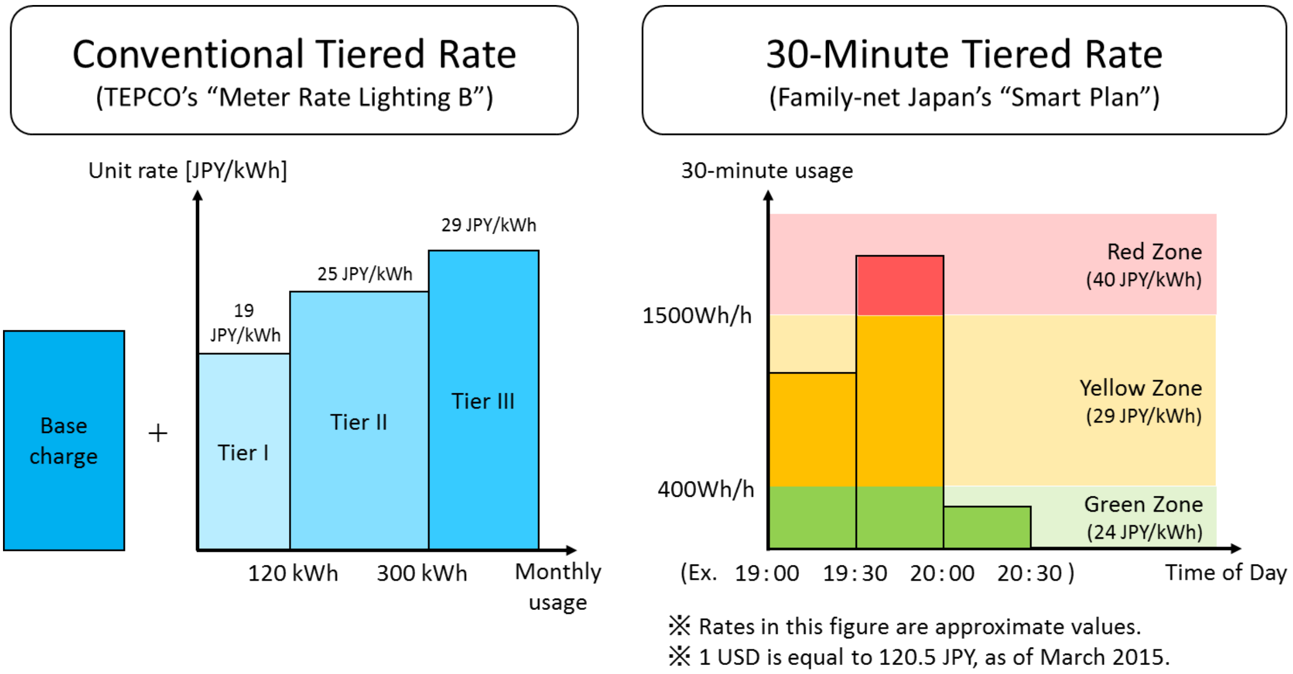

Figure 2. Tiered rates (Note that the rates in this figure are approximate values.)

Treatment group A was assigned a 30-minute tiered rate and an IHD. These two interventions are standard services of the condominium, so group A was intended to evaluate how much electricity condominium residents save.

The price-based intervention (the 30-minute tiered rate) was based on 30-minute interval data. That is, the rate increases as a function of electricity usage as measured every 30 minutes. As shown in Figure 2, each tier is named as follows: (1) a *Green Zone*, around 24 JPY (0.20 USD) per kWh, from 0 to 400 Wh per hour; (2) a *Yellow Zone*, around 29 JPY (0.24 USD) per kWh, from 400 to 1500 kWh per hour; and (3) a *Red Zone*, 40 JPY (0.33 USD) per kWh, from 1500 Wh per hour (1 USD = 120.5 JPY as of March 19, 2015). The 30-minute tiered rate is designed to reduce the condominium's peak demand at times such as when families spend time together after dinner. The 30-minute tiered rate is a standard service for the condominium, and thus all residents are billed with it (that is, those assigned the conventional monthly tiered rate were switched from the 30-minute tiered rate during the trial period).

The information-based intervention, an IHD, provides information related to (1) real-time feedback on electricity usage, (2) CO_2 emissions for the day, and (3) real-time supply demand forecasts within the TEPCO area. The first display in Figure 3, real-time electricity usage, consists of two informational factors: the display itself and a LED light in the bottom-right corner of the display. The feedback information on the display is colored green, yellow, and red, corresponding with the names of the 30-minute tiered rate zones. In addition, the LED light blinks when electricity consumption exceeds 1500 W, at which the Red Zone rate is applied. The IHD is thus intended to make it easier for customers to grasp the electricity rate at a particular time[1]. In addition to the IHD, households have access to a website through PCs, smartphones, and cell-phones that provides information such as electricity consumption data.

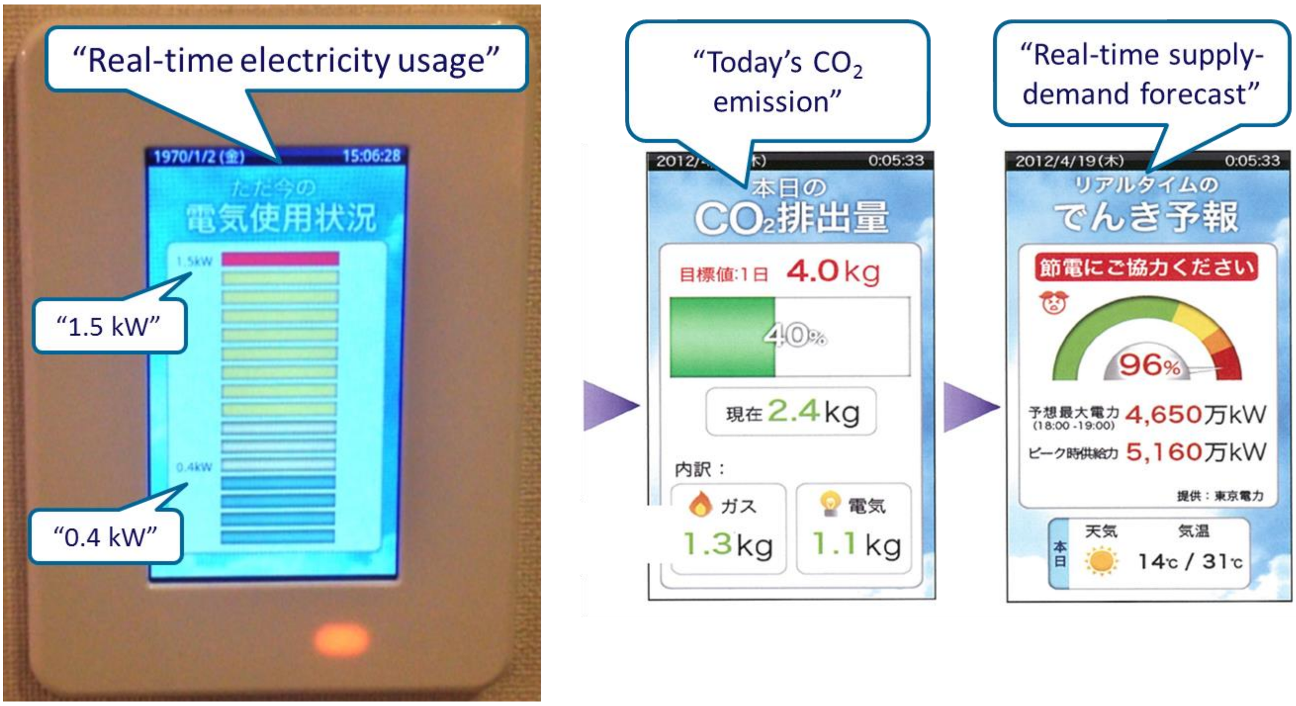

Figure 3. In-home display used in the Funabashi trial.

Treatment group B assigned weekly reports and email alerts in addition to the two interventions assigned to group A. As shown in Figure 4, the report is an A4-sized paper consisting of graphics, which we call "modules." Some modules visualize electricity usage during peak times and others show information on how to save during peak usage. The four modules were arranged to construct a "story" to strengthen the impact on the consciousness and behavior of the residents during peak times. Figure 5 shows an example story template. The aim of this storyline is to reduce usage during the grid peak time, around 2 pm on weekdays, by showing how much electricity is being used and by what. In total, we designed almost 20 story templates that have varied aims. We also developed a system to automatically personalize reports using each residential customer's 30-minute usage data.

Table 1 shows the mailing strategies for weekly report interventions in each evaluation period. As shown, we used paper-based reports sent via postal mail during S13 and W13. For S14 we changed to electronic reports (PDF-formatted files) sent via email to evaluate how recognition of reports changed according to the delivery media.

[1] To provide this informational service by IHD, units of this condominium are individually metered and each unit has an IHD.

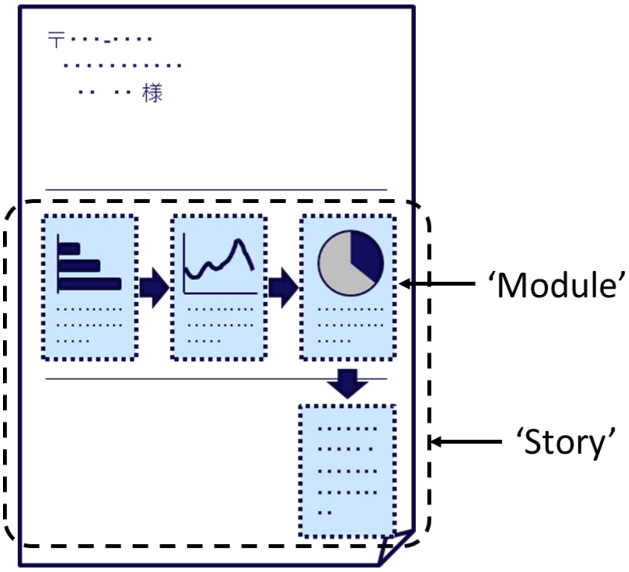

Figure 4. Image of a weekly report

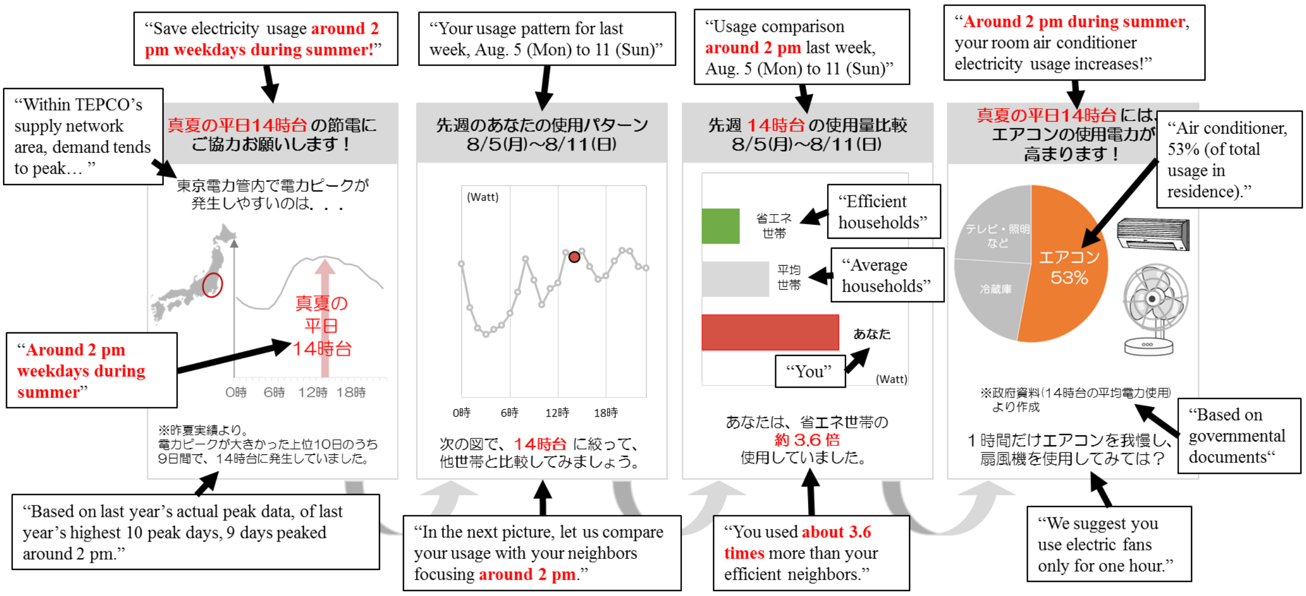

Figure 5. Examples of modules and messages forming a story used during S13

Table 1. Mailing strategies for weekly reports.

Period	Emphasized peak time	# of reports	Media and mailing type
S13	1–4 pm weekdays and 7–10 pm	5 times (over 5 weeks)	Paper-based via mail
W13	7–10 pm only	7 times (over 7 weeks)	Paper-based via mail
S14	1–4 pm weekdays only	5 times (over 5 weeks)	Electronic file via email

The email alert is sent to remind participants of peak times. We used different alert strategies in S13, W13, and W14, as shown in Table 2. For instance in S14, we set 3 alert days based on past climate and peak demand data provided by TEPCO and the Japan Meteorological Agency, and sent email alerts twice per alert day, one on the previous day at 7 pm, and another around 12 am on the alert day. In sum, group B was intended to measure the maximum potential outcome of all four interventions of the trial.

Treatment group C was assigned the same interventions as those for treatment group B, except for the price-based intervention; group C was assigned a conventional tiered rate instead of the 30-minute tiered rate assigned to group B. The aim of forming this group was to measure the potential outcome of the information-based interventions under a conventional tiered rate.

Table 2. Details of email alert intervention.

Period	Emphasized peak time	# alert days	# emails sent per alert day
S13	1–4 pm weekdays only	4	3 (once on the previous day and twice on the alert day)
W13	7–10 pm	10	1 (once on the alert day)
S14	1–4 pm weekdays only	3	2 (once on the previous day and once on the alert day)

Note: Only in S14, a URL link to a quick web-based questionnaire was provided in the alert email. The questionnaire asked respondents whether they will take actions to save electricity, functioning as a commitment to peak saving. Respondents to the questionnaire were provided a reward equivalent to 100 JPY (0.83 USD) per response, regardless of whether they actually performed the promised actions.

Participant overview

In terms of participation timing, there were two types of households. The first type was households who moved into the condominium before S13 and were recruited to this trial. These households were recruited on an opt-in basis. Specifically, we held several briefing sessions for condominium residents, and 235 (41%) of the 573 residents voluntarily applied to this trial. The second type was households who moved into the condominium and were recruited between S13 and W13. These too were recruited on an opt-in basis, and 268 (39%) of 686 residents applied to the trial. We call the two household types FIRST and SECOND, respectively. Both household types were randomly assigned to the treatment and control groups described in Figure 1.

Some households were precluded from participation in the trial. Of the FIRST type, 6 of the 235 households were randomly selected for participation in another trial project, one household failed to answer a questionnaire that was a precondition for participation, and another had not lived in the condominium within the trial period. Moreover, 3 households refused permission to use their pre-S13 consumption data, which was needed for DID estimation. Only one household of the SECOND type was omitted, due to not living in the condominium within the trial period. The preclusion occurred after random assignment of the interventions described below, but we do not consider this as affecting the internal validity of the experiment, since assignment types were not likely to cause these preclusion. In sum 494 households participated in this trial, 227 FIRST households and 267 SECOND households as of August 2014. We obtained permission to use pre-S13 consumption data from 491 households for DID estimation.

Compared to the characteristics of households in Japan, participants were generally younger households, many composed of only two persons. Of the FIRSTs, 46.5% of households were married couples with no other occupants, and 46.4% were in their thirties. Of the SECONDs, 41.0% were married couples with no other occupants, and 53% were in their thirties. Average floor space for the FIRST and SECOND participants were 80.1 and 79.7 square meters (862.2 and 857.9 square ft.), respectively. There was no statistically significant difference in monthly electricity consumption between the participating households and average households in Japan.

To reward cooperation with several questionnaire surveys, we provided electronic-cash awards of 20,000 JPY (166 USD) to FIRSTs and 15,000 JPY (124 USD) to SECONDs. We also provided 1000 JPY (8.3 USD) per month to those in group C and 2000 JPY (16.6 USD) per month to those in group D, since they were not provided with one or both of the condominium's standard services, a 30-minute tiered rate and an IHD.

Results

In this chapter, we show a series of analysis results using the consumption data obtained from metering, and consciousness and behavior data from the questionnaire surveys. This chapter is divided into three sections: The first section shows estimated results of the *average treatment effects* (ATE) of peak savings and electricity conservation for each intervention package. The second section shows some results of the questionnaire surveys to understand the extent of recognition of information-based interventions by households. The third section attempts to understand the effects of household attributes, focusing on *the size of consumption*.

Average treatment effects

For estimation, we use a simple DID panel data regression model. Let y_{it} be household i's electricity usage at time t, normalized by the average usage across both control group customers and days in the trial period[2]. The ATEs on groups A, B, and C are respectively β_A, β_B, and β_C, estimated as

$$y_{it} = a + \beta_A TreatA_i P_t + \beta_B TreatB_i P_t + \beta_C TreatC_i P_t + P_t + \mathbf{T}_t + c_i + u_{it}, \qquad (1)$$

where $TreatA_i$, $TreatB_i$, and $TreatC_i$ are treatment indicators taking 1 if household i is assigned to each group, and P_t is an indicator taking 1 if time t is in the post treatment period. The matrix of variables $\mathbf{T}_t$ consists of factors that tend to influence electricity consumption. In our analysis, we included four variables: the average temperature at peak times, the average humidity at peak times, the average temperature of the previous three days, and a weekday dummy except for models for S13 and S14. a is coefficient and c_i is household random effect. We separately use the consumption data of FIRSTs and SECONDs for meta-analysis. Standard errors were robust and clustered at the household level to control for serial correlation in u_{it}.

Table 2 shows the results of ATE of peak savings for each evaluation period and electricity conservation over a year of this treatment (August 2013–July 2014). To interpret the ATE of interventions in order, we firstly focus on treatment group B to understand the maximum effects of the four interventions in this trial, then compare the results of treatment groups A and B to understand the impact of an IHD plus the 30-minute tiered rate and the impact of weekly reports when provided in addition to an IHD plus the 30-minute tiered rate.

There were four main findings:

- Columns (1)–(5) of the row "ATE of group B" suggest that *the rates of peak saving are around 10%*, with 3 of 5 results statistically significant at the 0.05 level. In addition, we do not observe obvious differences between grid peak reduction effects (S13 and S14) and residential peak reduction effects (W13), implying that we may expect the effects of the four packaged interventions regardless of peak season or time slots.
- Comparing columns (1)–(5) with column (6) of the row "ATE of group B" suggests that *the peak demand reduction effects are likely higher than the yearly electricity conservation effect* (4.7%, which is not statistically significant at the 0.05 level). The results suggest two implications: that packaged interventions are likely to have positive effects on electricity conservation, but that these are, as designed, more effective for peak savings than at other times.
- Regarding the row "ATE of group A", comparing columns of (1)–(3) with (4)–(5) suggests that *the impact of the 30-minute tiered rate plus an IHD is higher at winter peak times than summer grid peak time*. This result is reasonable since a 30-minute tiered rate plus an IHD is designed to

[2] The normalized consumption data express by what percentage consumption was reduced. For example, if household i on day t uses 10% less electricity than the average usage of the control group, then $y_{it} = 10$.

reduce winter peak usage by showing real-time feedback with a red blinking LED when electricity usage is more than 1.5 kW. During grid peak times, this function may not frequently activate since residential consumption is low during summer at 1–4 pm.

- Comparing the row "ATE of group A" with "ATE of group B" suggests that the weekly report played an important role in stabilizing the impact of peak savings for households with a 30-minute tiered rate and an IHD. Although ATE of group A are likely unstable, ranging from –5.1 to 10.9%, those of group B are in the range from 7.6 to 13.0%. In particular, this stabilization effect seems stronger during grid peak times.

Table 2. ATE of peak savings (column 1–5) and electricity conservation (column 6) using DID panel data regression model.

Column	(1)	(2)	(3)	(4)	(5)	(6)
Evaluation period	S13	S14	S14	W13	W13	August 2013 - July 2014
Time slot	1–4 pm weekdays only	1–4 pm weekdays only	1–4 pm weekdays only	7–10 pm	7–10 pm	0 am– 12 pm
HH types	FIRST	FIRST	SECOND	FIRST	SECOND	FIRST
ATE of group A	0.5	10.9	–5.1	5.1	10.4	3.4
(β_A)	(5.4)	(5.9)*	(6.2)	(5.3)	(3.3)***	(2.6)
ATE of group B	11.6	8.8	7.6	10.9	13.0	4.7
(β_B)	(5.3)**	(5.8)	(6.1)	(5.3)**	(3.3)***	(2.6)*
ATE of group C	4.0	7.4	7.8	12.7	11.3	4.0
(β_C)	(5.2)	(5.7)	(6.0)	(5.2)**	(3.2)***	(2.5)
# HHs	224	224	267	224	267	224

Notes:

- Normalized consumption data is used as a dependent variable, so the estimates in this table are interpreted as average peak saving rates (columns 1–5) and electricity conservation rates (column 6) during the indicated time slots within each evaluation period.
- This table omits estimates of the following variables: post-treatment dummy, the average temperature of the peak times, the average humidity of the peak times, the average temperature of the previous three days, and a weekday dummy except for models for S13 and S14.
- Statistical significance: *** <0.01, ** <0.05, * <0.1.
- Standard errors are in parentheses. Standard errors are robust and clustered at the household level to control for serial correlation in the idiosyncratic error term.

Recognition to information-based interventions

In this section, we use survey data to understand the extent of recognition of information-based interventions by households.

Figure 6 summarizes the time-series changes of the frequencies of checking information devices, namely IHDs, PCs, smartphones, and cell-phones. There are two main findings; one is an advantage and another is a limitation of the information devices. The advantage is that households frequently checked IHDs. Specifically, more than 90% of households checked the IHD at least once per week, and this high frequency continued one year after the beginning of the interventions. It suggests that the IHD is well accepted and used by households. The limitation of information devices is that checking frequencies are likely to decline as time advances.

We also evaluated the frequency of opening weekly reports and the difference between media. As Figure 7 shows, 99% of reports were opened during S13, when paper reports were sent via postal mail. We also confirmed that this high opening rate continued in W13, implying that paper reports via mail were well accepted by households. As Figure 8 shows, however, the percentage declined to 49% in the summer of 2014, when electronic reports were sent via email.

Note: Summary of valid responses from group A to the question, “How frequently do you check each medium?”

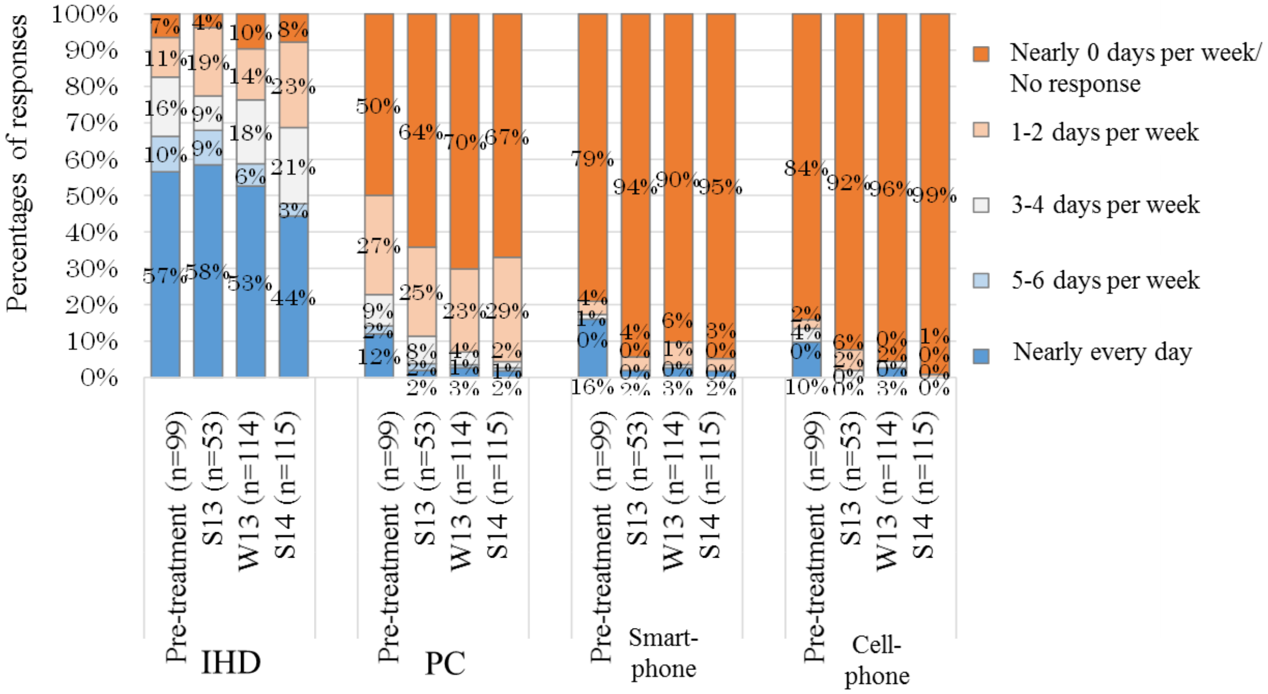

Figure 6. Information device checking frequency

Note: Summary of valid responses in summer 2013 from group B and C to the question, “Check each week in which you opened reports.”

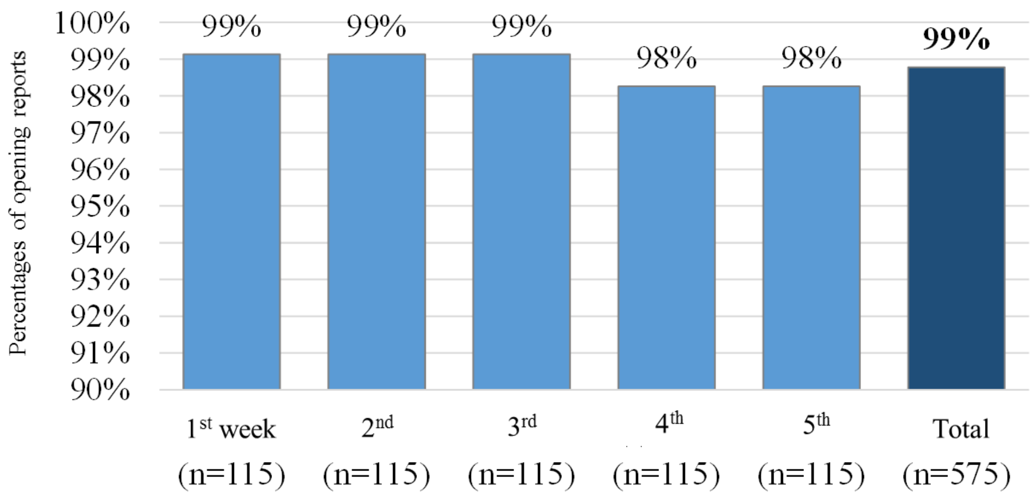

Figure 7. Frequency of opening paper weekly reports (summer 2013)

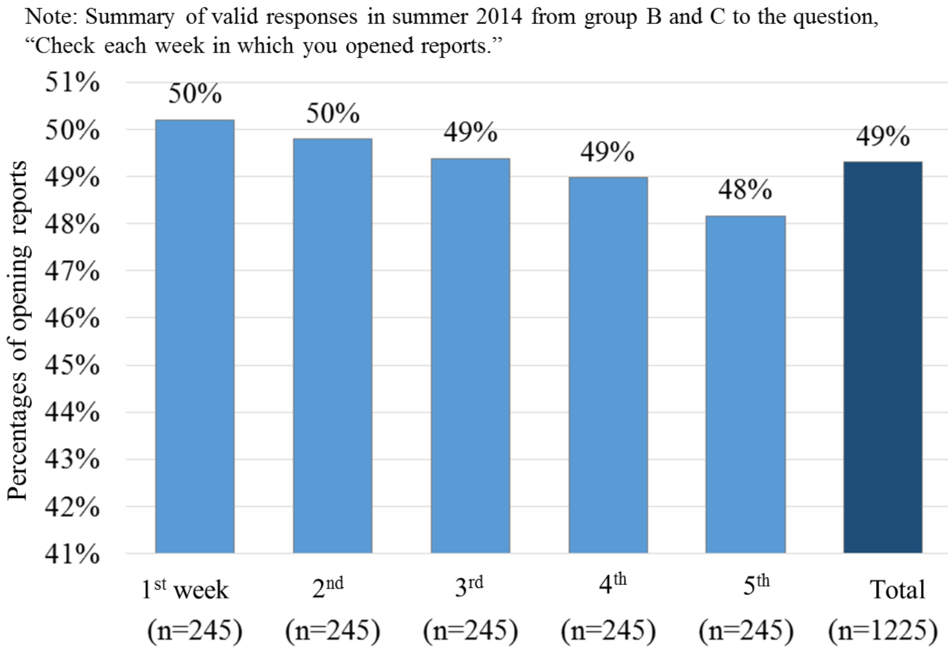

Figure 8. Frequency of opening the electronic weekly reports (summer 2014)

Heterogeneity in peak saving effects

At the beginning of this chapter, we considered the ATE of three treatment groups over time. It is natural to consider that the treatment effects vary across households in each treatment group. Clarifying variation in treatment effects may contribute to targeting households with higher treatment effect potentials, leading to improved cost effectiveness of interventions. This section investigates this point, focusing on the post-treatment consumption level of households.

Specifically, our approach here takes four steps: We first calculate average peak-time consumption of each household during each trial period. Then, the households of each group are partitioned into five subgroups based on the 20th, 40th, 60th, and 80th percentiles of the calculated average peak-time consumption. We call the five subgroups "efficient", "below average", "average", "above average", and "high consumption" households. Thirdly, consumption data of each subgroup is normalized based on the average consumption across the same subgroup's control group customers and days in the trial period. Finally, we estimated quantile treatment effects using Equation (1). Note that this section focuses on group B, since we found larger peak saving effects in group B, suggesting the likelihood of finding tendencies of the variation in treatment effects.

Figures 9 and 10 show the quantile treatment effects for savings during grid peak times in summer and residential peak times in winter, respectively. The results suggest that high-consumption households likely have higher potential for reducing peak usage than do other households. In particular, the saving effects in high-consumption households are mostly statistically significant at the 0.05 level. It implies that post-treatment consumption level is one of the household attributes that influence the treatment effects.

Note: Estimation results of the impact on the five sub-groups of group B, based on 20th, 40th, 60th, and 80th percentiles of post-treatment peak time average consumption. "+++", "++", "+", "-" and "--" in this figure denote "more than 80th percentile", "60th-80th percentile", "40th-60th percentile", "20th-40th percentile" and "less than 20th percentile", respectively. The results use normalized consumption data of group B and D for FIRST and SECOND pre-treatments and each post-treatment period.

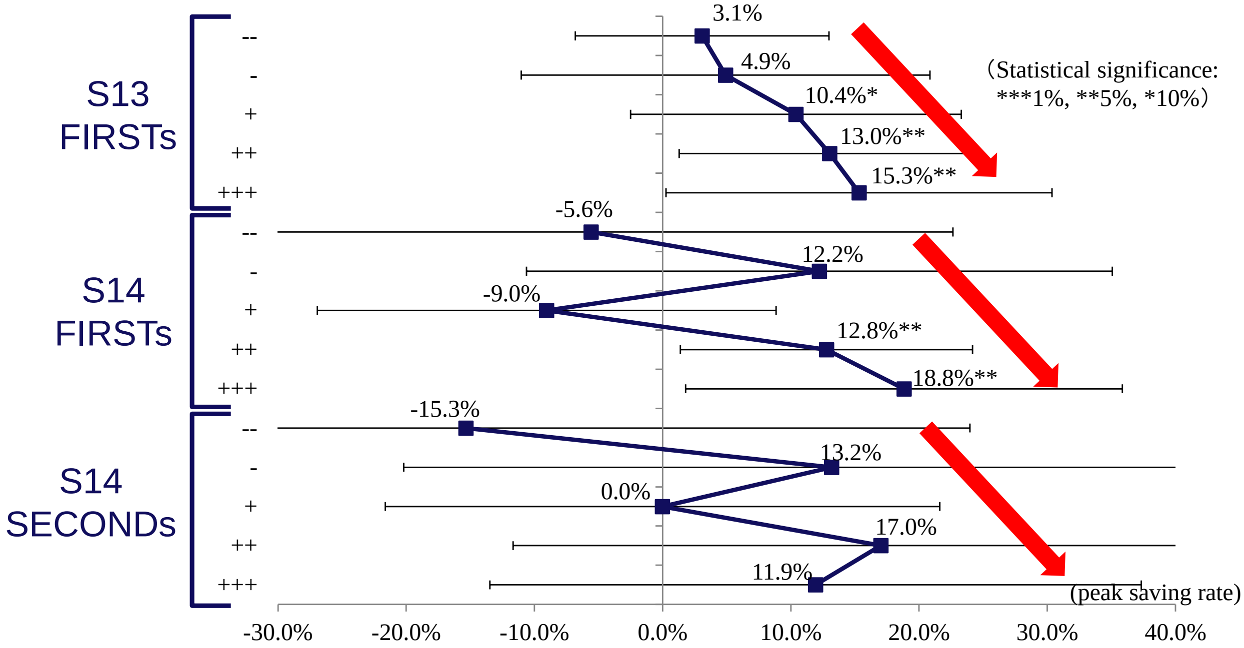

Figure 9. Variation in treatment effects of savings over grid peak hours across households of different consumption levels.

Note: Estimation results of the impact on the five sub-groups of group B, based on 20th, 40th, 60th, and 80th percentiles of post-treatment peak time average consumption. "+++", "++", "+", "-" and "--" in this figure denote "more than 80th percentile", "60th-80th percentile", "40th-60th percentile", "20th-40th percentile" and "less than 20th percentile", respectively. The results use normalized consumption data of group B and D for FIRST and SECOND pre-treatments and each post-treatment period.

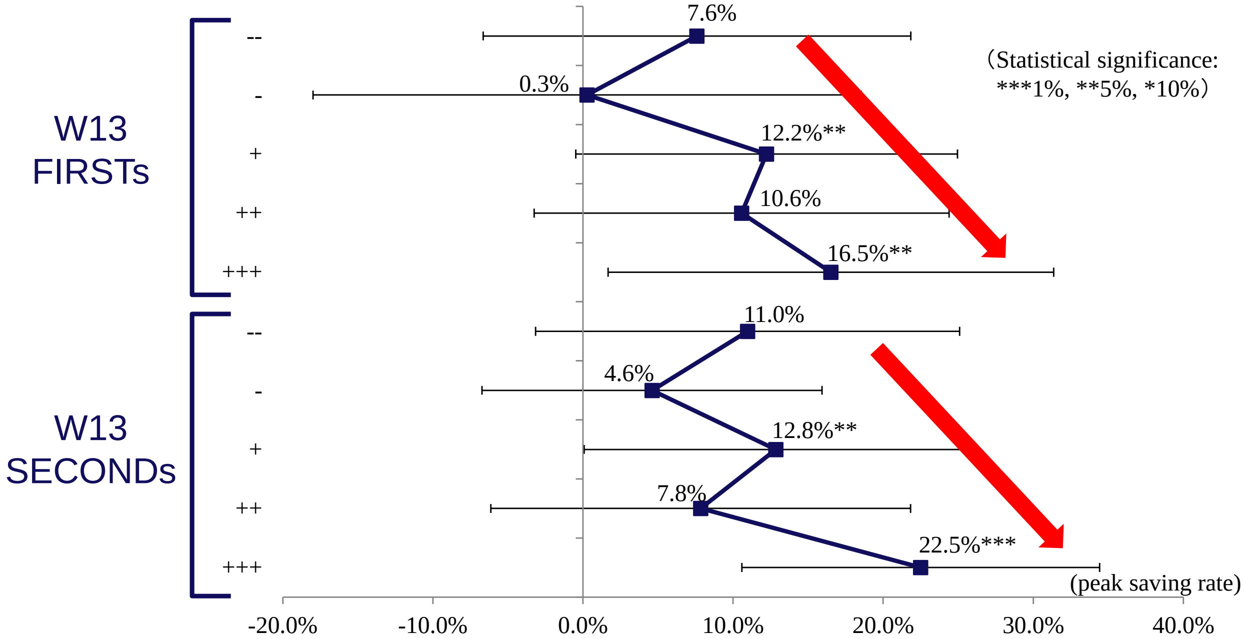

Figure 10. Variation in treatment effects of savings over residential peak hours across households of different consumption levels.

Conclusion

This paper evaluated the impact of behavioral interventions for peak savings and electricity conservations and showed that total ATE for peak savings were around 10%, some of which were statistically significant with a DID estimator. The peak saving effects were likely to be higher than the electricity conservation effects, implying that people were more responsive in peak times. In terms of the impacts of each intervention, a 30-minute tiered rate plus an IHD were more effective at reducing residential peak demand during winter than during grid peak demand in summer, and weekly reports stabilize the impact of peak savings when households have a 30-minute tiered rate and an IHD. The impacts were heterogeneous; households with larger consumption were likely to have larger potential for peak savings. Households well accepted the IHD, as 90% of households checked the IHD at least once per week. However there were large differences in the rate of opening weekly reports by media; nearly all households opened mailed paper reports, while only 50% opened electronic reports sent by email.

Our results imply that people are responsive to behavioral interventions for peak savings, provided that interventions are carefully designed. It is also evident that information-based interventions for peak savings are well accepted by households. This may be an advantage of the behavior interventions compared to price-based demand response in the residential sector. However, it may also be true that all information-based interventions are not effective for peak savings. For example, Holladay, Price and Wanamaker (2014) reported that emergency appeals by utilities for energy conservation over peak hours did not positively impact peak savings in the U.S. Investigating sophisticated behavioral intervention approaches for peak savings using smart-meter data may have potential for more effective demand management strategy.

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