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APPENDIX

Insights from Smart Meters: The Potential for Peak-Hour Savings from Behavior-Based Programs

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Appendices

These Appendices provide detailed descriptions as an addendum to the paper: “Insights from Smart Meters: The Potential for Peak Hour Savings from Behavior-Based Programs”. In Appendix A, we provide a detailed description of Home Energy Reports (HERs) and the experimental design (a Randomized Controlled Trial, (RCT)). Appendix B describes the data used in the analysis, and Appendix C provides summary statistics and a validation of the randomization. In Appendix D we describe our analytical approach and present the results in a table format (graphical representations are available in the main body of the paper).

Appendix A: Program description and experimental design

In this section we provide an overview of Opower's Home Energy Reports program that was implemented at PG&E, the program design employed, and a general overview of our analysis methods and the available data.

A.1 Description of Home Energy Reports

Opower worked with PG&E to provide its residential customers with periodic Home Energy Reports (HERs) by mail that contain energy usage feedback and behavioral suggestions (see Figure A-1 for an example). Specifically, the HER compares a customer's monthly electric and/or gas usage to an average of similar homes' usage as well as to an average of the most efficient 20% of similar homes' usage. These "neighbor comparisons" are based on a variety of customer characteristics, including location, home square-footage, presence of high energy consuming devices (e.g., pool), and type and number of air conditioning and/or heating units.

The neighbor comparison is used to give the customer one of three ratings:

- *Great* – the customer is more efficient than both average neighbors and efficient neighbors
- *Good* - the customer is more efficient than average neighbors but less efficient than their efficient neighbors
- *Using More than Average* - the customer is less efficient than both average and efficient neighbors

If a customer receives a rating of "Good" or "More than Average," the HER will include a dollar amount of savings that the customer could realize on their annual energy bills by matching their efficient neighbors' usage. A HER also provide a list of several simple energy savings tips and their potential annual dollar savings. For customers receiving reports on their electric usage, the reports include a graph of their load shape by hour for an average day from the last month of usage. Load shapes are not provided for natural gas usage because gas usage data are generally not collected hourly.

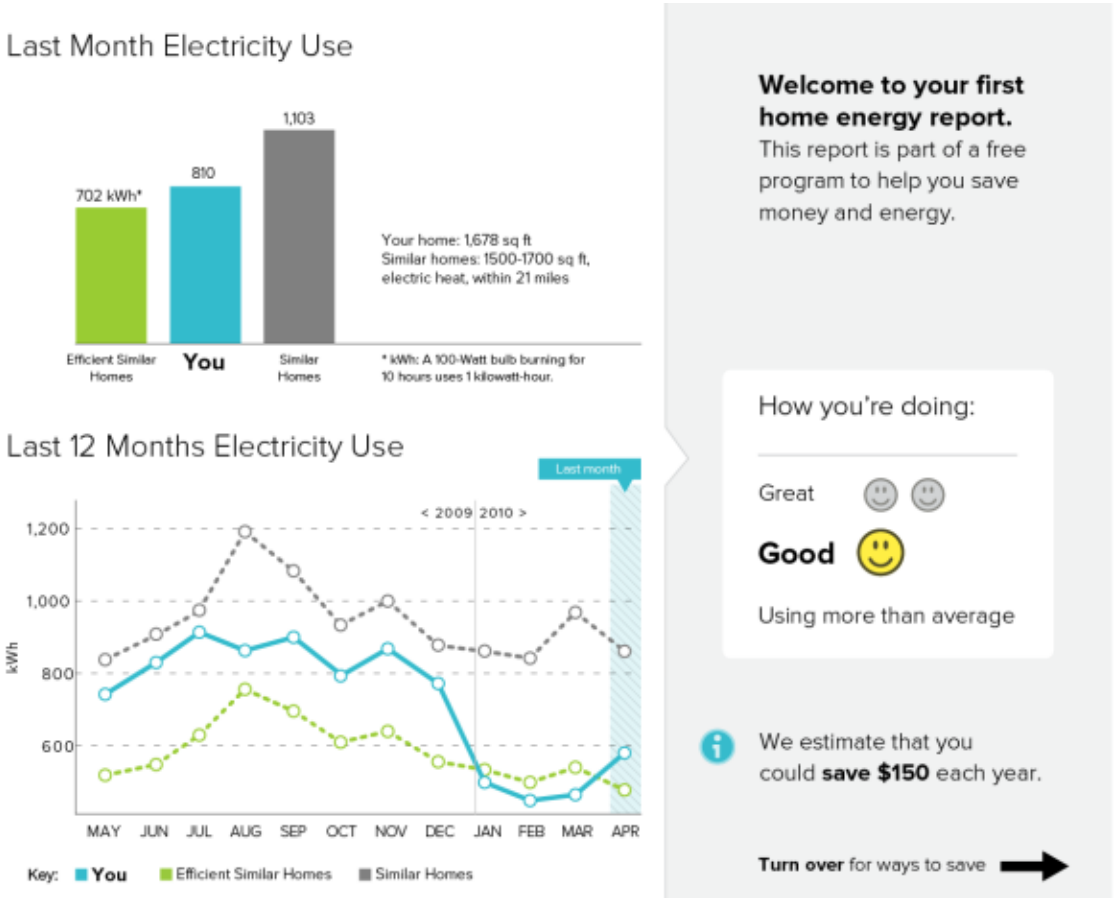

Figure A-1. Example of a Home Energy Report

A.2 Experimental Design

Opower's HER program in PG&E's service territory was designed as a field experiment that employed a randomized controlled trial (RCT). An RCT is a type of experimental design in which households in a given population are randomly assigned to two groups: a treatment group that receives the reports and a control group that does not.

The HER program utilizes an opt-out recruiting process. HERs are sent out to customers assigned to the treatment group without their prior knowledge or approval. These customers can elect to opt-out of receiving future HERs, if they wish by contacting PG&E.[1] Customers in the treatment group can then decide for themselves if and how to best respond to the energy usage feedback and behavioral suggestions contained in the HER. Customers in the control group are likely not aware that an experiment is occurring, since they are likely unaware their

[1] PG&E reports that the HERs generate very few complaints and opt-outs.

peers in the treatment group are receiving HERs, and are therefore unlikely to become dissatisfied.

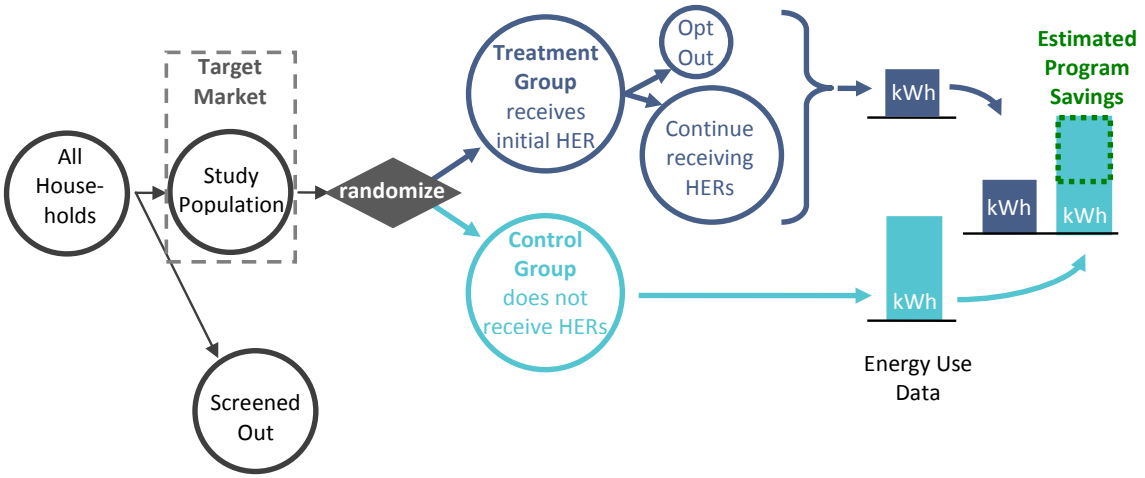

Figure A-2. Experimental design of HER program: opt-out randomized controlled trial

Because HERs are designed as RCTs, we can readily compare energy use data from customers in the treatment group to those in the control group in order to produce valid and unbiased statistical estimates of the total electricity savings, the peak demand savings, and the hour-by-hour electricity savings.

A.3 Screening criteria

PG&E's residential customers were screened into the study population using certain required inclusion criteria (in addition to satisfying geographic or energy usage criteria discussed in Appendix B). Customers must: have a full year of bills (to provide pre-treatment data for savings estimation); have had a functioning smart meter for greater than one year; be on selected rate schedules—either PG&E's standard residential rate schedule or one of its residential time-of-use rates; neither be on a medical baseline rate, nor flagged as "vulnerable or disabled" in PG&E databases; not be master metered;[2] not be net metered;[3] not live in a mobile home; not be on an electric vehicle rate; not be on a natural gas vehicle rate; not be in another HER pilot program; not live in a multifamily dwelling; not be billed by a municipality; and have not previously requested that PG&E cease sending them any and all marketing materials.

[2] Master metered means that several homes share one meter—such as in a trailer park.

[3] Net metered homes have the ability to generate as well as consume power.

Appendix B: Data description

In this study, we analyze hourly interval electricity consumption data for one particular HER program pilot rollout within the broader set of HER programs implemented in PG&Es service territory (called "Wave One" by PG&E; see Table B-1).[4] It includes 500,000 households in the top three quartiles of energy use[5], drawn from most geographic regions in PG&E's service territories (see Figure B-1 for more information about PG&E's geographic territories). The Wave One rollout began on February 2012, but only three months of data were made available for this analysis: August 1st - October 31st 2012. This period includes 6 of the 10 highest hourly consumption levels of 2012.[6]

Table B-1. Overview of the Wave One dataset

	# Treat	# Control	Launch Date	Hourly interval data available	PG&E territory	Quartile of energy use	Service received from PG&E
Wave One	400,000	100,000	Feb 2012	Aug 1, 2012-Oct 31, 2012	**P, Q**, R, S, T, **V**, W, X, **Y**	Top 3 quartiles	Electric & gas service, and electric-only service

[4] There were also two additional pre-pilot "waves" of HERs that went out to different portions of the PG&E residential population previous to Wave One: Beta Wave and Gamma Wave. The Gamma Wave includes fewer households (~150,000), in all quartiles of energy use in a smaller geographic region, and the Beta Wave includes even fewer households (~120,000) in only the top quartile of energy use in an even smaller geographic region. No member of the treatment or control group of any wave is also a member of a treatment or control group of another wave. Future research will examine the data from these pre-pilots.

[5] The top (4th or highest) quartile refers to the 25% of energy users who use the most total annual energy on average (using the most energy as compared to the rest of the population). The quartiles were determined based on a combined electric and gas usage index.

[6] The highest consumption levels were determined based on ranking the hourly system retail load for 2012.

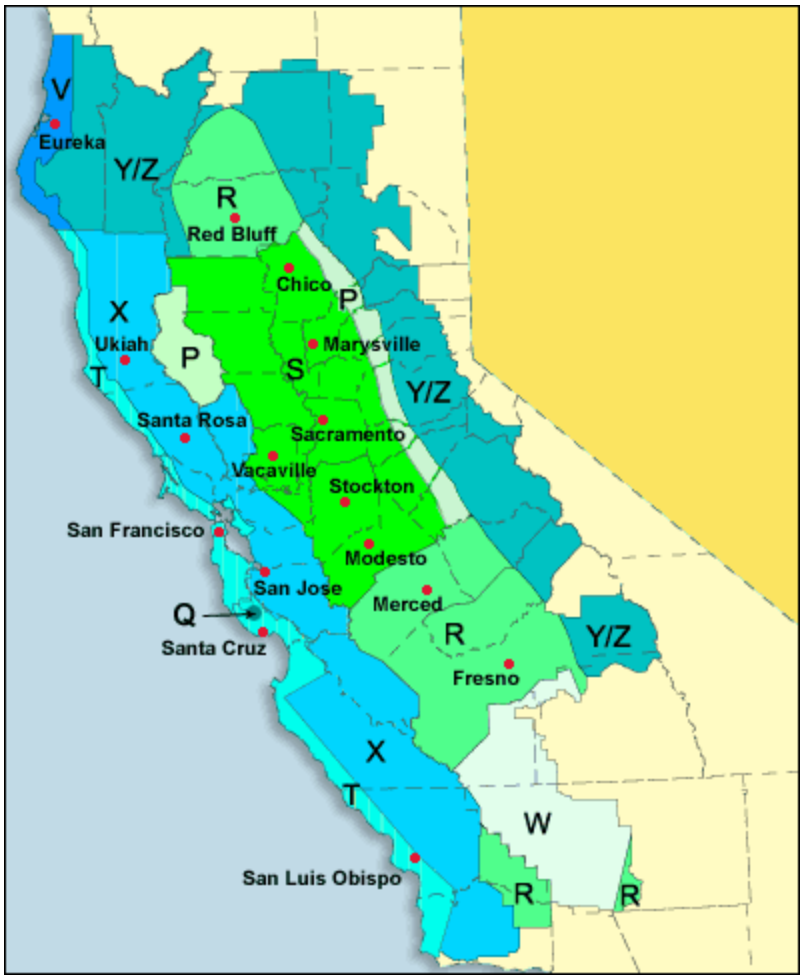

Figure B-1. PG&E Territory Map

Appendix C: Descriptive statistics and validation of randomization

In this section we present descriptive statistics of the pilot and pre-pilot study waves, and validate the comparability between the control and treatment groups through randomization. Figure C-1 presents the weekday hourly load profiles of control group customers in Wave One for the time period included in our dataset.

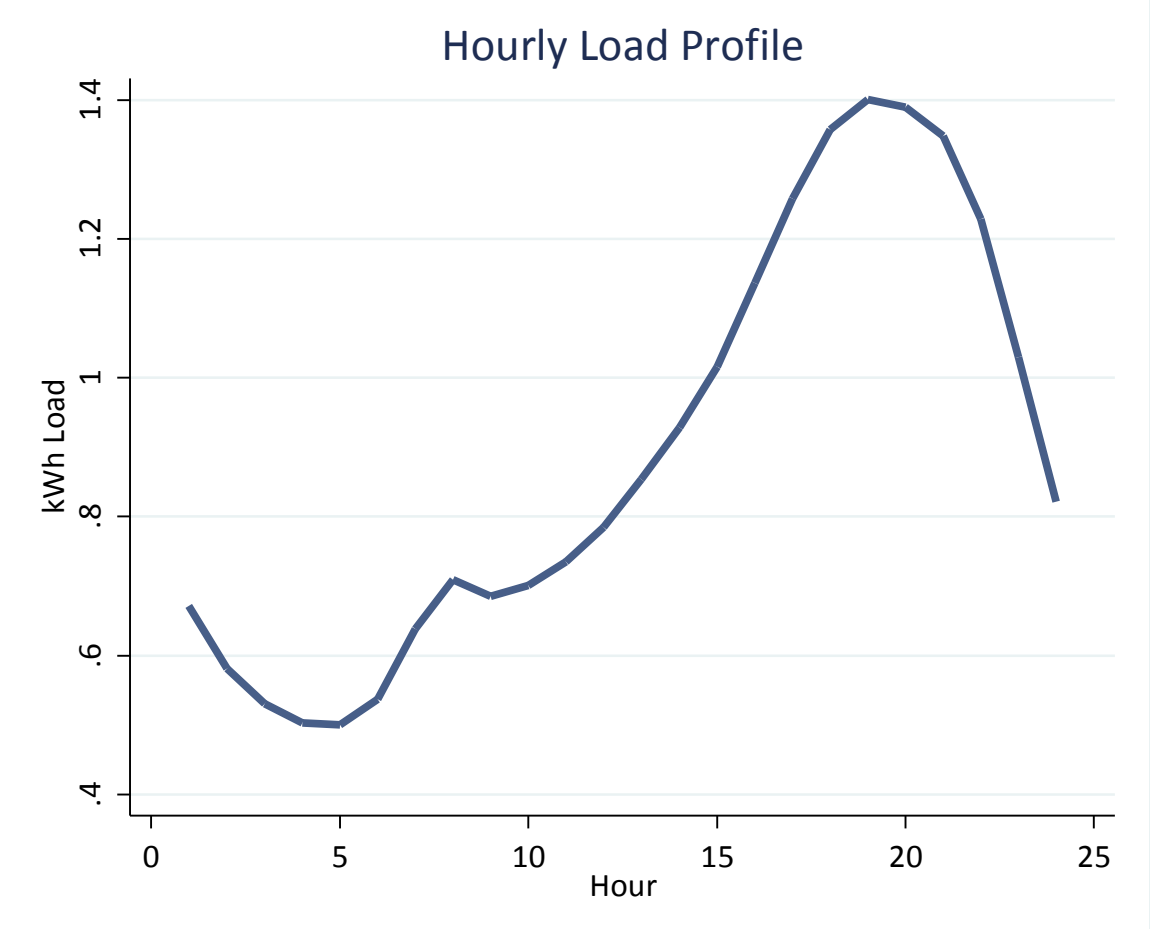

Figure C-1. Hourly control group weekday load profiles for Wave One

Table C-1 demonstrates the successful randomization of customers onto control and treatment groups, as well as showing basic summary statistics. The table shows both the percentage of customers with observed characteristics as well as mean values for quantitative variables.[7] The

[7] Data for tables C-1 and C-2 come from a combination of PG&E and third party databases licensed by PG&E.

observed characteristics in the table include baseline territory, CARE status (a program for low-income households offering subsidized rates), income level as estimated by a third party, homeownership status as estimated by a third party, home attributes, and monthly electricity usage prior to treatment. As the table shows, the distribution of each characteristic is similar across treatment and control groups.

The table also shows the results of statistical tests that tell us whether there is any evidence that the distribution of a given characteristic is correlated with treatment status. For binary variables, a z-test on the difference in means was used and the p-value for equality of means is shown. For metrics with more than two categories, the test used was Fisher's exact test and the p-value for independence of category with respect to treatment and control is shown.

Table C-2 shows the number of customers who were sent the first mailing in each wave; the number of months since wave inception through December 2012; and the average monthly attrition rate due to account closure from the beginning of the wave through December 2012. It is our understanding that account closure occurs almost primarily due to customers moving. In our analysis, we assume that moving (and any other source of account closure) is independent of being in the treatment or control groups. As the table shows, the Wave One control group was roughly four times smaller than the treatment group.

Table C-1. Distributions of Characteristics across Treatment and Control Groups (Wave One)

Metric	Category	Unit	Treatment	Control	P-value
Baseline Territory	P	(% of group)	1.1%	1.1%	0.36
	Q	(% of group)	0.0%	0.0%	
	R	(% of group)	11.3%	11.4%	
	S	(% of group)	23.9%	23.9%	
	T	(% of group)	12.2%	12.0%	
	V	(% of group)	0.0%	0.0%	
	W	(% of group)	6.0%	6.0%	
	X	(% of group)	45.4%	45.5%	
	Y	(% of group)	0.1%	0.1%	
Dual-fuel		(% of group)	90.1%	90.0%	0.60
CARE Rate		(% of group)	29.7%	29.8%	0.43
Estimated Household Income	<$30k	(% of group)	12.8%	12.8%	0.79
	$30k-$50k	(% of group)	13.3%	13.5%	
	$50k-$80k	(% of group)	29.6%	29.4%	
	>$80k	(% of group)	44.3%	44.3%	
Renter Status		(% of group)	5.4%	5.4%	0.98
Presence of Pool or Spa		(% of group)	13.4%	13.5%	0.47
Estimated Number of Residents		(number of residents)	2.8	2.9	0.16
Living Space		(square feet)	1734.3	1702.8	0.61
Year Home Built		(year)	1972.1	1972.1	0.93
Estimated Age of Head of Household		(years)	52.2	52.4	0.05

Pre-HER Usage	**Jan-11**	**(monthly kWh)**	637	638	0.29
	Feb-11	**(monthly kWh)**	598	598	0.84
	Mar-11	**(monthly kWh)**	558	558	0.68
	Apr-11	**(monthly kWh)**	535	536	0.64
	May-11	**(monthly kWh)**	521	521	0.93
	Jun-11	**(monthly kWh)**	664	666	0.32
	Jul-11	**(monthly kWh)**	728	729	0.24
	Aug-11	**(monthly kWh)**	722	725	0.10
	Sep-11	**(monthly kWh)**	690	692	0.38
	Oct-11	**(monthly kWh)**	549	550	0.29
	Nov-11	**(monthly kWh)**	593	594	0.16
	Dec-11	**(monthly kWh)**	662	663	0.15
	Jan-12	**(monthly kWh)**	638	639	0.38

Table C-1. Monthly Attrition Rate by Wave and Fuel Type

Wave		Wave One	
		Dual	Electric-only
# of Customers at Launch of Wave	Control	89,026	9,825
	Treatment	356,419	39,124
# of Months of HERs*		11	11
Monthly Rate of Attrition (%)	Control	0.9%	1.4%
	Treatment	0.9%	1.4%

Appendix D: Analysis and results

In this section, we describe our analytical approach used to estimate the total overall savings, the savings during each hour, the peak versus off-peak savings, and the savings during the 10 highest and 10 lowest system peak days. Here, we present the results in a table format (a graphical representation of the results is in the main body of the paper).

We only estimate savings for the time period during which we have data: Aug 1, 2012-Oct 31, 2012. We chose to include only weekdays for the analyses in this section because those are typically the times when electricity is most likely to have large demand spikes and corresponding price spikes. Weekends also tend to have noticeably different usage patterns.

To account for correlation within customers across days and hours, the standard errors for all specifications in this report are robust and clustered at the household level unless explicitly stated. Because of computing limitations, we maintained unique observations for each customer, but we aggregated all weekday data within a week for each hour, so that there were 24 hourly observations per week for each customer.

D.1 Overall savings

First, we estimate the total overall electricity savings, using the following specification:[8]

$$kwh_{it} = \alpha + \beta T_i + \varepsilon_{it} \quad (0.1)$$

Where:

- kwh_{it} indicates energy use per hour, averaged across days within a season;
- t indicates each hour;
- T_i is an indicator variable for customers in the treatment group; and
- β is the estimated average treatment effect (i.e., the estimated overall savings).

Table D-1 displays the results; note that the total overall savings is statistically significant.

[8] Pre-treatment data was not available and thus we could not perform a difference-in-differences approach. Because this is a randomized controlled trial, we would expect that adding pre-treatment data for a difference-in-difference analysis would increase the precision but not affect the estimates of savings.

Table D-1. Overall savings estimates

	Wave One
Treatment	-0.0136***
	(.0018)
Constant	0.6866***
	(.0016)
Hour of Day FE	No
Week FE	Yes
R-squared	.0334373
Number of hh	493,416
Dates	Aug 1 - Oct 31

Standard errors in parentheses
Note: SE clustered at household level
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

D.2 Savings during each hour

Next, we estimate the electricity savings for each weekday hour. Our specification compares electricity use of the control group to that of the treatment group in each hour:

$$kwh_{it} = \sum_{h=1}^{24} \beta_h H_h T_i + \nu_h + \varepsilon_{it} \quad (0.2)$$

Where:

- kwh_{it} indicates energy use per hour;
- h indicates the hour;
- H_h is an indicator variable for each hour;
- T_i indicates customers in the treatment group;
- ν_h is a set of hourly fixed effects; and
- β_h is the estimated average treatment effect (i.e., the estimated savings) for each hour.

Table D-2 displays the numerical results (graphical results are shown in the main body of the report). The results show statistically significant savings for each weekday hour.

Table D-2. Savings estimates for each hour

	Wave One –
Treat X Hour 1	-0.0081***
	(.0017)
Treat X Hour 2	-0.0068***
	(.0016)
Treat X Hour 3	-0.0064***
	(.0015)
Treat X Hour 4	-0.0059***
	(.0014)
Treat X Hour 5	-0.0051***
	(.0014)
Treat X Hour 6	-0.0051***
	(.0014)
Treat X Hour 7	-0.0071***
	(.0016)
Treat X Hour 8	-0.0075***
	(.0017)
Treat X Hour 9	-0.0091***
	(.0017)
Treat X Hour 10	-0.0097***
	(.0017)
Treat X Hour 11	-0.0118***
	(.0019)
Treat X Hour 12	-0.0137***
	(.002)
Treat X Hour 13	-0.0171***
	(.0022)
Treat X Hour 14	-0.0198***
	(.0025)
Treat X Hour 15	-0.0219***
	(.0028)
Treat X Hour 16	-0.0235***
	(.0031)
Treat X Hour 17	-0.0251***
	(.0033)
Treat X Hour 18	-0.0246***
	(.0034)
Treat X Hour 19	-0.0226***
	(.0033)
Treat X Hour 20	-0.0211***
	(.003)
Treat X Hour 21	-0.0181***

	(.0028)
Treat X Hour 22	-0.0145***
	(.0026)
Treat X Hour 23	-0.0125***
	(.0023)
Treat X Hour 24	-0.0095***
	(.002)
Hour of Day FE	Yes
Week FE	Yes
R-squared	.1558469
Number of hh	493416
Dates	Aug 1 - Oct 31

Standard errors in parentheses
Note: SE clustered at household level
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

D.3 Peak versus off-peak savings

We also explicitly estimate the electricity savings during peak hours, defined as 3-8pm during weekdays, and during off-peak hours, defined as all other hours in a weekday. Our specification compares electricity use of the control group to that of the treatment group, using an indicator for peak hours and an indicator for off-peak hours:

$$kwh_{it} = \beta_{peak} H_{peak} T_i + \beta_{off-peak} H_{off-peak} T_i + \nu_h + \varepsilon_{it} \quad (0.3)$$

Where:

- kwh_{it} indicates energy use per hour, averaged across days within a season;
- h indicates each hour;
- H_{peak} and H_{peak} are indicator variables for on and off-peak hours;
- T_i is an indicator variable for customers in the treatment group, ν_h is a set of hourly fixed effects, and β_h is the estimated average treatment effect for each hour.

Results are displayed in Table D-3. The results show statistically significant peak savings, and a t-test shows that the peak savings are also statistically significantly different than off-peak savings.

Table D-3. Savings estimates for peak versus off-peak hours

	Wave One
Treat X Peak	-0.0231***
	(.003)
Treat X Off Peak	-0.0104***
	(.0016)
Hour of Day FE	Yes
Week FE	Yes
R-squared	.1558435
Number of hh	493416
Dates	Aug 1 - Oct 31

Standard errors in parentheses
Note: SE clustered at household level
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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