Load Impact Analysis of Green Mountain Power Critical Peak Events, 2012 and 2013

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Executive Summary

> **Definitions**
>
> **Critical Peak Pricing (CPP):** During a few peak hours electricity prices increase substantially (in this case to $0.60/kWh) in proportion to the cost of transmission and generation capacity payments.
>
> **Critical Peak Rebate (CPR):** During peak hours customers earn rebates by reducing their electricity usage below a baseline level. This rate is also commonly known as Peak Time Rebate, PTR.
>
> **In Home Display (IHD):** A small device that wirelessly communicates with a smart meter and provides the customer with real-time information

This report summarizes results from a two-year Consumer Behavior Study (CBS) executed by Green Mountain Power (GMP) as a component of the eEnergy Vermont Smart Grid project. The purpose of this study was to understand and compare two different types of electricity pricing structures: Critical Peak Pricing (CPP) and Critical Peak Rebate (CPR; also known as the Peak Time Rebate), both of which are intended to provide incentives for residential electricity customers to reduce demand during peak hours. In addition the study sought to identify the additional value of In-Home Display technology in reducing peak hour and monthly electricity consumption.

During the fall of 2012 and summer of 2013, GMP called fourteen critical peak event days (four in 2012 and ten in 2013, including five consecutive days in July 2013). Each event began at 1 pm and ended at 6 pm. Participating customers (all located in the Rutland, Vermont area) were notified of events the evening before each forthcoming event. Temperatures during the 2012 critical peak events were seasonably mild (68-77°F), with correspondingly moderate levels of demand. Temperatures during the 2013 critical peak events were substantially warmer (69-90°F), with higher levels of demand.

Analysis of customer-level electricity consumption showed that, on average, customers in both the CPR and CPP rate groups measurably reduced electricity consumption during declared critical peak events. Table E-1 summarizes the estimated average customer responses over the course of the study. The table separates load impacts into three time horizons: the six hours preceding the start of a critical peak event (7 am to 1 pm); the critical peak event itself (1 pm to 6 pm); and the six hours following the end of a critical peak event (6 pm to midnight). The data indicate that customers on CPR reduced their average hourly loads by 0.038 to 0.081 kW (5 to 8 percent), relative to a control group that was not notified of peak events and was not placed on any special rate during the critical peak event hours. Customers on CPP exhibited larger average hourly load reductions of 0.045 to 0.142 kW (5 to 15 percent), relative to the control group. Customers equipped with In-Home Displays (IHDs) generally exhibited larger reductions during peak events. While CPR customers equipped with IHDs exhibited reductions around 20% larger than CPR customers without the IHD in 2012 and four times as large in 2013, CPP customers equipped with the IHD exhibited critical peak reductions nearly twice as large, on average, as CPP customers without the IHD. Monetary savings to customers on CPR and CPP averaged between $0.18 and $0.42 per customer per event, suggesting that average savings over the course of the fourteen peak events in 2012 and 2013 ranged from $2.52 to $5.88.

While we found that customers, on average, reduced consumption during critical peak events throughout the course of the study, we also found a large variation in load impacts from one event to another. No treatment group exhibited consistent response levels over the course of the fourteen events called during this study.

Table E-1: Summary of load impacts (percentage reductions relative to the no-notification control group), 2012 and 2013

	2012			2013		
Treatment	**Before**	**During**	**After**	**Before**	**During**	**After**
Flat Rate w/ Notification	-6.45%	-3.38%	*0.15%*	-3.81%	-8.18%	-5.81%
CPR-CPR	-4.72%	-5.29%	*-0.57%*	1.06%	-2.17%	*-1.52%*
CPR-CPR w/IHD	-2.65%	-7.64%	*3.41%*	2.41%	-9.55%	-5.77%
CPP-CPP	-1.51%	-7.42%	1.77%	-0.56%	-7.46%	-3.79%
CPP-CPP w/ IHD	-8.67%	**-11.80%**	*2.68%*	3.56%	**-14.48%**	-0.67%
CPR-CPP	-4.29%	-8.57%	*-1.27%*	**16.86%**	1.40%	1.90%
CPR-CPP w/ IHD	-5.29%	-6.24%	*-4.40%*	1.82%	-16.40%	-3.43%

Note: the figures represent averages of estimated treatment-group load impacts over the four 2012 events and the ten 2013 events. Figures in **bold** *indicate those impacts that were statistically significant at the 5% level or better during every event in that year. Figures in italics indicate those impacts that were not statistically significant (at the 10% level or larger) during every event in that year. Figures in* normal *typeface represent impacts that were statistically significant for some events but not others.*

The GMP consumer behavior study design also featured a rate transition group in which customers who started the study on CPR were recruited to switch to CPP for the second study year. Our analysis found that customers in the transition group equipped with IHDs exhibited response magnitudes during critical peak events that were somewhat larger than those of customers with IHDs who remained on the CPP during both years of the study. Transition-group customers that did not have IHDs used more electricity on critical peak days than any other customer group without IHDs, although the difference was not always statistically significant.

Following the completion of the first set of declared critical peak events, GMP surveyed participants in the CBS program to assess their level of satisfaction with the program and customers' perceived benefits. Analysis of the customer survey data shows that participants were moderately satisfied with the program, though the variance among customers was very high, making it difficult to identify statistically significant differences in overall satisfaction among customers on different rate structures. The survey data do clearly show that a number of customers were not successful in activating their IHDs, or did not receive notification of the peak events, which may have limited their response during event days. Our analysis of the rates at which customers opted out of the study indicated that customers in the CPP groups were nearly twice as likely to remove themselves from their assigned rates during the treatment months, relative to the CPR groups, suggesting that some customers were unsatisfied with the CPP rate structure. We also observed a high attrition rate for the CPR-CPP transition groups during the period where they were asked to transition from the CPR rate to the CPP rate, although because of the circumstances under which customers were asked to transition it is difficult to tell if the observed attrition was due to the CPP rate or to other factors.

1. Introduction

1.1 Project Overview

This report presents results from a two-year Consumer Behavior Study (CBS) conducted by Green Mountain Power (GMP). This study was a component of the eEnergy Vermont Smart Grid Investment Grant and GMP's Smart Power program. The study tested a combination of peak-time rate structures and information technology that jointly leveraged smart-grid infrastructure investments within GMP's service territory. The general focus of the study was to identify the best combination of financial incentives and information technology to enable peak-time demand response by residential customers, in order to reduce peak-hour electricity costs for GMP and its ratepayers. An important benefit to ratepayers of advanced metering infrastructure—a reduction in customer outage times—was noted by a number of customers in the surveys conducted by GMP but is not included in the benefits portion of this analysis. As such, the analysis in this report focuses on the effectiveness of rate and information treatments on electricity consumption behaviors during declared critical peak events. The results reported here are based on smart meter data collected from March/April of 2012 (when Advanced Metering Infrastructure was deployed) until October 2014.

1.2 Research Questions of Interest

Using customer-level electric usage data available from March/April 2012 (when Advanced Metering Infrastructure was deployed in the GMP territory) through October 2014, the discussion in this report addresses the following research questions.

1. What is the impact of time-varying electric rates (Critical Peak Pricing and Critical Peak Rebates) on residential average hourly kW usage before, during and immediately after critical peak event hours?
2. What is the impact of information technology (the In-Home Display or IHD) on residential average hourly kW usage during declared peak-time events, when coupled with a time-varying electric rate?
3. What is the impact of peak-event notification (without a time-differentiated rate and without IHDs) on customer-level average hourly kW usage before, during and immediately after critical peak event hours?
4. Did consumers that were transitioned from a Critical Peak Rebate to a Critical Peak Price in 2013 respond any differently to critical peak events than customers that remained on the same rate treatment (Critical Peak Rebate or Critical Peak Price) during both 2012 and 2013?
5. How persistent are load impacts across events? Are there differences in persistence between rate and information treatments?
6. What are the financial impacts of critical-peak rate reductions on residential electric bills?
7. Does the presence of the IHD induce changes in total monthly electricity consumption?

This report provides analysis with respect to each of these research questions, based on data collected from four critical peak events called in September and October of 2012 and ten critical peak events called in July and August 2013. Temperature conditions during the four events in 2012 were relatively moderate (temperatures in the 60s and 70s; cooler than what would be expected in Vermont during the summer months). Temperature conditions during the ten events in 2013 were more variable, with temperatures in the 70s to 90s, including an unusually warm five-day period in July.

In summary, our analysis suggests the following conclusions with respect to each of the seven research questions:

1. *The impact of time-varying electric rates on response to declared critical peak events (Research Question 1)*: We found that customers on CPP and CPR rates did reduce average hourly kW demand by statistically significant magnitudes. Average hourly per-customer reductions during critical peak events ranged from 5.3-15% for the CPP groups, and 3.8-8.1% for the CPR groups, when compared to the control group that was not notified of events. We qualitatively observed a "pre-emptive" reduction in consumption for some rate and information treatment groups beginning two to six hours before the start of critical peak events.
2. *The impact of the In-Home Display on response to declared critical peak events (Research Question 2)*: Customers who were given an IHD did exhibit significantly larger hourly kW demand reductions during declared critical peak events. Hourly kW responses for the IHD-enabled CPR group were approximately 20% larger than for CPR customers without the IHD. Customers in the CPP group with the IHD exhibited average hourly kW reductions during critical peak events that were nearly twice as large as those from CPP customers without the IHD.
3. *The impact of peak-time notification on response to declared critical peak events (Research Question 3)*: Customers who received notifications of peak-time events but remained on the standard GMP flat residential rate and were not given IHDs did reduce average hourly kW consumption during declared peak periods. Notably, the reductions due to event notification alone (without any associated technology intervention or rate incentive to reduce consumption) were comparable, relative to every other rate and information treatment except the combination of the CPP and IHD (which showed larger reductions).
4. *The impact of transitioning from the Critical Peak Rebate to the Critical Peak Price (Research Question 4)*: The option to transition from the CPR to the CPP did not appear to significantly impact uptake rates for the CPP – when invited to transition, customers in this group took up the CPP at rates comparable to the rate at which customers agreed to take up CPP during initial recruitment. We observed significant differences in consumer behavior during critical peak event days for customers that transitioned from the CPR in year one to the CPP in year two. Transition-group customers with IHDs exhibited larger magnitudes of load reduction during critical peak events, particularly in the

second year of the study (after transitioning to CPP). Assessing the load impacts of the transition-group customers without IHDs is difficult, since this group exhibited higher levels of consumption than any other group, including the control group that was not notified of critical peak event days.

5. *Persistence of customer response during several consecutive critical peak days (Research Question 5)*: We observed that customer responses were quite persistent during the hours of the critical peak event, suggesting that customers take response actions at the beginning of critical peak times or prior to the start of the critical peak period, rather than managing their electricity usage on an hour-to-hour basis during critical peak events. We observed very little persistence among any treatment group on an event-to-event basis, even after controlling for different weather conditions when critical peak events were called. This suggests that the types of demand response programs being evaluated in this study may not be suited to act as capacity resources, for resource adequacy or other types of system planning.
6. *Impacts on customer bills (Research Question 6)*: Customer savings during declared critical peak events were between 18 to 42 cents per customer, per event. Customers equipped with IHDs generally saved more money than customers who did not have IHDs.
7. *Impacts of IHDs on monthly energy consumption (Research Question 7)*: Customers with IHDs were observed to reduce total monthly kWh usage by approximately 28 kWh per customer per month, or about 4 percent of average monthly kWh usage for customers that did not have IHDs. Based on the Rate 1 energy charge in the GMP territory, this level of monthly energy savings suggests a total annual bill reduction of $50 per customer. We did observe, however, that monthly energy savings for IHD-equipped customers was highest around August or September 2012 (when customers had just received their devices) and fell off thereafter.

The remainder of this report is organized to answer these seven research questions in detail and to provide pertinent details about the study's implementation. Section 2 provides a detailed description of the project design and implementation. Section 3 describes the interval meter and survey data used in our analysis. Section 4 describes the econometric models and other methods utilized to address each of the seven research questions. The results of our analysis, for each of the seven research questions, is provided in Section 5. Also included in Section 5 is a discussion of the process used to implement the critical peak pricing program, as well as the estimated monetary savings associated with peak-time demand reductions. Section 6 provides some conclusions. The remainder of this report contains supplemental appendices with detailed information about the study design and analysis.

2. Project Description

2.1 Design Elements of the GMP Consumer Behavior Study

The GMP Consumer Behavior Study was designed as a randomized control trial (RCT) featuring seven treatment groups and two control groups (each of which serves a different purpose as discussed below).[1] Because customers were permitted to opt-out of the study at any time, this report treats the study design as a Randomized Encouragement Design (RED). The 'encouragement' in the case of this study involved recruitment to be part of the study population. The study was carried out between March 2012 and December 2013 (though the last of the critical peak events was called in August 2013). The treatments included two different critical peak rate structures; informational treatments (In-Home Displays provided to customers in relevant groups); and a simple notification treatment where customers are informed of declared critical peak events but are not given the IHD or placed on a time-differentiated rate. Note that all of the participants in this study were previously on a flat, non-dynamic rate structure (as opposed to a daily time-of-use rate); this study focuses only on the impact of critical peak price differentiation. The study did not include non-critical peak rate changes, as would be included in a time of use study.

2.1.1 Target Population

The target population for the study included residential customers in the GMP service territory in the vicinity of Rutland, VT, who currently pay their own electric bills and who are year-round Vermont residents.[2] Note that Rutland, VT has a somewhat lower than average income, relative to other portions of the Green Mountain Power service territory. Eligibility for this study was determined in two stages.

In the first stage, an eligibility screen was conducted by GMP, based on information in their Customer Information System (CIS) database. Customers were deemed to be ineligible if they met any of the following characteristics:

a. Customers were located outside the vicinity of Rutland, VT;
b. Customers were not on Rate 1;
c. Customers did not have consistent monthly kWh data for 12 months;
d. Customers had average monthly bills less than 50kWh and or greater than 10,000kWh;
e. Customers would be unlikely to have smart meters by the summer of 2012.

[1] In the most general sense, a Randomized Control Trial randomly assigns eligible customers to either a control or treatment group. Once assigned, the customer must remain in that experimental group throughout the duration of the study.

[2] GMP is the largest electric utility in Vermont, with a service territory covering roughly 70 percent of the state. The original study area (Rutland, Vermont) was initially served by Central Vermont Public Service Corporation. GMP and Central Vermont Public Service merged in 2012.

Based on these criteria, 19,936 potentially qualified customers were identified in late 2011. 1200 of these customers were assigned to the no-survey control group, leaving 18,736 customers.

In the second stage, Metrix Matrix, a market-research firm retained by GMP, contacted customers (primarily by telephone, but also by mail) to determine final eligibility for this study. The following criteria were used in the recruitment surveys to determine final eligibility.

- The customer lives in or near Rutland County (confirmation of CIS data);
- The customer's primary residence charged for electricity using "Rate 1" (flat rate pricing);
- The customer lives in a single-family dwelling;
- The customer's residence is used either year-round or during the summer (the intent is to exclude from eligibility customers who are not in their homes over the summer);
- The customer intends to remain at the specified address for the two years covering the study.

Additional details of the recruitment process are provided in Section 2.3 and Appendix 2.

2.1.2 Randomization and Assignment Method

Power analysis was performed to determine appropriate sample sizes for the study's treatment and control groups. GMP hoped the study would be able to measure a minimum detectable effect size of 5% of average customer-level monthly kWh consumption, and 10% of average hourly kW demand, following the declaration of a critical peak event. The sampling was designed to measure these minimum detectable effects with a Type I error (i.e., false positive) probability of 10% and a Type II error (i.e., false negative) probability of 20%.

The costs of administering the experiment vary widely by treatment group. We use an optimal allocation of study participants to control and treatment groups, as per equation (1):

$$\frac{P}{1-P} = \sqrt{\frac{C(Control)}{C(Treatment)}}$$

where P is the proportion of subjects in the treatment group, *C(Control)* is the cost of including a participant in the control group and *C(Treatment)* is the cost of including a participant in the treatment group, above and beyond the costs of inclusion in the control group. Table 2.1 shows how estimated costs at the time of the power analysis and allocation of study participants differ by treatment group.

Table 2.1: Treatment Cost and Optimal Proportion in the Treatment Group

Group	Participant Cost	Optimal Proportion
Control Group (unsurveyed)	$10	N/A (Varies by treatment)
Control Group (surveyed)	$50	31%
Rate treatment, without IHD	$50	31%
Rate treatment, with IHD	$500	12%

Note that in Table 2.1, the high estimated cost of the IHDs affects the proportion of participants in treatment groups featuring IHDs. The cost of including customers in specific rate treatments is assumed to be negligible. The cost differential in the surveyed control group and the non-IHD rate treatment group can be attributed to the cost of surveying participants. The costs included in Table 2.1 represent the best estimates of GMP at the time that randomization and recruitment was undertaken.

Oversampling rates were determined based on conservative assumptions provided by GMP personnel to help in sampling planning. Table 2.2 shows the assumed *acceptance* rates; the oversampling rate is thus equal to one minus the acceptance rate. GMP's experience in recruitment was that the actual acceptance rates were quite a bit higher than those indicated in Table 2.2 (see Section 2.2). Most customers were recruited through phone surveys. A relatively small fraction of those who completed the phone survey decided to opt out of the study.

Customer-level data on monthly kWh consumption were gathered for 2007 through 2010, for GMP Rate 1 residential customers only. We note here that since the consumer behavior study was rolled out in conjunction with the installation of smart meters throughout the GMP territory, we do not have pre-treatment interval meter data for residential Rate 1 customers; the best pre-treatment data available were monthly kWh consumption. The mean and standard deviation of monthly kWh Rate 1 residential consumption was calculated to be 550 kWh per customer and 526 kWh per customer, respectively.

Table 2.2: Anticipated Acceptance and Oversampling Rates
(from the Consumer Behavior Study Plan)

Variable	Acceptance Rate	Oversampling Rate
Surveys	85%	15%
CPP (Opt-in)	15%	85%
CPR (Opt-out)	80%	20%
Persistence (non-attrition)	80%	20%
IHD	60%	40%

Based on these data, we calculated sample sizes required to achieve the aforementioned levels of statistical significance and power. Table 2.3 shows the resulting treatment and control groups and the required sample sizes. These figures suggest that a total of 3,735 customers would need to be involved in some aspect of the study. Given the assumptions about acceptance rates (in Table 2.2), 12,867 customers would need to be randomized prior to being contacted for eligibility determination and recruitment into the study.

Table 2.3: Treatment Groups and Sample Sizes[3]

Group No	Group Name	Survey	Year 1	Year 2	IHD	Notification	Required sample size
1	CPR	X	CPR	CPR		X	390
2	CPR+IHD	X	CPR	CPR	X	X	195
3	CPP	X	CPP	CPP		X	390
4	CPP+IHD	X	CPP	CPP	X	X	195
5	CPR-CPP	X	CPR	CPP		X	390
6	CPR-CPP+IHD	X	CPR	CPP	X	X	195
7	Flat+Notification	X	Flat	Flat		X	390
C1	Flat w/o Notification (Control)	X	Flat	Flat			390
C2	Control, No Survey		Flat	Flat			1200
Totals							3735

The recruitment process began in late 2011, when GMP identified 19,936 individuals who were pre-qualified to participate in this study (see Figure 2.1). Upon identifying the potentially qualified customers, GMP assigned 1200 to the un-surveyed control group (Group C2); these customers were not contacted at any

[3] Note that the group numbering shown here differs from what was shown in the original Consumer Behavior Study Plan for this study. Specifically, treatment group 7 was previously labeled C1. Relabeling this group also triggered a renumbering of the groups currently labeled C1 and C2. This relabeling did not impact the analysis.

point during this study. Contact information for the remaining 18,736 customers was given to Metrix Matrix, a market research company, who implemented the remaining steps of the recruitment process. These 18,736 customers were, at this point, randomly assigned to the nine treatment and control groups. After some additional screening, Metrix Matrix found that 2,191 of the 18,736 did not have up-to-date account information or were businesses, leaving 16,545 pre-screened customers. Of the 16,545 customers, 2,187 did not have valid phone numbers listed, and were thus marked for mail/web recruitment. The remaining 14,358 were marked for telephone recruitment. After being assigned to web and/or mail recruitment groups, each customer was randomly assigned to one of the treatment groups (1-7) or the control group C1.

There was an important difference in the recruitment process for prospective participants assigned to the CPR and CPP treatment. Prospective customers assigned to the CPR treatment would not see any change in their base rate (they would just receive the rebate for measured reductions in consumption). CPR customers were thus only asked to consent to participation in the study. CPP customers, on the other hand, would be placed on the CPP rate and would be taken off of their previous rate. These customers thus needed to explicitly consent to participation in the study, and then needed to explicitly consent to placement onto the CPP rate structure.

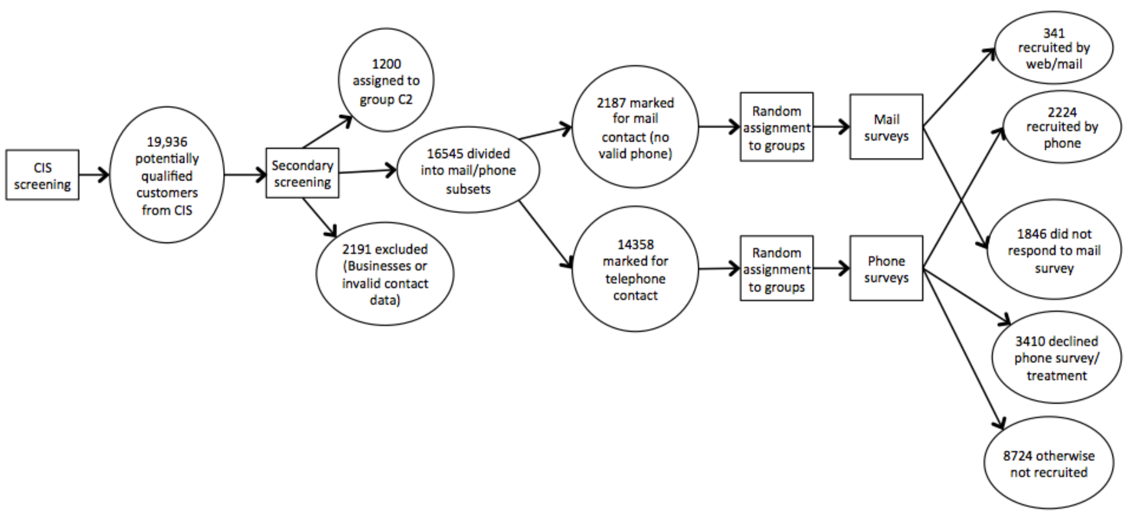

Figure 2.1 – Overview illustration of the recruitment and assignment process. Additional details on the recruitment process are provided in Section 2.2.

2.1.3 Description of the Rate and Information Treatments

The seven treatments used in this study are as follows, and are summarized in Table 2.1

1. **Critical Peak Price (CPP):** During declared critical peak events, the energy charge for customers on the CPP rate was set to rise to $0.60 per kWh. During non-critical peak hours the energy charge for customers

on the CPP rate was reduced by $0.00373/kWh, relative to the customer's default rate, which ranged from $0.109/kWh to $0.189/kWh[4]. The standard flat rate is referred to as "Rate 1."

2. **Critical Peak Price + In-Home Display (CPP+IHD):** The energy charge is the same as the CPP group but customers in this group were given an IHD in addition to the time-differentiated rate. The IHD provided users with near-real-time feedback on household energy usage and could receive peak-time notifications from GMP.
3. **Critical Peak Rebate (CPR):** Customers on this rate treatment receive a rebate of $0.60/kWh for measured energy reductions during declared critical peak events. Energy reductions for rebate determination purposes were calculated using the PJM Customer Baseline methodology.[5]
4. **Critical Peak Rebate + IHD (CPR+IHD):** The rate structure was the same as the CPR group but customers in this group were given an IHD in addition to the time-differentiated rate.
5. **CPR to CPP:** Customers in this group were placed on CPR for the first year of the study and were then recruited to move to the CPP rate in year two. The purpose of this treatment group was to examine whether customer acceptance of Critical Peak Pricing can be increased if customers are first placed on CPR and then asked to transition (compared with customers placed on CPP straightaway). Customers in this group did not know at the time of enrollment or during the first year of the study that they would be recruited to transition to CPP in year two.
6. **CPR to CPP + IHD:** Customers in this group were placed on CPR for the first year of the study and then recruited to move to the CPP rate in year two. These customers were also given IHDs.
7. **Flat rate + Notification:** Customers in this group remained on Rate 1 (flat rate pricing) but were given notification of peak-time events.

All customers except those in the two control groups were given the option to receive notification of peak events by e-mail, text and/or phone call. We note that all

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[4] Note that different customers in this study had different flat rates. The default for Rate 1 customers for the period Oct. 2012 to Oct. 2013 was $0.14557/kWh, before adding the energy efficiency charge. Customers who elected to purchase power through GMP's "Cow Power" program had rates that were increased from this by $0.01, $0.02, or $0.04/kWh, depending on the amount purchased. Customers on a low-income assistance program had reduced rates of $0.10918/kWh for the first 600 kWh consumed.

[5] The baseline level of consumption for each customer was calculated by averaging that customer's hourly consumption between 1:00 pm and 6:00 pm during the four highest-usage weekdays leading up to the CPR event date (excepting holidays and CPR event days). This average baseline is adjusted by comparing usage during the 1:00 pm to 6:00 pm period with usage during the 9:00 am to 12:00 noon period during the same baseline days. A full description of the baseline calculation can be found at http://www.greenmountainpower.com/upload/photos/307PTR_and_CPP_Pilot_Rates_10-1-14.pdf.

customers in IHD-enabled treatment groups received the same IHD (more information about the IHD is provided in Appendix C).

Table 2.4. Summary of rate treatments used in this study[6]

	Base rate (all hours, other than critical peak)	Critical peak rate (1pm-6pm on critical peak days)
Flat rate (Rate 1)	\$0.148/kWh	\$0.148/kWh
Critical Peak Rebate	\$0.148/kWh	\$0.148/kWh – (\$0.60/kWh reduction from baseline)
Critical Peak Pricing	\$0.144/kWh	\$0.60/kWh

GMP calculated the prices used for the rate treatments (shown in Table 2.4) as follows. Based on historical costs of state and regional transmission services and capacity costs, GMP estimated that the market value of a peak-hour kW reduction in New England was \$30.00 per kW of reduction. In this study, a customer is being asked to save power for 10 events, 5 hours during each event. If a customer saved 1 kW during each of the event hours they would save 50 kWh. A 1 kW reduction during one of those hours would save GMP \$30.00. Thus the average cost of a critical peak kWh is:

$$\frac{\$30/kW}{50hr} = \$0.60/kWh$$

This calculation was applied to both the CPP and the CPR rate treatments. Note that the CPP rate, as described here, is based only on marginal capacity costs and does not include an additional energy cost.

The control group (C1) in this study consists of customers on Rate 1 who are aware of the study and their participation but not given any notification by GMP of declared peak-time events. For this reason we will refer to this group as the "No-notification control." In addition, the study includes a second control group (C2) with customers who were not made aware of the study, and were not surveyed.

2.2 Implementation of the GMP Consumer Behavior Study

Figure 2.2 shows a timeline of events in the GMP consumer behavior study. Participants in the study were contacted, recruited and assigned to treatment or control groups beginning in the fall of 2011, with interval meter installations beginning soon thereafter. By the end of March 2012 (the beginning of our interval meter data set) most participants had interval meters installed. Customers in the CPR and CPP groups were transitioned to their new rate structures in August of

[6] Note that these figures approximately reflect the rates seen by standard Rate 1 customers who were not members of the CowPower or low-income assistance programs. Monetary savings calculations in this report use these rates as a reference, though actual individual customer savings may differ.

2012. In-home displays were mailed to customers receiving IHDs as part of their treatment during the second two weeks of August 2012. It is important to note that GMP did not explicitly install IHDs for customers. Thus, GMP was not able to track whether customers had received their IHD as intended; or whether customers who did receive the IHD were able to install and use the IHD successfully. Our load impact analysis includes all customers who were assigned to one of the IHD-enabled treatment groups, but we cannot identify specific customers that either failed to receive the IHD or were not able to use the IHD as intended.

Since advanced metering systems had not been rolled out in the GMP territory prior to the beginning of the study, we have only a limited quantity of pre-treatment interval meter data to use in our load impact analysis. On the other hand, the data are sufficient to identify impacts on hourly average kW consumption during event periods relative to non-event periods.

The first set of four critical peak events was called in September and October of 2012. The second set of ten critical peak events was called in July and August of 2013. Surveys of customer-participants were conducted in the fall of each study year (October/November 2012 and 2013), with survey data collection complete by December of each study year (2012 and 2013).

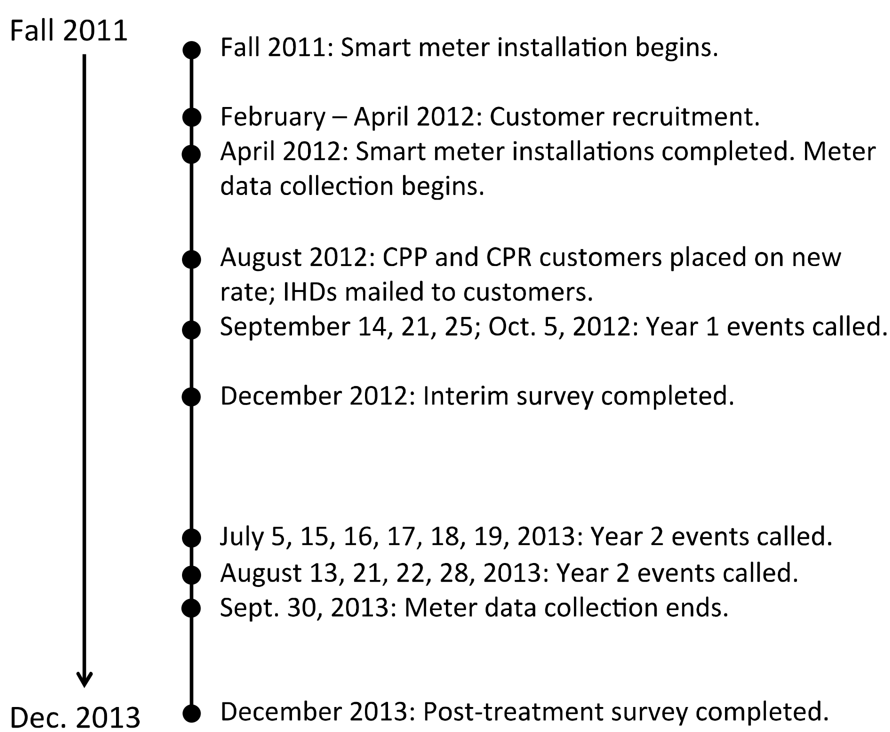

Figure 2.2. Timeline for recruitment and implementation of the GMP Consumer Behavior Study.

As previously mentioned, the 16,545 customers with valid contact data were separated into separate groups for mail and phone recruitment. The 2,187 customers marked for mail recruitment were randomly divided among the 8 remaining groups and sent postcards (see Appendix A) on Feb. 13, 2012 notifying them of their selection for the study. On Feb. 20, customers in these mail-recruitment groups were sent a recruitment letter (see Appendix A) and a paper version of the survey. Figure 2.3 illustrates the mail recruitment process.

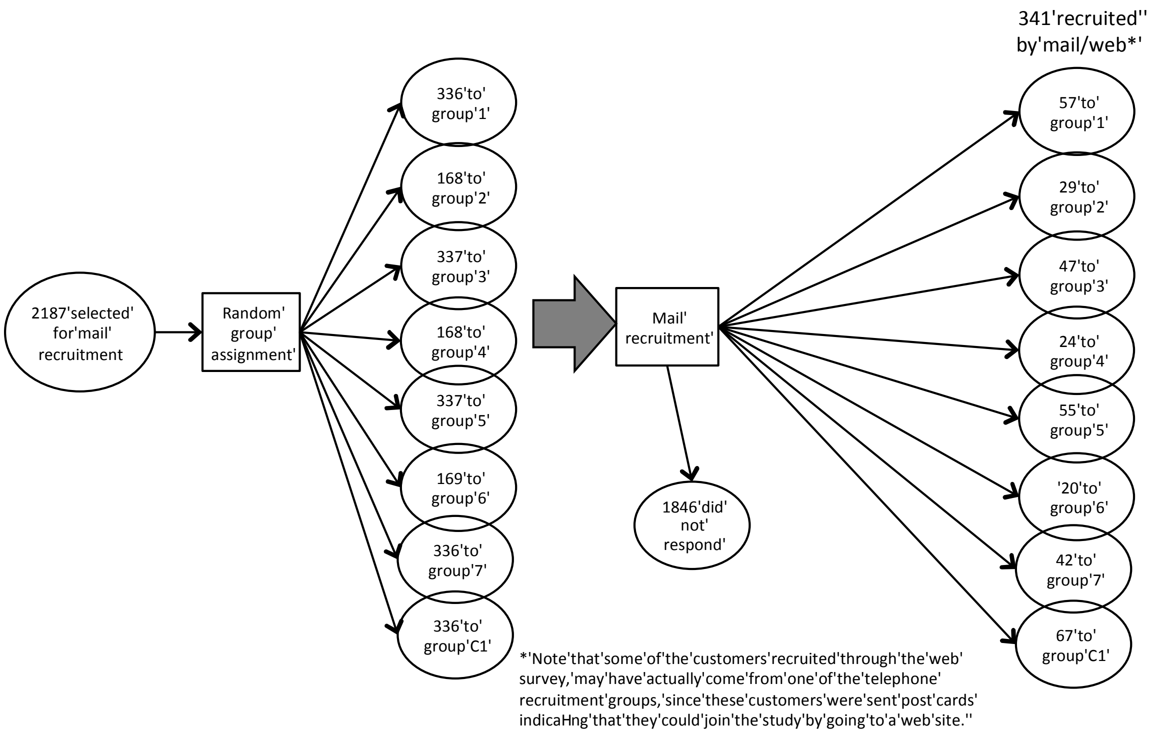

Figure 2.3. Illustration of the mail/web recruitment process

The 14,358 customers marked for telephone recruitment were first randomly assigned to one of the 8 remaining treatment or control groups. After being assigned to groups, customers were sent post cards and then contacted by telephone in five waves from February to April, 2012 (see Appendix A). About one week after receiving post cards, customers were contacted by telephone using the script given in Appendix 2. In short, the script asked several pre-screening questions, introduced the customer to their treatment group, and then proceeded to ask the remaining demographic questions. The recruitment script for the CPP groups differed slightly from the CPR group, in that CPP-assigned customers were explicitly asked if they wanted to participate in the new rate trial. CPR customers, on the other hand, were not explicitly asked if they wanted to participate in the CPR rate, but many did indicate during their recruitment phone calls that they were not interested to participate in the study. In both cases, customers who indicated that they did not want to participate in the study were not included in the treatment groups. Note that not every customer who was initially slated for telephone recruitment was actually contacted by telephone. Metrix Matrix discontinued its telephone recruitment process when each treatment group had been filled with the required number of customers (from Table 2.3).

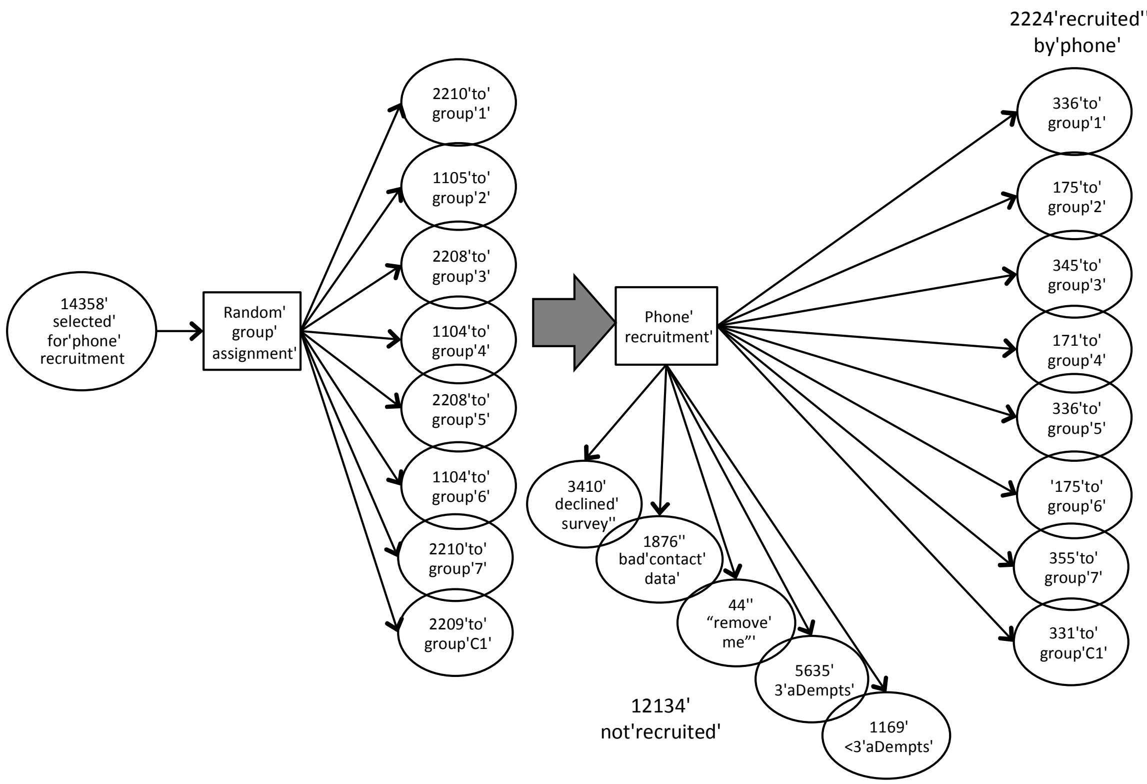

Figure 2.4. Illustration of the Telephone Recruitment Process

By the end of April 2012, the required number of customers had been recruited into their respective groups. Also by early April almost all customers had Smart Meters installed, making it possible to begin gathering interval data. Due to implementation challenges, customers in the CPR and CPP rates were not officially transferred to their new rate structures until August of 2012.

In-home displays were mailed to customers receiving IHDs as part of their treatment during the second two weeks of August 2012. It is important to note that GMP did not explicitly install IHDs for customers, making it difficult to verify exactly which customers used the devices, although some indication of this is available in the interim survey data.

Since advanced metering systems had not been rolled out in the GMP territory prior to the beginning of the study, we have only a limited quantity of pre-treatment interval meter data to use in our load impact analysis. On the other hand, the data are sufficient to identify impacts on hourly average kW consumption during event periods relative to non-event periods.

2.3 Eligibility determination

The **target population** for this study was residential customers in the vicinity of Rutland, VT, who currently pay their own electric bills and who are year-round Vermont residents. Note that Rutland, VT has a somewhat lower than average income, relative to other portions of the Green Mountain Power service territory.

With this in mind, eligibility for the study was determined in two stages.

In the first stage, GMP conducted an initial eligibility screening, based on information in their Customer Information System (CIS) database. Customers were deemed to be ineligible if they met any of the following characteristics:

f. Customers located outside the vicinity of Rutland, VT;
g. Customers were not on Rate 1 (flat rate);
h. Customers did not have consistent monthly kWh data for 12 months;
i. Customers had average monthly bills less than 50kWh and or greater than 10,000kWh;
j. Customers would be unlikely to have smart meters by the summer of 2012.

Based on these criteria, 19,936 potentially qualified customers were identified in late 2011. 1,200 of these customers were assigned to the no-survey control group, leaving 18,736 customers.

In the second stage, Metrix Matrix, contacted customers primarily by telephone, but also by mail, to determine final eligibility for this study. The following criteria were used in the recruitment surveys to determine final eligibility.

- The customer lives in or near Rutland County (confirmation of CIS data);
- The customer's primary residence charged for electricity using "Rate 1" (flat rate pricing);
- The customer lives in a single-family dwelling;
- The customer's residence is used either year-round or during the summer (the intent is to exclude from eligibility customers who are not in their homes over the summer);
- The customer intends to remain at the specified address for the two years covering the study.

Additional details of the recruitment process are provided in Appendix 2.

2.4 Customer recruitment and retention results

In this section we review the results from the recruitment process, and describe the rates at which customers continued with their assigned treatment, after their initial assignments. Our initial conjectures going into this analysis were as follows:

1. Recruitment rates will be higher for CPR groups relative to CPP groups, roughly corresponding to the acceptance rates shown in Table 2.2.
2. Retention rates (the rate at which customers continue with their assigned rates) during the summer treatment months will be higher for CPR groups, relative to CPP groups, given that some customers may not be happy with the high critical peak prices during the treatment periods.
3. Year 2 retention rates will be higher in the CPR-CPP transition groups, relative to the pure CPP groups, given that the transition customers had the additional year to become accustomed to the new rate, before being exposed to the high peak-hour prices.

4. Acceptance of the CPP rate will be higher for the transition-group customers, relative to the pure CPP groups, given that these customers have had time to grow accustomed to critical peak rate structures.

We examine customer retention behavior using monthly billing data, which indicate the rate each customer was on for each billing cycle. It is important to note that the monthly counts provided in this section indicate the number of customers that were on their assigned rate during billing cycles that ended in the month indicated. This means that the "September" data (for example) indicate customers that remained on their assigned rate through the month of August.

Recruitment Results (Conjecture 1)

Table 2.5 provides a numerical summary of the recruitment process results. There are two potential measures of acceptance rates. The first is the number of customers who agreed to take up the treatment, after the phone/mail recruitment process was completed. By this measure all of the treatment groups had recruitment rates in the range of 33-36%. Because customers were informed generally about the study at the beginning of the recruitment process, these rates reflect a combination of customers' willingness to complete the survey and their acceptance of the particular treatment to which they were assigned. A more clear measure of the acceptance rate is the number of customers who actually transitioned to their new rate, when the new rates began in August 2012. By August of 2012 customers had time to consider the implications of their assigned rate and withdraw from the study (by calling GMP) if they were unhappy with their assignment. This acceptance rate can be measured by counting the number of customers who remained on their assigned rate through the August/September billing cycle, and is thus reflected in the Sept. 2012 billing data. By this measure the CPR groups had acceptance rates in the range of 30-34%, and the CPP groups had acceptance rates of 27% and 28% (for non-IHD, and IHD groups, respectively). While there was a lower acceptance rate for the CPP rate than for the CPR rate, the difference was not as large as in the anticipated acceptance rates in Table 2.2.

Table 2.5. Numerical summary of the recruitment results

	Group	Intial assignment	Contacted by mail	Contacted by phone	Not contacted	Declined phone survey	Recruited	Active in Sept. 2012	Acceptance rate *
1	CPR	2884	336	753	1795	417	393	356	33%
2	CPR+IHD	1442	168	413	861	238	204	188	32%
3	CPP	3323	337	839	2147	494	392	329	28%
4	CPP+IHD	1441	168	410	863	239	195	158	27%
5	CPR-CPP	2881	337	779	1765	443	391	353	32%
6	CPR-CPP+IHD	1441	169	413	859	238	195	172	30%
7	Notification	2881	336	790	1755	435	397	384	34%
C1	C1	2443	336	722	1385	391	398	388	37%
C2	C2	1200	0	0	1200	-	-	1119	-
	Total	19936	2187	5119	12630	2895	2565	3447	32%

* Acceptance rate is the percent of customers who accepted the survey and transitioned to the new rate (based on Sept 2012 billing data), after being contacted by mail or phone

Retention results (Conjectures 2-4)

In order to address conjectures 2 and 3 we measured the rate at which customers remained participants during various periods of the study. Table 2.6 shows the results of this analysis. In order to measure the "Year 1 retention rate" we compared the number of customers that remained active in the study through the November 2012 billing cycle (after all Year 1 events were included in the billing data, but before the interim survey) to the number of customers who initially agreed to participate from the survey data. In order to measure the "Transition rate" we compared the number of customers active in the study in May of 2013 (before the beginning of the 2013 critical peak events) to the number of customers active in November 2012. During this period, Metrix Matrix contacted participating customers by phone and mail in order to assess customer satisfaction, and to encourage customers in the CPR-CPP groups (groups 5 and 6) to transition to the new rate. Some customers accepted/declined the transition during the phone survey, whereas others wanted more information and decided later about the transition. The billing data is the most accurate record of exactly who made the transition during this time period. In order to measure the retention rate through the 2013 critical peak events, we compared the number of customers who remained on their assigned rate through their September billing cycle, with the number of customers active in May 2013. Finally, the "Overall retention rate" measures the number of customers who remained in the study through the entire period (from September 2013 billing data), relative to the number of customers who were exposed to their assigned rate for at least one billing cycle (from September 2012 billing data).

Not all of the customers who were recorded as dropouts explicitly chose to drop out of the study for reasons related to the study itself. Some customers moved, resulting in closed accounts. Some customers opted out of having a smart meter in their home (the Vermont Legislature passed a law allowing anyone to opt out of using a smart meter, without penalty), rendering them ineligible to participate further. Other customers decided that they were no longer interested to participate in the study after learning more about their assigned rate. The background "move-out" rate can be seen from the retention rates for the control groups C1 and C2. The Year 1 retention rate for C2 is lower than that of C1 because there was less initial screening for this group of customers.

Table 2.6. Retention analysis results

	Group	Recruited	Active in Sept. 2012	Active in Nov. 2012	Year 1 retention rate	Active in May 2013	Transition rate	Active in Sept. 2013	Year 2 retention rate	Overall retention rate
		(a)	(b)	(c)	(d) = (c)/(a)	(e)	(f) = (e)/(c)	(g)	(h) = (g)/(e)	(i) = (g)/(a)
1	CPR	393	356	352	90 %	322	91 %	309	96 %	87 %
2	CPR+IHD	204	188	187	92 %	174	93 %	167	96 %	89 %
3	CPP	392	329	320	82 %	299	93 %	270	90 %	82 %
4	CPP+IHD	195	158	153	78 %	139	91 %	132	95 %	84 %
5	CPR-CPP	391	353	343	88 %	217	63 %	191	88 %	54 %
6	CPR-CPP+IHD	195	172	172	88 %	112	65 %	104	93 %	60 %
7	Notification	397	384	383	96 %	379	99 %	371	98 %	97 %
C1	C1	398	388	383	96 %	376	98 %	368	98 %	95 %
C2	C2	*1200*	1119	1105	92 %	1081	98 %	1044	97 %	93 %
	Total	3765	3447	3398	89 %	3099	88 %	2956	94 %	82 %

Table 2.6 summarizes the retention analysis results. Across all of the rate treatment groups, the attrition rates were higher (from 2-18%), relative to the notification-only and control group (C1). This is an indication that at least some customers prefer the standard rate structure, or perhaps did like being part of the study in general.

As anticipated (Conjecture 2), we observed higher retention rates within the CPR groups, relative to the CPP groups. In Year 1 the CPP groups show 78% and 82% retention rates, compared to 88%-92% for CPR. In Year 2, retention rates for the CPP groups are 88-95%, relative to 96% for CPR. Notably, the IHD groups tended to have higher retention rates than the non-IHD groups, potentially indicating the value of this additional information in ensuring continued participation. Similarly, the overall retention rate for the pure CPR groups is a few percentage points higher than that of the CPP groups. The CPP+IHD group had a 5% higher retention rate than the non-IHD CPP group, potentially indicating the value of this information technology.

Between Years 1 and 2 customers in the CPR-CPP transition groups were encouraged to transition from the CPR rate to the CPP rate. Some customers accepted or declined the transition during the phone survey, whereas others wanted more information and decided later about the transition. As a result, the most accurate measure of actual acceptance of the transition came from the billing data, which showed exactly which customers remained on their assigned rates at various points during the study. Table 2.6 shows the number of customers who were still active in their assigned groups in November of 2012 and May of 2013. The results show that about 35% of customers declined to transition to the CPP rate. While this is an indicator of customers' reaction to being asked to transition to CPP, customers may have had multiple reasons for refusing to transition, other than not wanting to be put on the CPP rate. Attrition during the transition period may reflect dissatisfaction with dynamic rates in general or perhaps being a part of a study, as much as actual dissatisfaction with the CPP in particular. Because the circumstances under which customers were encouraged to transition to the CPP rate differed from the initial recruitment circumstances significantly, it is difficult to thoroughly address Conjecture 4, but the data here provide some information about customers' willingness to make the transition.

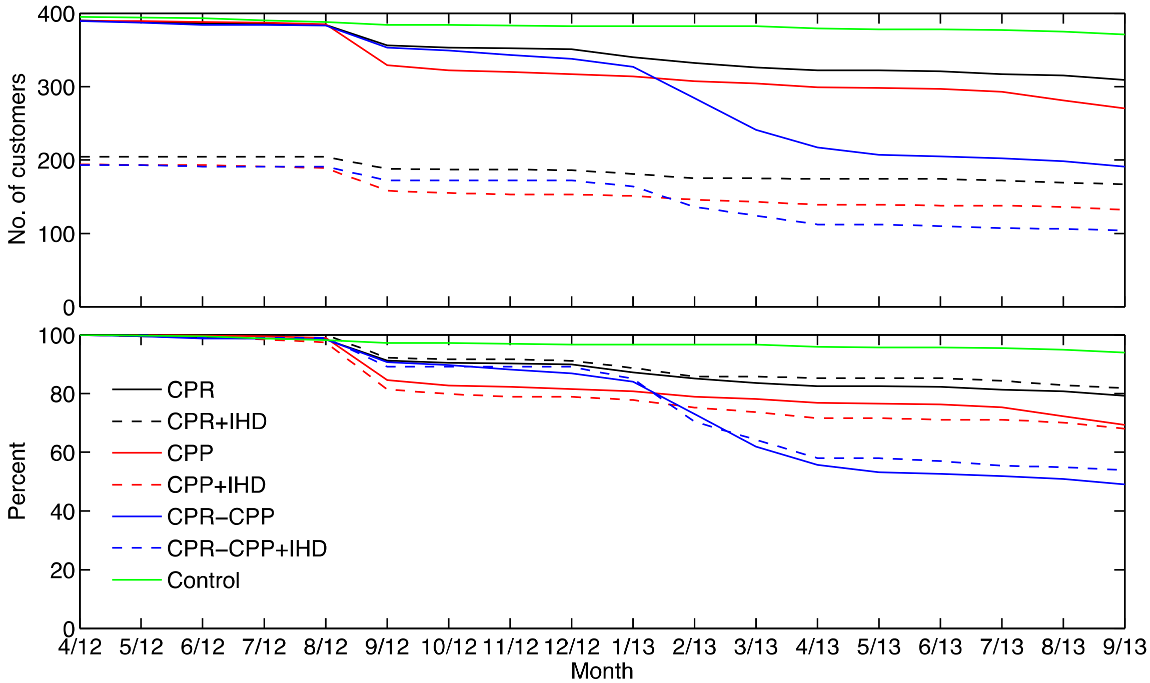

Figure 2.5. The number of study participants remaining on their assigned rate, vs. time. The top panel shows the absolute number of customers, whereas the lower panel shows the same numbers as a percent of customers initially assigned to each treatment group.

2.5 In home display and technology implementation

Green Mountain Power mailed in-home displays to customers in groups 2, 4 and 6 during August of 2012. The IHD technology chosen was the Tendril Insight IHD. Appendix 4 describes this technology in additional detail. The IHD was used to provided the following information to customers:

- Current household power usage in kW or dollars per hour
- Notification of critical peak events
- Notification of each customer's baseline power level

Appendix 4 includes a description of the In Home Display technology, and Appendix 5 includes detailed information from GMP about their AMI technology implementation process, as well as an evaluation of this process.

3. Data collection and descriptive statistics

Figure 3.1 shows a timeline of the first year of the GMP consumer behavior study. Participants in the study were contacted, recruited and assigned to treatment or control groups beginning in the fall of 2011, with interval meter installations beginning soon thereafter. By the end of March 2012 (the beginning of our interval meter data set) most participants had interval meters installed. Customers in the CPR group were transitioned to their new rate in March 2012, while customers in the CPP group were transitioned to their new rate in August 2012. In-home displays were mailed to customers receiving IHDs as part of their treatment during second two weeks of August 2012. It is important to note that GMP did not explicitly install IHDs for customers. Thus, GMP was not able to track whether customers had received their IHD as intended; or whether customers who did receive the IHD were able to install and use the IHD successfully. In our load impact analysis, we include all customers that were supposed to get the IHD in the IHD-enabled treatment groups but we cannot identify specific customers that either failed to receive the IHD or were not able to use the IHD as intended.

Since advanced metering systems had not been rolled out in the GMP territory prior to the beginning of the study, we have only a limited quantity of pre-treatment interval meter data to use in our load impact analysis. On the other hand, the data are sufficient to identify impacts on hourly average kW consumption during event periods relative to non-event periods.

Figure 3.1. Timeline for recruitment and year 1 of the GMP Consumer Behavior Study.

3.1 Event days

The analysis in this report is based on 15-minute interval data collected from GMP for all customers who were informed of their treatment and control groups. This dataset includes data from customers that declined to participate after being informed of their treatment group, customers that decided to stop participating after being placed on their treatment, as well as customers that remained on their treatments. The dataset covers the period from March 2012 to October 2013. During this period a total of fourteen critical peak events were called: four in 2012 and ten in 2013. All customers in the rate and information treatment groups, as well as one customer group remaining on the flat rate, were notified by e-mail, text message, and/or automatic phone calls by 6 pm the day before each critical peak event. Each critical peak event lasted from 1 pm to 6 pm on the event day.

Table 3.1 provides an overview of weather conditions on the fourteen event days. The four event days in 2012 were seasonably mild, with mean temperatures of 68-77°F. Events were not called earlier in the summer of 2012 due to overall eEnergy Vermont project delays. The ten events called during the summer of 2013 happened primarily during periods of warm weather, with temperatures above 80°F except on one date (August 13, 2013).

Table 3.1. Average Temperatures and Heat Index Values During Critical Peak Days in 2012 and 2013

Event Date	*Temperarure (F)*	*Heat Index (F)*
9/14/2012	77.8	75.7
9/21/2012	69.2	66.9
9/25/2012	65.4	62.6
10/5/2012	70.4	68.2
7/5/2013	86.4	83.5
7/15/2013	87.8	84.7
7/16/2013	86.4	83.6
7/17/2013	89.0	85.7
7/18/2013	87.0	84.1
7/19/2013	90.0	86.6
8/13/2013	68.4	66.2
8/21/2013	82.2	79.8
8/22/2013	82.0	79.6
8/28/2013	82.4	80.0

After collecting interval data for March 2012 through October 2013, 15-minute kWh data were summed over each one-hour period in order to produce hourly data for each one-hour time period. Hours with missing data were not included in the data analysis. A very small fraction (<0.1%) of the data were marked as estimated in the database. These estimated readings were not excluded from our analysis; we assumed that the estimations were not poor enough to bias our results.

Table 3.2. Descriptive statistics, and summary of treatments, for the 2012 CPP/CPR treatments. Mean and Standard Deviation (SD) are for hourly average kW.

(a) All hours

Group	*Number of Customers*	*All Observations*	
		Mean	*SD*
CPR	809	0.84	0.91
CPR+IHD	332	0.79	0.85
CPP	445	0.81	0.85
CPP+IHD	167	0.79	0.86
Flat + Notification	400	0.83	0.91
Control	354	0.81	0.87
Total	*2507*	*0.82*	*0.88*

(b) Weekday hours

Group	*Number of Customers*	*Weekday*	
		Mean	*SD*
CPR	809	0.83	0.89
CPR+IHD	332	0.78	0.83
CPP	445	0.80	0.84
CPP+IHD	167	0.78	0.85
Flat + Notification	400	0.82	0.85
Control	354	0.80	0.85
Total	*2507*	*0.81*	*0.86*

(c) Peak event hours

Group	*Number of Customers*	*Critical Peak Event Hours*	
		Mean	*SD*
CPR	809	0.69	0.76
CPR+IHD	332	0.65	0.75
CPP	445	0.66	0.71
CPP+IHD	167	0.61	0.67
Flat + Notification	400	0.72	0.74
Control	354	0.72	0.78
Total	*2507*	*0.68*	*0.74*

Table 3.3. Descriptive statistics, and summary of treatments, for the 2013 CPP/CPR treatments. Mean and Standard Deviation (SD) are for hourly average kW.

(a) All hours

Group	*Number of Customers*	*All Observations*	
		Mean	*SD*
CPR	433	0.82	0.88
CPR+IHD	223	0.78	0.84
CPP	603	0.80	0.84
CPP+IHD	307	0.78	0.91
Flat + Notification	350	0.81	0.87
Control	353	0.80	0.87
Total	*2269*	*0.80*	*0.87*

(b) Weekday hours

Group	*Number of Customers*	*Weekday*	
		Mean	*SD*
CPR	433	0.81	0.87
CPR+IHD	223	0.77	0.83
CPP	603	0.79	0.83
CPP+IHD	307	0.77	0.83
Flat + Notification	350	0.80	0.82
Control	353	0.79	0.85
Total	*2269*	*0.79*	*0.85*

(c) Peak event hours

Group	*Number of Customers*	*Critical Peak Event Hours*	
		Mean	*SD*
CPR	433	0.97	1.05
CPR+IHD	223	0.94	1.01
CPP	603	1.02	1.07
CPP+IHD	307	0.97	0.95
Flat + Notification	350	1.00	0.95
Control	353	1.06	1.08
Total	*2269*	*0.99*	*1.05*

3.2 Descriptive statistics

Our interval meter data set includes 26,378,106 hourly observations, divided among six customer groups as shown in the panels of Tables 3.2 and 3.3. Customers in our dataset had an average load (over all groups) of 0.82 kWh/h (or average kW), with a standard deviation (over all samples) of 0.88 kW. Note that the large standard deviation reflects the large diversity of users in the dataset. Table 3.2 also reflects customer counts after attrition (i.e., the table includes only those customers who remained in the pilot study throughout 2012).

3.3 Average load shapes for treatment and control groups

The descriptive statistics above show that there are small differences in the mean consumption among the various treatment and control groups within years, while the differences in average consumption during critical peak events between 2012 and 2013 are larger. This difference is almost certainly due to the warmer weather at the times when critical peak events were called in 2013.

Figures 3.2 through 3.7 show average non-event weekday and weekend load shapes for both the treatment and control groups for the first study year; the second study year; and an average over both study years together. All of the figures indicate, as does Table 3.2, that there are small differences in the mean load for the various treatment groups. The CPR group in particular exhibited a somewhat higher average load than what was observed in the other groups. It is possible (though difficult to confirm) that this could be an effect of the rate design; customers could be using more in order to achieve a greater reduction during critical peak hours. On the other hand, the graphs clearly show that the general load patterns among the groups were very similar during the study period.

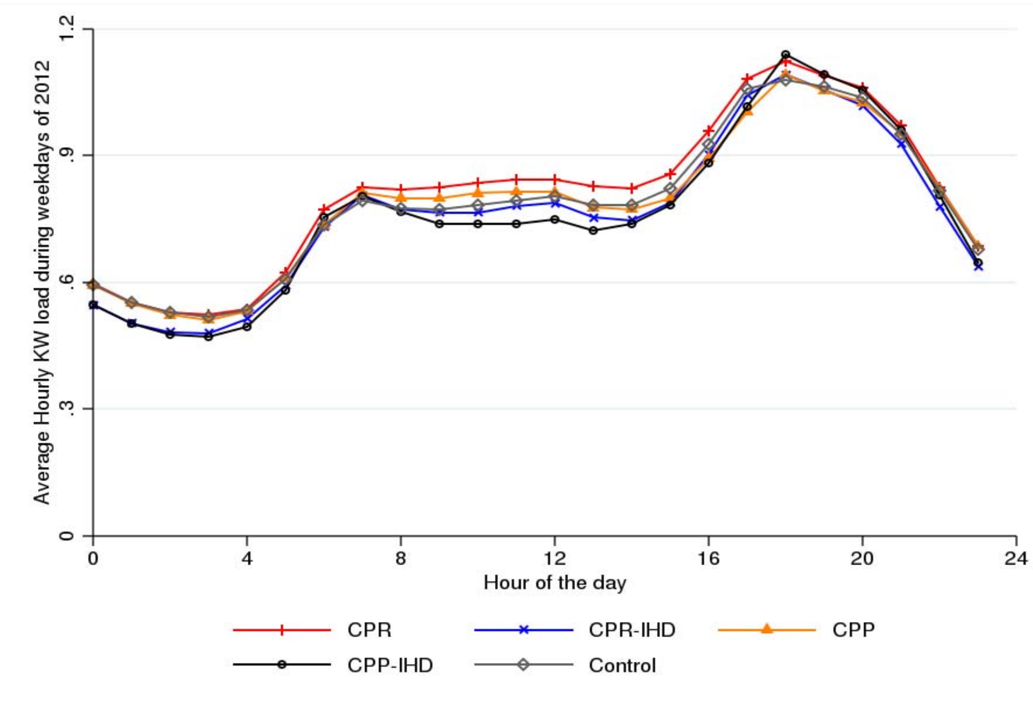

Figure 3.2. Mean weekday load pattern for the treatment and control groups during the study period in 2012.

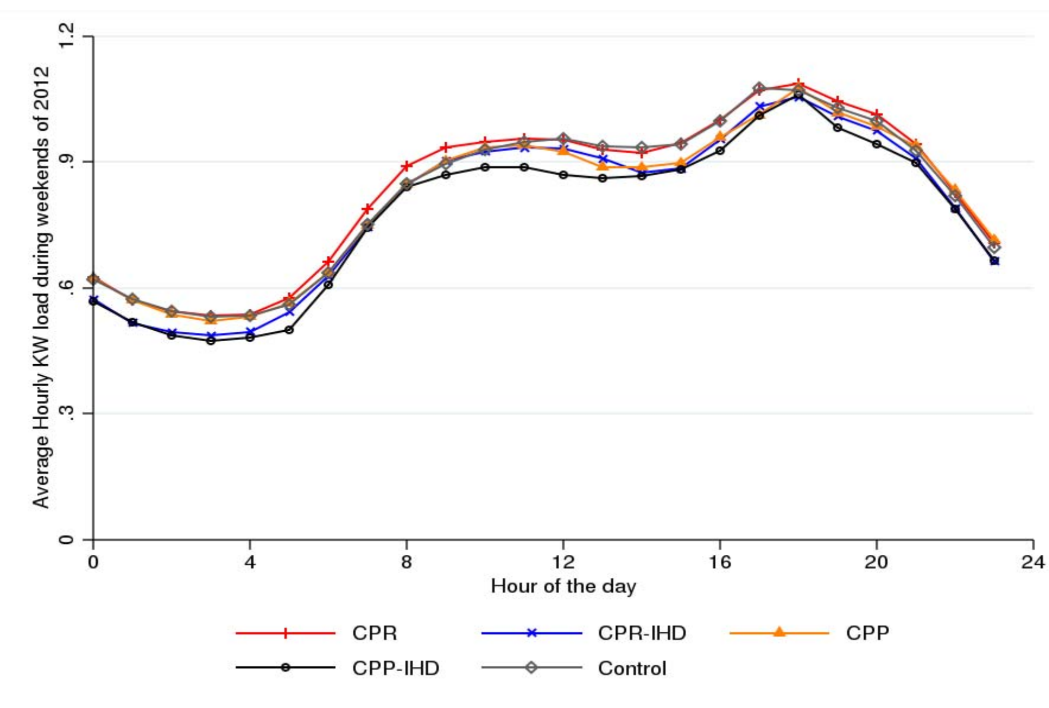

Figure 3.3. Mean weekend load pattern for the treatment and control groups during the study period in 2012.

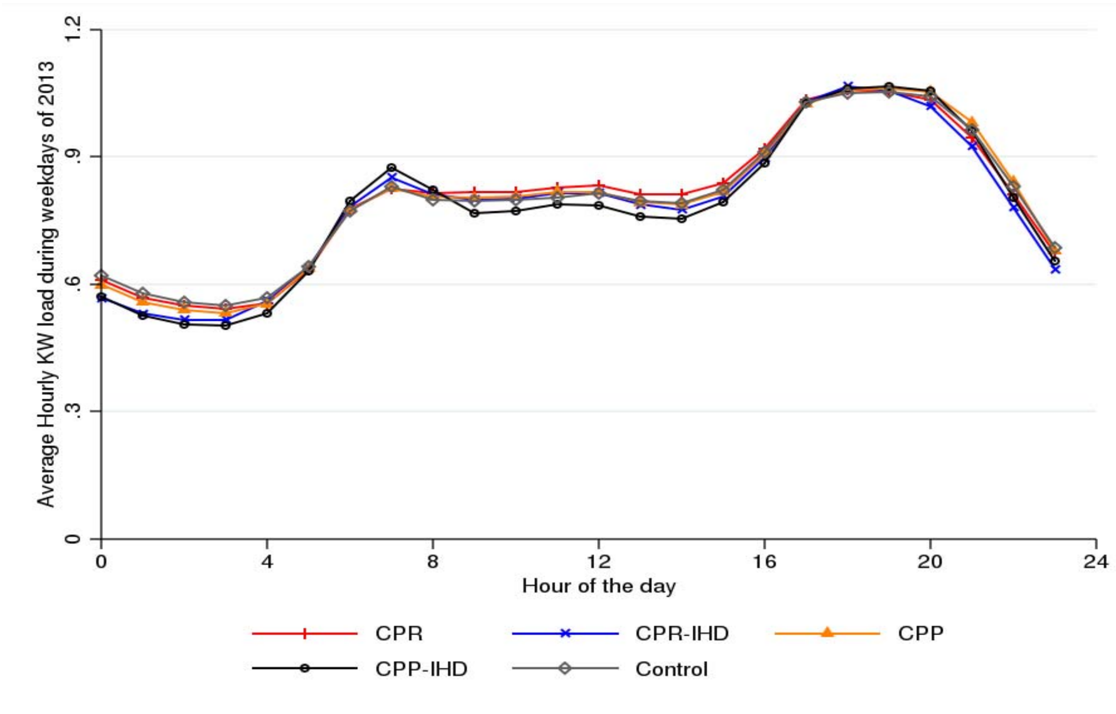

Figure 3.4. Mean weekday load pattern for the treatment and control groups during the study period in 2013.

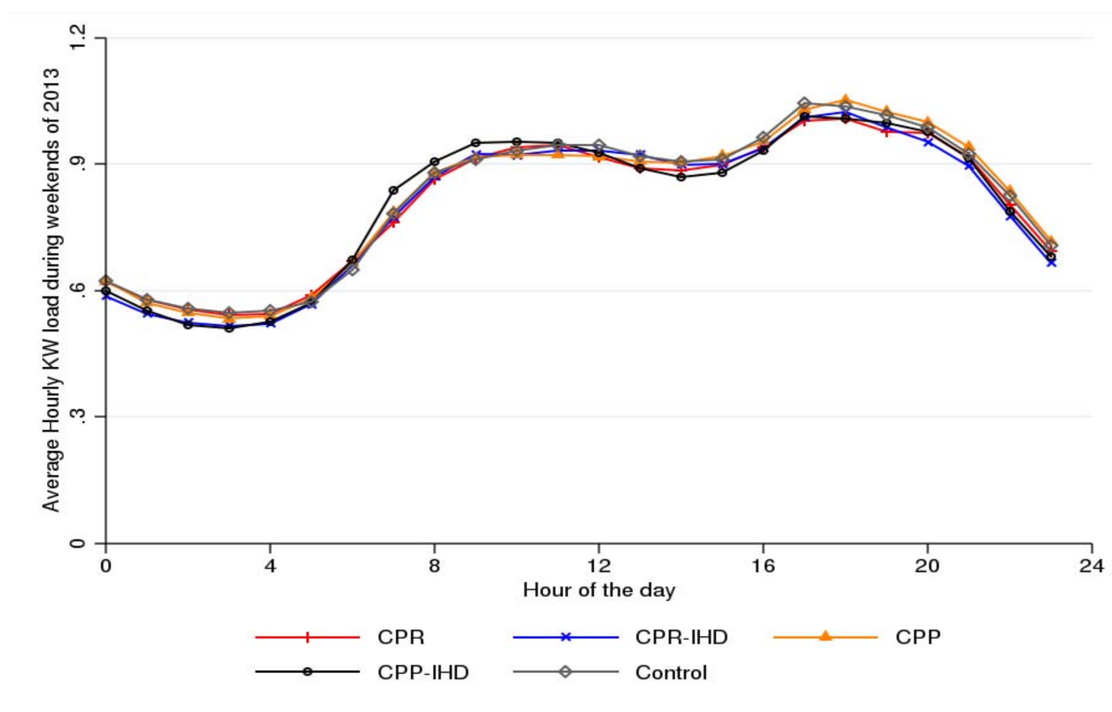

Figure 3.5. Mean weekend load pattern for the treatment and control groups during the study period in 2013.

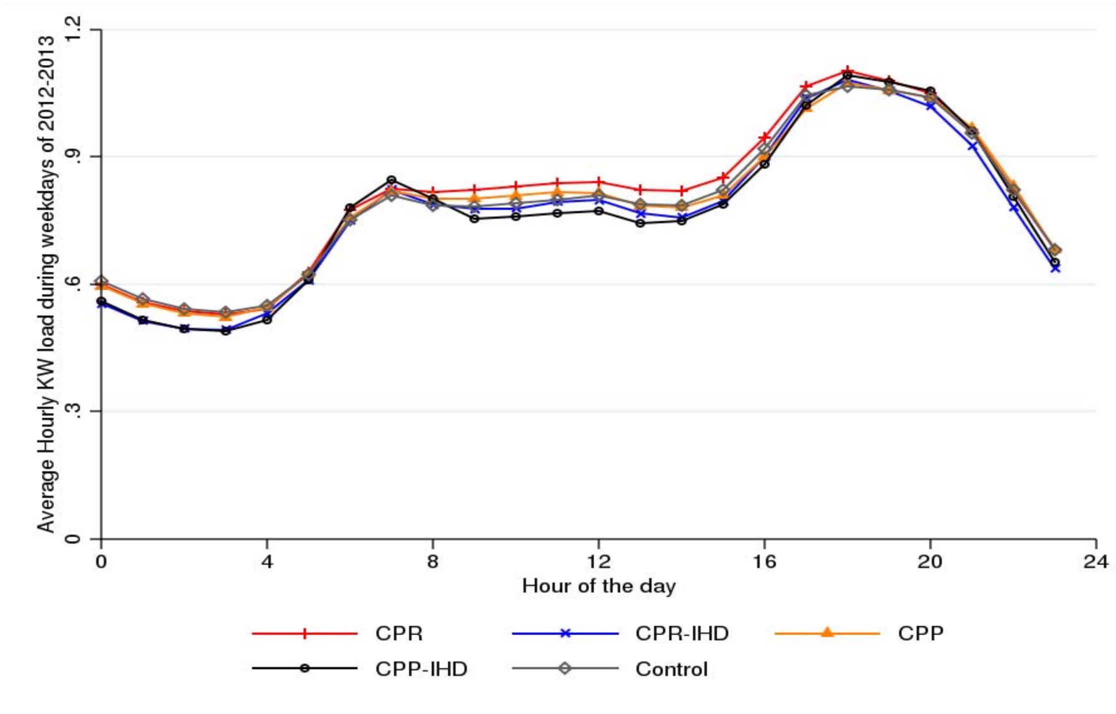

Figure 3.6. Mean weekday load pattern for the treatment and control groups during the study period in both 2012 and 2013.

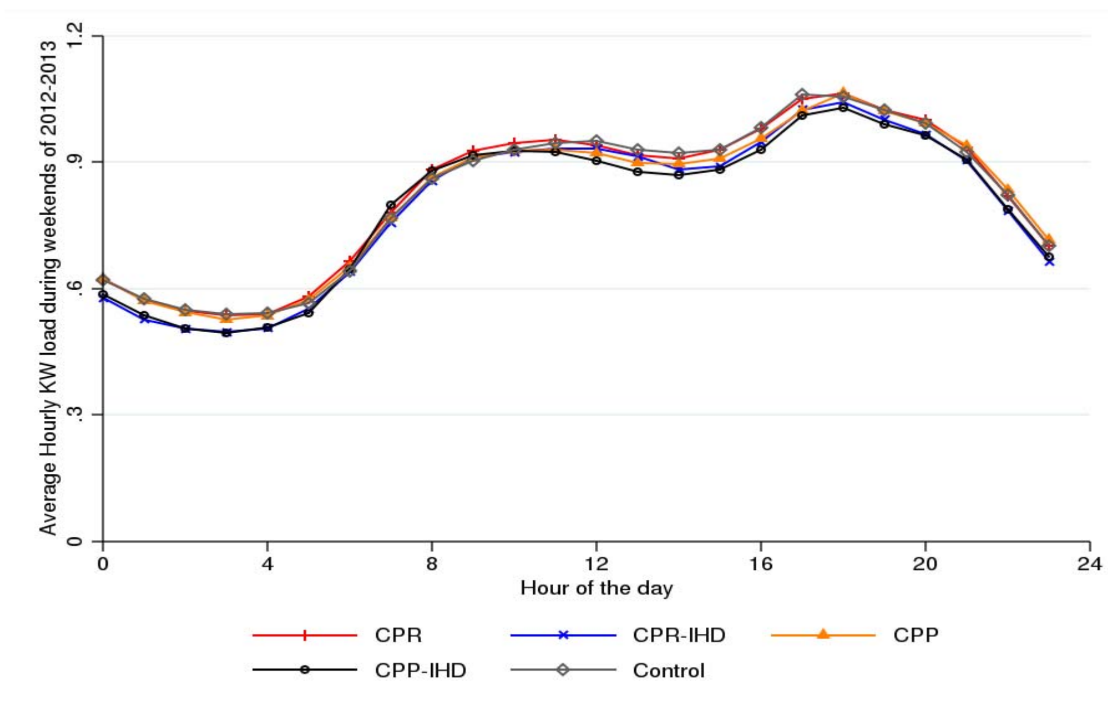

Figure 3.7. Mean weekend load pattern for the treatment and control groups during the study period in both 2012 and 2013.

4. Analysis Methods

This section describes the econometric models used to address the seven research questions outlined in Section 1. We note that a number of the research questions effectively share the same modeling approach.

4.1 Estimating the Impacts of Rate and Information Treatments on Average Hourly kW Consumption (Research Questions 1 through 3)

The first three research questions focus on the effects of the various rate treatments (CPR and CPP) and information treatments (in-home displays and notification of critical peak events) on hourly average kW consumption by the target population of GMP customers. A single modeling approach was used to address all three of these research questions.

We estimate the impact of rate and information treatments using a difference-in-difference regression model. This analysis procedure decomposes differences in observed electricity consumption between treatment and control groups into: (i) differences that would be observed during a non-event period on event days; and (ii) differences specifically during critical peak events.

Although the GMP Consumer Behavior Study was structured as a randomized control trial (RCT), we need to incorporate customers who declined to participate or dropped out in our analysis. To do this, we analyze the results as if they were generated through a "randomized encouragement" study design (RED), in which participants are actively encouraged to adopt a particular treatment. In our analysis, all customers who were recruited into a particular treatment were treated as if they were "encouraged" to adopt the treatment. Those that declined to participate during the initial survey contact (before actually being put on their rate and/or information treatment) were treated as the group that declined to take up the treatment. Given our data we are not able to identify specific customers who dropped out of the CPR treatment since such customers could effectively drop out by ignoring or not responding to peak time notifications. The percentage of CPP and CPP-IHD recruits that accepted the invitation to join the study were 80.75% and 82.89%, respectively.

The RED analysis proceeds in two stages. In the first stage, we run a difference-in-difference regression analysis as discussed above, to obtain coefficient and standard error estimates. Standard errors in the first stage are robust and clustered at the household level. The first-stage coefficients could be interpreted as those that would arise from a standard RCT design. The GMP consumer behavior study, however, does not follow a strict RCT design, since participants had the option to decline inclusion in one of the study's treatment groups or to drop out of the study at any time. In the second stage, we divide both the relevant CPP coefficients and standard error estimates by the percentage of customers in each CPP group that were recruited and signed up for specific treatments. This is known as the 'local average treatment effect' (LATE) method of accounting for the fact that customers were permitted to drop out of the study at the recruitment stage or at any point during the study (though most dropouts effectively happened during the recruitment phase, as customers declined to participate). Standard errors in the second stage are thus calculated by dividing the first-stage standard errors by the proportion of customers taking up each treatment. The difference-in-difference regression equation is shown in equation (2).

$$(2) \qquad y_{it} = \beta + \sum_j \beta_j T_{ij} + \sum_k \beta_k^{DB} DB_{ik} + \sum_k \beta_k^{DE} DE_{ik} + \sum_k \beta_k^{DA} DA_{ik}$$

$$+ \sum_j \sum_k \beta_{jk}^{DE(k)} T_{ij} DB_{kt} + \sum_j \sum_k \beta_{jk}^{DB(k)} T_{ij} DE_{kt} + \sum_j \sum_k \beta_{jk}^{DB(k)} T_{ij} DA_{kt}$$

$$+ \beta_t^{CD} CD_t + \beta_t^{HI} HI_t + \varepsilon_{it}$$

In equation (2), i, j, k, and t are indices for household, treatment group, event number, and hour number respectively. y_{it} is hourly average kW consumption. T_{ij} is an indicator variable for those customers i who were recruited to take up treatment j and deemed eligible. Note that customers who were not randomized into treatment group j cannot take up treatment j; thus by design the rate of customer acceptance of treatment j by customers that were not encouraged is zero. DE_{kt} is an indicator variable for those hours when a critical peak event had been called. DB_{kt} and DA_{kt} are indicator variables for the six-hour period leading up to the start of an event (7 am to 1 pm on event days); and the six-hour period following the conclusion of the event (6 pm to midnight on event days). We index these variables using both k and t in order to estimate event-specific effects for each particular event. The weather variables included in this second regression model are the heat index at hour t (HI_t), the number of cooling degree-hours during hour t (CD_t). ε_{it} is the error term (unexplained variance) for customer i at time t. Each β is an estimated model parameter.

The intercept variable β essentially gives us the mean load in kW for the no-notification control group. The treatment parameter estimates β_j give the mean difference in load between group j and the no-notification control (the fixed-effect of treatment j) during the pre-treatment period. The parameter β_k represents the average impact of event k on all groups, essentially indicating how loads differed during event hours, on average. Finally, $\beta_{jk}^{DE(k)}$ and $\beta_{jk}^{DB(k)}$ give the estimated impact of treatment j during event k and before event k, after controlling for the other factors. These β_{jk} are the primary variables of interest in this analysis.

Equation (2) was estimated for all critical peak events simultaneously, and included all interval meter data available through the end of 2013 for customers recruited into the treatment groups (whether or not they decided to participate; and whether or not they dropped out of the study or remained in the study for its duration), as well as customers assigned to the control group. We also implemented a version of equation (2) that did not include an explicit weather variable, but instead limited the analysis for each event to days where temperatures were similar to the average temperature during the event period. We defined "similar" using criteria of +/- 5 degrees and +/- 10 degrees. Either way, the results were virtually identical to the results of the model presented in equation (2). We also estimated a version of equation (2) using customer-level fixed effects and got virtually identical parameter estimates for each of the β_{jk} parameters.

We also estimated a version of equation (2) that did not include event-specific effects, but rather included indicator variables *DB, DE* and *DA* that were equal to one during the six hours prior to any critical peak event in 2012 and 2013 (*DB*); equal to one during the hours of any critical peak event in 2012 and 2013 (*DE*); and equal to one during the six hours immediately following any critical peak event in 2012 and 2013 (*DA*). This model specification is shown in equation (2a).

$$(2a) \qquad y_{it} = \beta_{control} + \sum_j \beta_j T_{ij} + \beta^{DB} DB_t + \beta^{DE} DE_t + \beta^{DA} DA_t$$
$$+ \sum_j \beta^{DB(T)} T_{ij} DB_t + \sum_j \beta^{DE(k)} T_{ij} DE_t + \sum_j \beta^{DA(k)} T_{ij} DA_t$$
$$+ \beta_t^{CD} CD_t + \beta_t^{HI} HI_t + \varepsilon_{it}$$

The regression results that we report in Section 5 are those from equation (2a), i.e., the version of the regression that uses treatment-specific effects rather than customer-level fixed effects; and uses the indicator variables covering all critical peak events rather than event-specific effects. The coefficients on the event indicator variables β^{DB}, β^{DE}, β^{DA}, $\beta^{DB(T)}$, $\beta^{DE(T)}$, and $\beta^{DA(T)}$ from equation (2a) would essentially represent the average effects from each of the fourteen events over the two years of the study period, but establishing statistical significance of customer response to critical peak events (the coefficients $\beta^{DB(T)}$, $\beta^{DE(T)}$, and $\beta^{DA(T)}$) is more straightforward using equation (2a). We did find that the load reduction response of customers in many of the rate and information treatments was statistically significant over the course of the fourteen events, but responses to individual events were not always statistically significant. Coefficient estimates from equation (2) are used in our analysis of persistence of customer response, also shown in Section 5.

4.2 The Impact of the CPR-CPP Transition (Research Question 4)

A unique aspect of the GMP consumer behavior study is the presence of a rate treatment that shifts from a Critical Peak Rebate in year one to a Critical Peak Price in year two. A consumer in this transition group would theoretically save the same amount of money for each average hourly kW of demand reduction under either the CPR or CPP, but the structure of the rate treatment may induce different behaviors. We examine whether this transition group behaved differently than other CPR customers in year one and other CPP customers in year two by estimating versions of equation (2) that: (a) are for only year one or year two; and (b) separate out the transition group as a distinct treatment. In the analysis described in Section 4.1, customers in this transition group were counted as CPR customers during year one and CPP customers during year two (since that represented the rate they were on at the time). In our analysis of the transition group in particular, we consider the transition customers (i.e., groups 5 and 6 from Table 2.3) as distinct treatments and estimate separate treatment-level coefficients and treatment-interaction effect coefficients.

4.3 Persistence of Response (Research Question 5)

We examine persistence of response across three different time horizons – within critical event period, across critical events, and between year 1 and year 2. We use a different regression framework than in the previous section to estimate persistence across all treatment groups simultaneously, and we use the coefficient estimates from equation (2) to estimate group-specific persistence across critical peak events.

A group of events called during five consecutive days (July 15 through 19) is of particular interest. This was a particularly warm week in Vermont, with daytime temperatures in the upper 80s to lower 90s. We use this opportunity to examine more closely whether consumers on rate or information treatments responded consistently to each of the five consecutive events, or whether there was some time-variance in response levels within the week. We are particularly interested in whether any evidence of response fatigue arose among consumers during this time period (i.e., whether the average kW reduction during critical peak events declined as events were called on more consecutive days).

We then utilize equation (3) to assess the persistence of response within individual events.

$$(3) \qquad y_{it} = \alpha_i + \alpha_1 HI_t + \alpha_2 DE \sum_t H_t HI_t + \alpha_3 DE \sum_t \sum_j T_{ij} H_t HI_t + \varepsilon_{it}$$

As with equation (2), i indexes households, j indexes treatment groups, and t indexes time. n_t and n_j indicate the number of time periods (hours) and treatment groups, respectively. HI is the heat index[7] and H is the hour of the day. The coefficient α_2 indicates the temperature controlled hourly change in electricity consumption in each hours within the critical peak event. Similarly, α_3 indicates the hourly change in customers' electric load by treatment groups across the event period.

4.4 Financial Impacts of Critical Peak Usage Reductions (Research Question 6)

For each customer, we calculated the average per-event monetary savings by multiplying the calculated average hourly kW reduction (relative to the no-notification control group) by the duration of each event (six hours) and the relevant rate for each treatment group. During-event savings for the CPR groups are relatively straightforward to interpret, since those customers receive a credit on their monthly utility bill. During-event savings for CPP groups amount to an avoided

[7] For persistence analysis, we only use heat index to control for weather since all critical peak events were called during the summer months.

cost, since by reducing demand consumers avoid paying the higher energy charge during peak events. CPP customers also received a slightly lower rate during periods other than critical peak events. While we incorporate this lower rate in our calculations for critical peak event days, we did not incorporate savings from the lower rate during non-peak days since our focus is on savings associated with critical peak events. With an average weekday consumption level of approximately 20 kWh, the average CPP customer would have seen a bill reduction of approximately 8 cents per weekday from being on the CPP rate schedule during non-critical peak days, as compared to remaining on the Rate 1 schedule.

Since the estimated coefficients for the pre-event period were generally statistically significant (and many were positive in sign, indicating an increase in consumption during the pre-event periods), we then added the value of the pre-event change in consumption to the value of the during-event change in consumption. Where they were statistically significant, we also accounted for increases or decreases in demand during the six-hour period immediately following the conclusion of the peak event (i.e., 6 pm to midnight). In many cases, pre-event and post-event consumption increases offset during-event consumption declines (though not always completely). We note that these calculations effectively use consumption by the no-notification control group as the baseline for determining kW reductions and associated monetary savings. These savings are expressed mathematically in equation (4).

(4)
$$S_{CPP,k} = \underbrace{\left(6 \times \beta_k^{DB(k)} \times \$0.144\right)}_{pre-event} + \underbrace{\left(6 \times \beta_k^{DE(k)} \times \$0.60\right)}_{during-event} + \underbrace{\left(6 \times \beta_k^{DE(k)} \times \$0.144\right)}_{post-event}$$
$$S_{CPR,k} = \underbrace{\left(6 \times \beta_k^{DB(k)} \times \$0.148\right)}_{pre-event} + \underbrace{\left(6 \times \beta_k^{DE(k)} \times \$0.60\right)}_{during-event} + \underbrace{\left(6 \times \beta_k^{DE(k)} \times \$0.148\right)}_{post-event}$$

4.5 Impacts of Information Treatments on Monthly Energy (kWh) Consumption (Research Question 7)

In this section we describe our method for assessing whether the presence of the IHD, which gives consumers continuous feedback on electricity usage (as long as the customer is paying attention to the IHD), has the effect of lowering electricity usage during periods other than declared critical peaks. Our analysis compares monthly energy usage (monthly kWh) for customers with and without IHDs, during the periods before and after the IHDs were installed. We first construct a monthly kWh variable for each customer by summing the observed hourly average kW readings for each customer over the course of a month. The pre-IHD period is defined as March 2012 through July 2012, while the IHD period is defined as August 2012 through December 2013. Since customers received their IHDs over the course of the month of August, this definition is somewhat inexact. Since the IHDs were not installed by GMP, however, we have no way of pinpointing a specific date that an individual customer started using their IHD.

We run a differences-in-differences type of panel regression using all customer data (including those who declined to participate) over the period March 2012 through December 2013. The two relevant differences examined in this analysis are: (i) monthly kWh usage by customers with and without IHDs; and (ii) monthly kWh usage before and after IHDs were mailed to customers in the relevant treatment groups. The specific equation that we estimate is shown in equation (5):

$$(5) \qquad Y_{it} = \beta_0 + \beta_1 CD_t + \delta_1 IHD + \delta_2 IHD \times AUG12$$

In equation (5), Y_{it} measures monthly kWh consumption by customer i during month t; CD_t is a measure of cooling degree days during month t; IHD_i is an indicator variable identifying those customers with an IHD; and AUG12 is a dummy variable indicating the period starting in August 2012, when the IHDs were delivered to customers. ε_{jt} is the error term. The weather variable we use is the total number of cooling-degree days during each month.

5. Results

This section presents the results of the load impact analyses described in Section 4, following the progressions of the research questions laid out in Section 1 (and analysis frameworks described in Section 4).

5.1 Load Impacts of Rate, Information and Notification Treatments (Research Questions 1 through 3)

The first three research questions focus on the rate treatments (CPR and CPP); information treatments (customers who received IHDs versus customers who did not); and notification treatments (i.e., the control group of customers that received no notification of peak-time events). The same regression framework, shown in equation (2) in Section 4.1, is used to address all three research questions so we present the integrated results in this section.

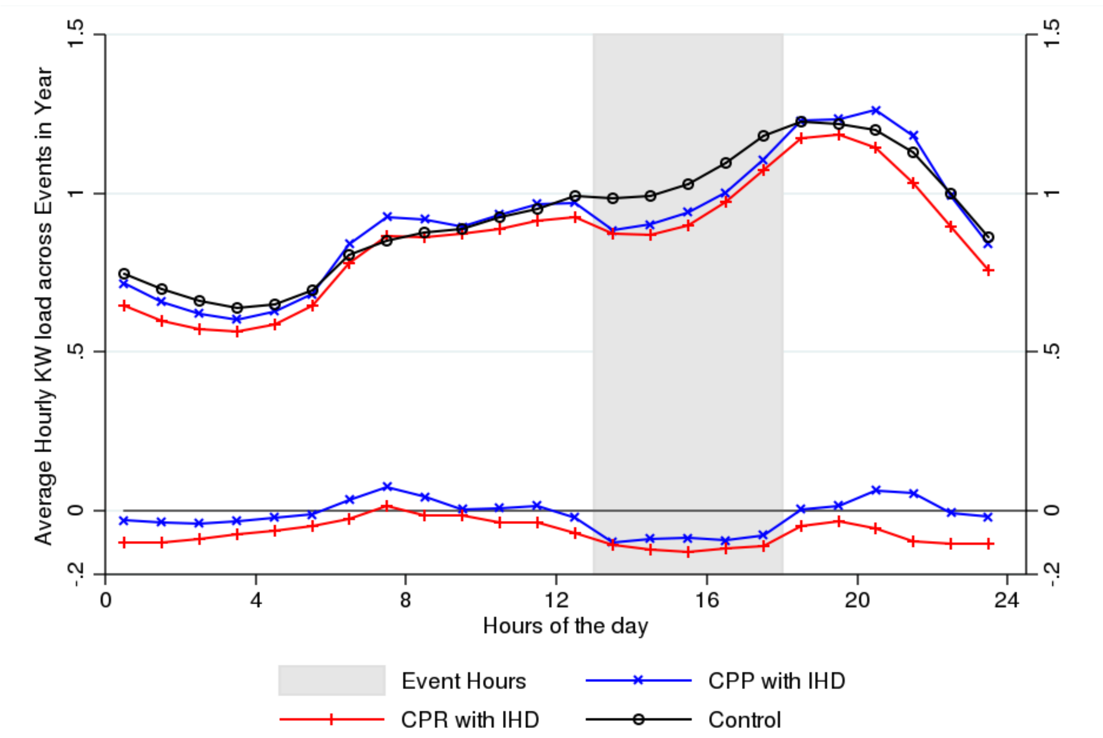

Figure 5.1. Average hourly kW consumption (top set of lines) and difference from the no-notification control group (bottom set of lines, equal to treatment minus control) across all critical peak events in 2012 and 2013 for all customers in a treatment group that included an In-Home Display.

In order to visualize customer loads during the hours before during and after the critical peak events, we plotted hourly average kW consumption for each of the rate and information treatment groups. Figure 5.1 shows these load profiles, as well as differences between load profiles for the treatment and control groups, averaged over all event horizons, for all treatment groups without the IHD and the no-notification control group (simply denoted "control" in the figure). Figure 5.2 shows the same information but for treatment groups that did not include the IHD. Figures 51 and 5.2 were constructed using hourly averaging of actual 15-minute interval meter data at the customer level (in other words, the figures represent actual load shapes and not modeled load shapes).

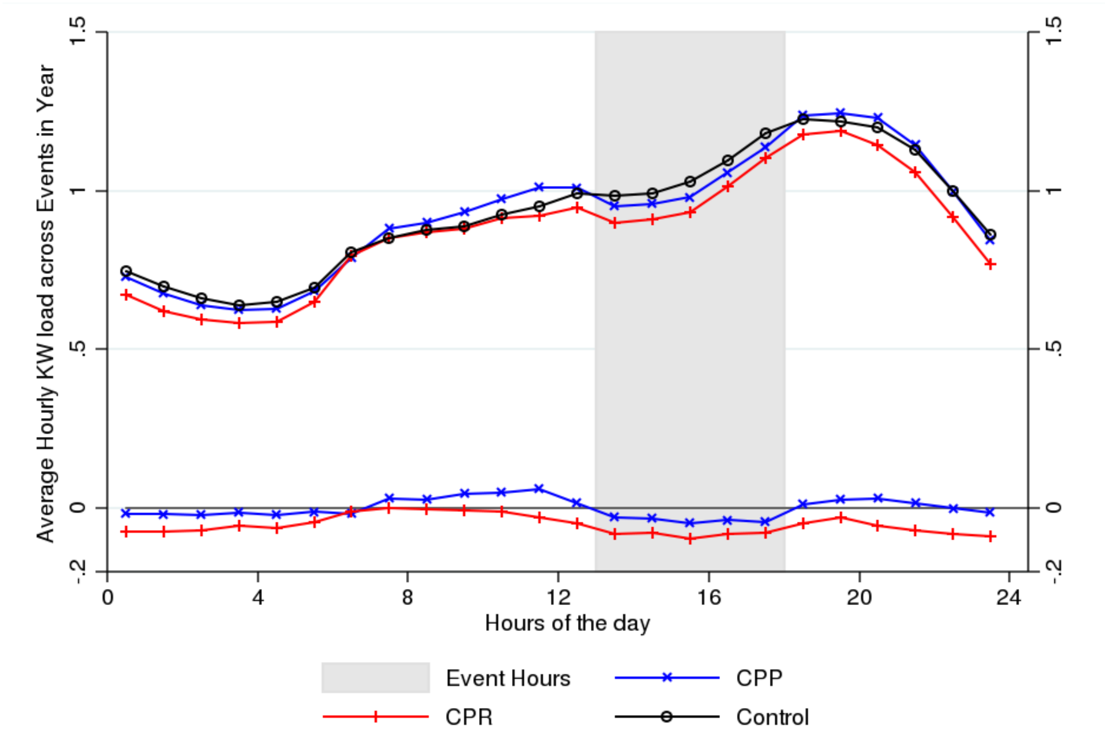

Figure 5.2. Average hourly kW consumption (top set of lines) and difference from the no-notification control group (bottom set of lines, equal to treatment minus control) across all critical peak events in 2012 and 2013 for all customers in a treatment group that did not include an In-Home Display.

Figures 5.1 and 5.2 visually suggest that customers in rate and technology treatment groups responded by reducing consumption during declared critical peak events. Customers in some treatment groups also appear to have undertaken pre-emptive measures to reduce electricity consumption (both in magnitude and relative to the no-notification control group) between two and six hours prior to the onset of critical peak events. Of these groups, customers on CPP treatments generally started this pre-emptive consumption response earlier than customers on the CPR rate.

Figures 5.3 through 6 show average load shapes during critical peak event days for 2012 and 2013 separately. In each of the figures, the top set of curves represents the average load shapes, while the bottom set represents the simple difference in average hourly kW consumption between each treatment group and the no-notification control group. While there are differences in the load shapes from year to year (primarily due to differences in weather conditions during critical peak event days), the figures suggest that the IHD groups exhibited a somewhat larger response during critical peak hours in both study years, compared to the non-IHD groups. Consumers on the CPP rate treatment also generally exhibited larger levels of response during critical peak periods relative to consumers on the CPR rate treatment.

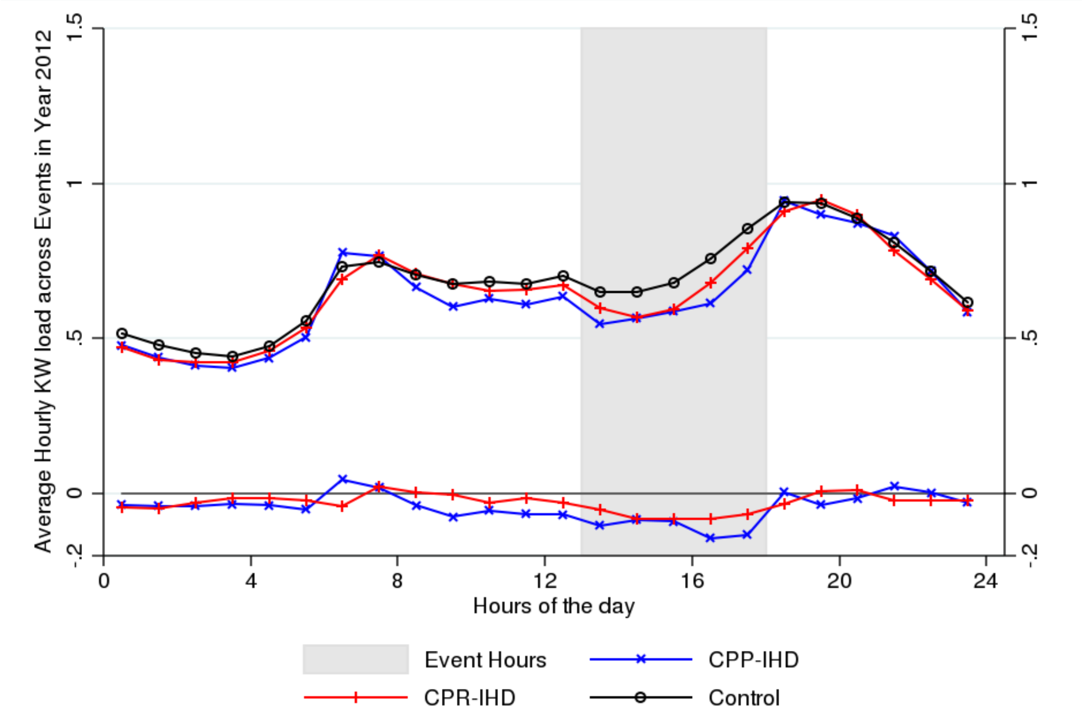

Figure 5.3. Average load shapes for IHD-enabled customers and the no-notification control group during critical peak event days in 2012.

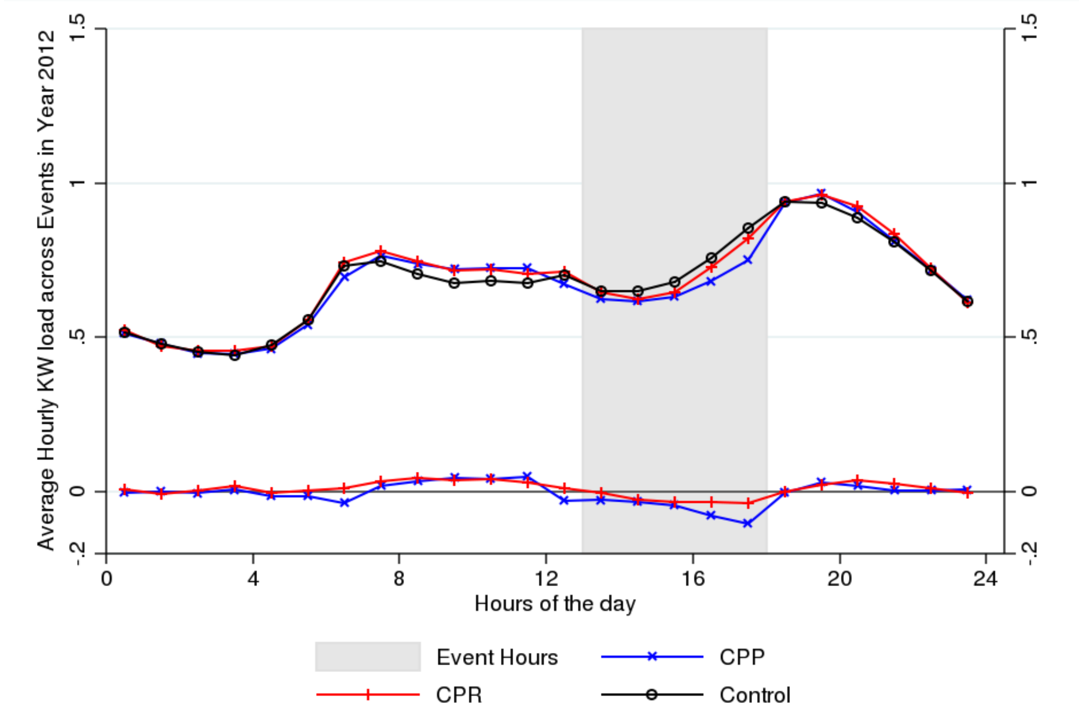

Figure 5.4. Average load shapes for non-IHD customers and the no-notification control group during critical peak event days in 2012.

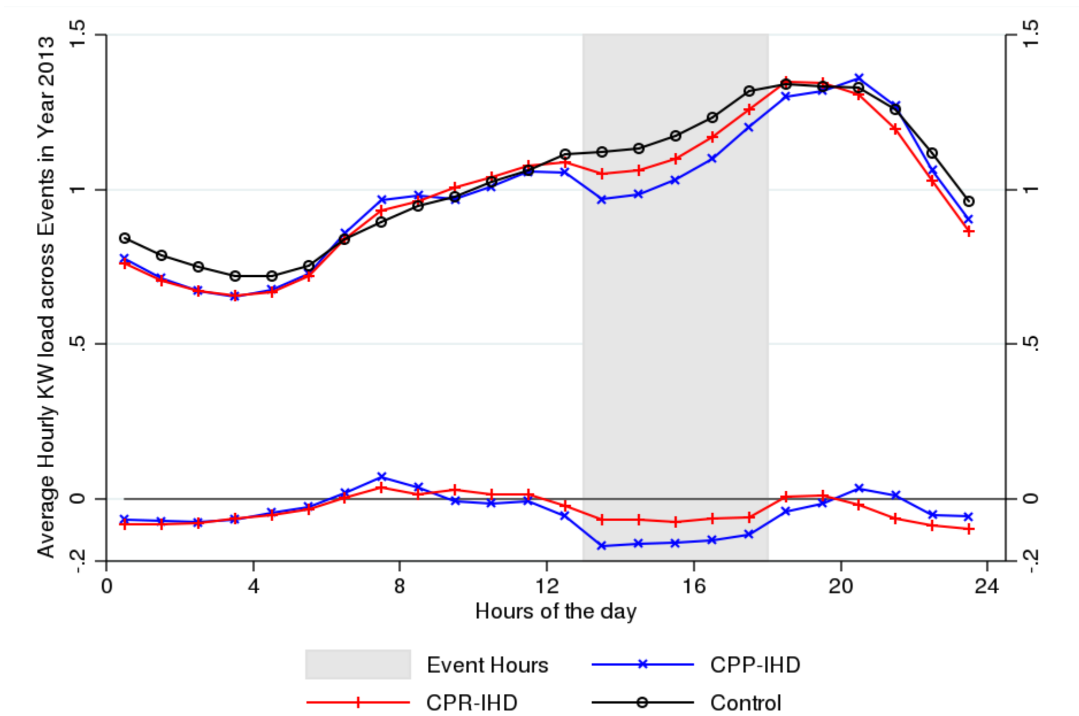

Figure 5.5. Average load shapes for IHD-enabled customers and the no-notification control group during critical peak event days in 2013.

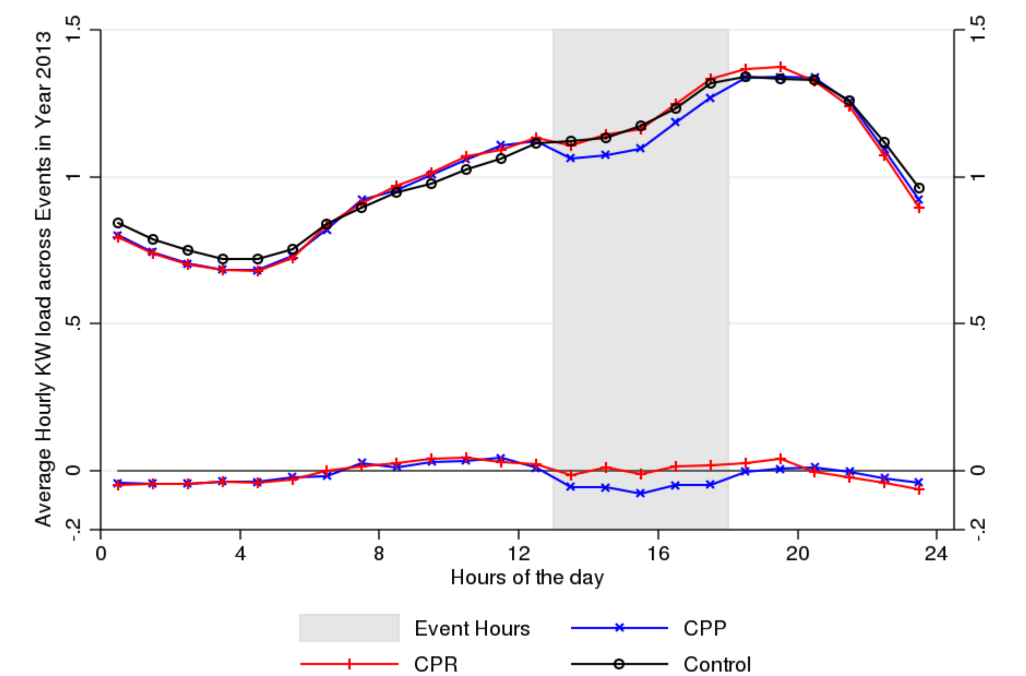

Figure 5.6. Average load shapes for non-IHD customers and the no-notification control group during critical peak event days in 2013.

Figure 5.7 and Table 5.1 summarize the results from the regression model in equation (2a).[8] This regression model is run for both years 2012 and 2013 together, and does not utilize event-specific fixed effects or event-specific interaction effects with individual treatments. The analysis in this section thus provides a summary of how consumers on each rate and information treatment responded to critical peak events called across the two years of the study. More detailed analysis of customer response to individual events can be found in Section 5.3, where we present the results of the model in equation (2).

In summary, we find statistically significant usage reductions for most of the rate and technology treatment groups during declared critical peak events in 2012 and 2013. Figure 5.7 shows the average per-customer hourly kW reduction for each treatment group, based on the estimates of the regression model, plus a 95% confidence interval for each estimate, based on the standard errors of the parameter estimates. Average hourly kW savings for customers on time-differentiated rate and information treatments during critical peak events (relative to the no-notification control group) ranged from 5.3 to 7.4 percent for customers on all treatments except the CPP-IHD treatment. That treatment group saw a larger average usage reduction during peak events of approximately 14 percent. The two IHD groups exhibited the largest declines in average hourly kW consumption. Average hourly

[8] Many of the regression models that we estimated contained a large number of coefficients. We present summary information regarding the magnitude and statistical significance of the load impact coefficients of interest in the main body of this report. The full regression output from each equation estimated is shown in Appendix A1 (Section A1.2).

kW reductions for the notification-only group (group 7) were similar to the reductions exhibited by the CPR group and the CPP/CPR-IHD groups.

We performed pairwise Wald parameter restriction tests to assess whether any differences in observed load impacts between treatment groups are statistically significant. The results of this analysis are shown in Table 5.2 for the five parameters $\beta^{DE}_{CPR}, \beta^{DE}_{CPR-IHD}, \beta^{DE}_{CPP}, \beta^{DE}_{CPP-IHD}$ and $\beta^{DE}_{Flat/Notification}$. Because of the large number of observations in our sample (approximately 26 million, including all customers for all hours in both years), the relevant F critical value would be 3.84 for a significance level of α=0.05. We thus reject the hypothesis of pairwise equality for the rate and information treatments employed in this study.

We do observe, however, that some rate and information treatments induced similar levels of response during the study period (even if those small differences are statistically significant). Notably, Figure 5.7 suggests that over the course of the study period, simply receiving notifications about critical peak events was comparably effective to the rate and information treatments (with the exception of the CPP-IHD group) in reducing consumption during declared peak event periods. The CPR+IHD and CPP without IHD treatments also elicited very similar reductions in peak-time demand.

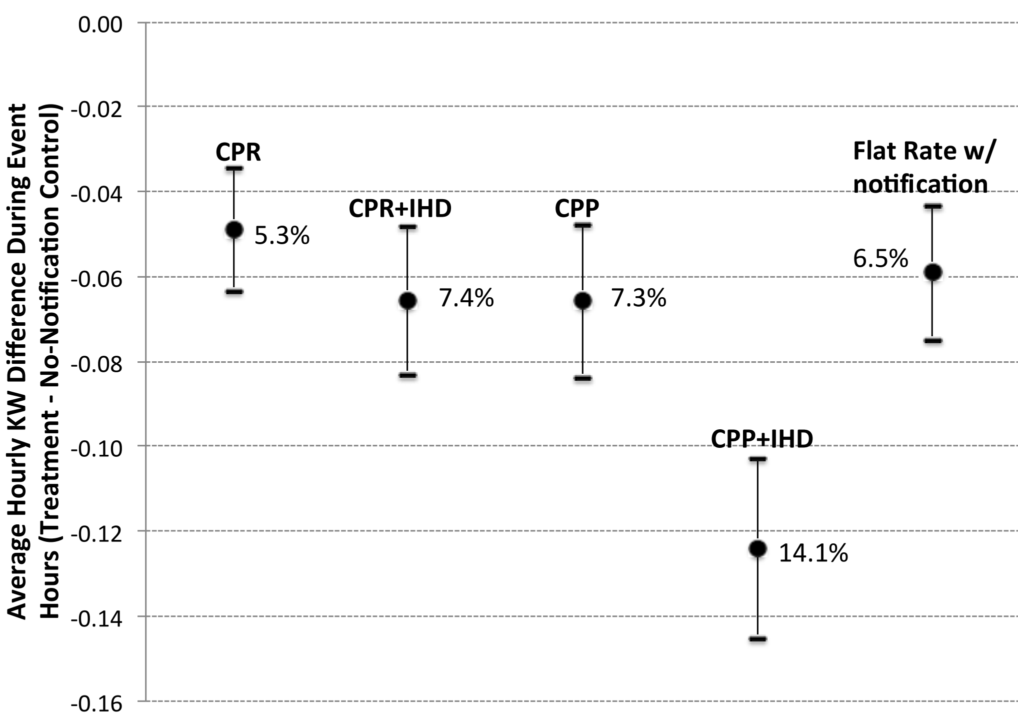

Figure 5.7. Estimated peak-hour reductions for each rate and information treatment group, relative to the no-notification control. The markers indicate average estimated reduction (in kW and percentage terms) while the lines above and below the markers indicate a 95% confidence interval.

Table 5.1. Regression results from Equation 2(a), 2012 and 2013 events

Treatment	Before	During	After
Flat Rate w/ Notification	0.029***	-0.006***	-0.039***
CPR	-0.010	-0.049***	-0.036***
CPR w/IHD	0.008	-0.066***	-0.026***
CPP	0.033***	-0.063***	0.002
CPP w/ IHD	0.041***	-0.124***	0.013

*note: *** p<0.01, ** p< 0.05, * p<0.1*

Table 5.2 shows the results of these pairwise Wald tests. For all treatment pairs, we reject the null hypothesis (at the α=0.05 significance level) that the load impacts of any treatment are identical to those of any other treatment.

Table 5.2. Pairwise Wald tests for coefficient equality

	CPR	CPR w/IHD	CPP	CPP w/IHD	Flat Rate w/Notification
CPR	N/A				
CPR w/IHD	128.12	N/A			
CPP	64.12	92.29	N/A		
CPP w/IHD	492.78	947.57	1430.16	N/A	
Flat Rate w/Notification	256.09	61.15	12.33	558.79	N/A

5.2 The Impact of the CPR-CPP Transition Group (Research Question 4)

In this subsection we focus on load impacts for the CPR-CPP transition group (with and without IHDs). Customers in this rate treatment group were placed on CPR for year one, and then were recruited to transition to CPP for year two. Customers who were not willing to transition to the CPP were transitioned back to Rate 1 (the GMP flat residential rate). Customers in the transition group were not informed that they would be recruited to switch from CPR to CPP until that recruitment actually happened at the end of the study's first year.

Not all customers in the transition groups agreed to transition from the CPR to the CPP, although the decline rates for customers in both transition groups (with and without the IHD) were similar. 22% of customers in the CPR-CPP transition group that also had the IHD declined to transition to the CPP beginning in 2013 and were thus moved back to Rate 1. 20% of customers in the transition group without the IHD declined to transition to the CPP beginning in 2013. The decline rates observed in the transition group are qualitatively similar to the decline rates observed among customers initially recruited to the CPP rate at the beginning of the study. During initial recruitment, 19% of the qualified customers assigned to the

CPP+IHD group declined to participate, while 26% of the qualified customers assigned to the CPP group (without IHD) declined to participate.

Figure 5.8 shows the daily average kW consumption (top set of curves) and differences from the no-notification control group (bottom set of curves) for each IHD-enabled customers in each of the rate treatments. Figure 5.9 shows the same information for customers in each of the rate treatments that were not sent the IHD. Both Figures 5.8 and 5.9 are based on actual data (i.e., not modeled load shapes). Since they were not informed about the rate transition at the beginning of the study, customers in the transition group during year one should have believed that they were simply being placed on the CPR rate treatment. We would thus expect that customers in the transition group would exhibit similar response to critical peak events in year one as the group that remained on the CPR rate treatment for both study years. During year two we did observe differences between the transition group and the group placed on either rate treatment (CPR or CPP) for both of the study years.

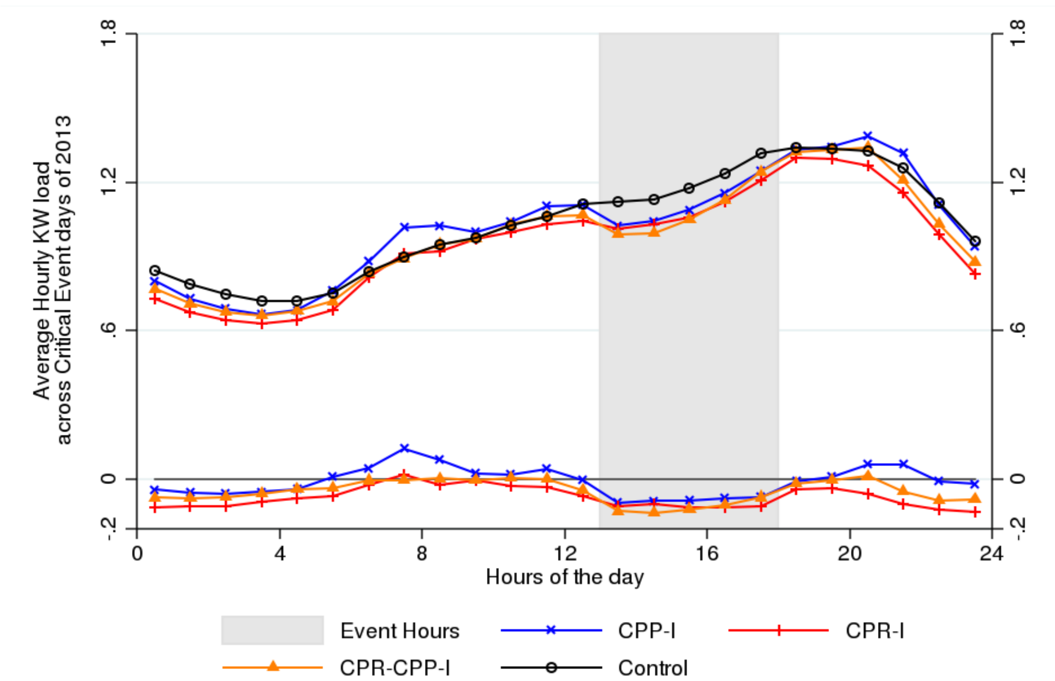

Figure 5.8. Average hourly kW consumption (top set of curves) and differences between treatment and the no-notification control (bottom set of curves) for IHD-enabled customers across all critical peak days in 2013. The shaded region represents the duration of the critical peak event.

Figure 5.8 suggests that IHD-enabled customers in the transition group reduced usage similarly to those in the "pure" CPR and CPP group during peak events. In the period prior to the start of a peak event, we observed a slight increase in consumption for CPP customers that we did not observe for the transition group.

The differences in behavior among customers in the transition group without the IHD are more noticeable. Figure 5.9 suggests that this customer group, on average, had higher average kW consumption than any other treatment group or the control group on event days. This difference persisted (on average) during the pre- and post-event period as well as during the critical peak event itself. As shown in Figure 5.9, the increase in consumption among customers in the non-IHD transition group, relative to consumption in other rate treatment groups or the control group, is most pronounced during the pre-event period.

On non-event days, we find evidence that the CPR-CPP group exhibited higher average consumption levels than the no-notification control group. In a simple comparison of means, we calculated a two-sided t-test statistic of 63.18, well above the α=0.05 critical value of 1.96, suggesting that the observed average consumption difference between the CPR-CPP group and the control group is statistically significant and that the CPR-CPP group exhibited a higher level of baseline consumption than the control group. Since the randomized assignment did not produce a CPR-CPP transition group with mean consumption levels equal to that of the control group, it is difficult to tell whether the higher consumption levels on event days (observed in Figures 5.8 and 5.9) really suggest that the CPR-CPP group increased consumption relative to the control group during event hours, or whether the observed higher levels of consumption are an artifact of the randomization.

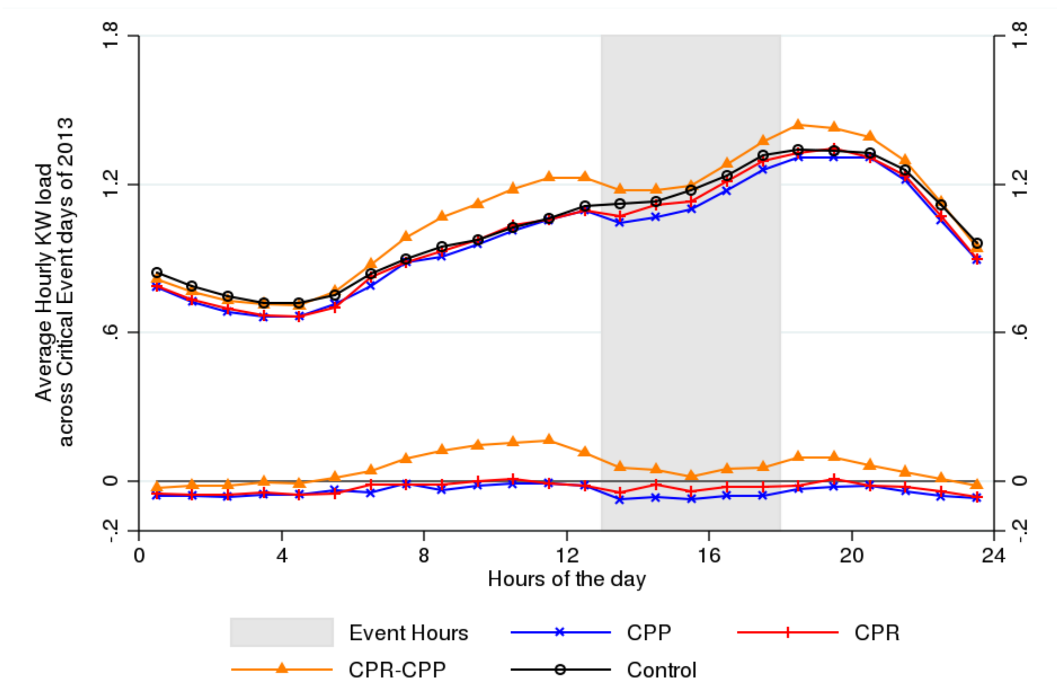

Figure 5.9. Average hourly kW consumption (top set of curves) and differences between treatment and the no-notification control (bottom set of curves) for non-IHD customers across all critical peak days in 2013. The shaded region represents the duration of the critical peak event.

To evaluate whether the differences that we observed through visual inspection of the load shapes in Figures 5.8 and 5.9 are statistically significant (after controlling for weather and other variables), we use the estimated load impact coefficients from equation (2), averaged over each of the events in 2012 and 2013, including the transition groups as separate treatments. The full regression output is shown in Table A2 in the appendix. Table 5.3 shows these load impacts in terms of average hourly kW reductions during peak events (corresponding to the group-event interaction coefficients in equation 2a), while Table 5.4 shows the load impacts in terms of percentage reductions (relative to the no-notification control group). Pairwise Wald tests for coefficient equality show statistically significant differences in average load impact during critical peak events in 2012 for the CPR-CPR and CPR-CPP groups as well as the CPR-CPR-IHD and CPR-CPP-IHD groups. The Wald test statistic for the CPR-CPR/CPR-CPP group comparison is 30.25, while the test statistic for the CPR-CPR-IHD/CPR-CPP-IHD group comparison is 86.61. Both are well above the $F(1,\infty)$ critical value of 3.28, indicating that we reject the null hypothesis of equal load impacts.

Table 5.3: Summary of load impacts (average hourly kW), 2012 and 2013

	2012			2013		
Treatment	**Before**	**During**	**After**	**Before**	**During**	**After**
Flat Rate w/ Notification	-0.058	-0.030	0.001	-0.034	-0.073	-0.052
CPR-CPR	-0.042	-0.048	-0.005	0.010	-0.019	-0.014
CPR-CPR w/IHD	-0.024	-0.069	0.031	0.022	-0.086	-0.052
CPP-CPP	-0.014	-0.067	0.016	-0.005	-0.067	-0.034
CPP-CPP w/ IHD	-0.078	-0.106	0.024	0.032	-0.130	-0.006
CPR-CPP	-0.039	-0.077	-0.011	0.151	0.013	0.017
CPR-CPP w/ IHD	-0.047	-0.056	-0.040	0.016	-0.147	-0.031

Table 5.4: Summary of load impacts (percentage reductions relative to no-notification control; negative numbers indicate reductions), 2012 and 2013

	2012			2013		
Treatment	**Before**	**During**	**After**	**Before**	**During**	**After**
Flat Rate w/ Notification	-6.45%	-3.38%	0.15%	-3.81%	-8.18%	-5.81%
CPR-CPR	-4.72%	-5.29%	-0.57%	1.06%	-2.17%	-1.52%
CPR-CPR w/IHD	-2.65%	-7.64%	3.41%	2.41%	-9.55%	-5.77%
CPP-CPP	-1.51%	-7.42%	1.77%	-0.56%	-7.46%	-3.79%
CPP-CPP w/ IHD	-8.67%	-11.80%	2.68%	3.56%	-14.48%	-0.67%
CPR-CPP	-4.29%	-8.57%	-1.27%	16.86%	1.40%	1.90%
CPR-CPP w/ IHD	-5.29%	-6.24%	-4.40%	1.82%	-16.40%	-3.43%

The average load impacts shown in Tables 5.3 and 5.4 are consistent with what we observed through visual inspection of average load shapes during critical peak events. A larger average hourly load reduction (roughly 2% larger) was observed in 2013 for customers in the CPR-CPP transition group with the IHD during critical peak event hours relative to the pure CPP group with the IHD. Consumers in the

CPR-CPP transition group without the IHD were observed to consume more during critical peak event hours in 2013, relative to the no-notification control group and the pure CPP group without the IHD, although these differences were not always statistically significant. Because of some statistically significant differences in hourly kW usage between the CPR-CPP transition group without the IHD and other treatment groups or the control, the results for the non-IHD transition group should be taken with some caution. The differences in non-event consumption for the non-IHD group are considered more closely in Sec. 5.2.1.

In the hours preceding the start of a critical peak event in 2013, both transition groups (those with and without the IHD) increased average hourly kW loads relative to both the no-notification control group and the pure CPP group, with the non-IHD transition group exhibiting a pre-event increase roughly 0.1 kW larger than the IHD-enabled transition group. This increase in average hourly kW consumption prior to the critical peak event hours is statistically significant for the transition group, whereas it is not for either the pure CPP or CPP with IHD groups. In the hours following the conclusion of critical peak events, consumers in the non-IHD transition group were observed to increase consumption (relative to the no-notification control group) by statistically significant levels; the transition group without the IHD increased average kW usage by 0.017 kW in the hours following the completion of critical peak events. The IHD-enabled transition group exhibited a decline in consumption of 0.03 kW (relative to the no-notification control group) in the hours following the conclusion of critical peak events.

The increase in consumption during the hours prior to the start of critical peak events has implications for bill savings among transition-group customers. Applying equation (6) to the transition group customer regression analysis, we found that transition group customers without IHDs saw bill increases of around 15 cents per critical peak event in 2013.

5.2.1 Further Analysis of the Non-IHD CPR-CPP Transition Group

Because the CPR-CPP transition group without IHDs exhibited a statistically significant higher level of average consumption during non-event days, the regression results in Tables 5.3 and 5.4 should be taken with some caution. They may suggest that this group actually did use more electricity during critical peak event periods or the results may be an artifact of the randomization. To investigate this finding further, we ran second regression using data from just the CPR-CPP group, in order to test whether this group of customers reduced usage during critical peak events in 2012 and 2013, relative to average use during non-event hours. The regression equation that we estimate is shown in equation (6):

$$(6) \qquad Y_{it} = \beta_0 + \beta_1 HI_t + \beta_2 CD_t + \beta_3 Event_t + \varepsilon_{it},$$

where Y_{it} is average kW consumption during hour t for CPR-CPP customer I; HI_t and CD_t are heat-index and cooling-degree-day weather variables; and $Event_t$ is an indicator variable for all critical peak event hours. We ran separate versions of equation (6) for 2012 events and 2013 events. The coefficient β_3 in equation (6) measures how the CPR-CPP group lowered consumption, relative to its non-event-day average (β_0), during critical peak events. While this comparison does not carry the same explanatory weight as the comparison between during-event consumption for the CPR-CPP group and consumption for a randomly-selected control group with the same mean level of non-event-day consumption as the treatment, it may nonetheless be instructive.

The detailed regression output from equation (6) is shown in Appendix 1. We estimated a value of -0.197 for β_3 during 2012 and a value of 0.005 for 2013. Our coefficient estimate for 2012 is statistically significant whereas our coefficient estimate for 2013 is not statistically significant. This suggests that, relative to usage within that group on non-event days, CPR-CPP customers did reduce usage by close to 0.2 kW during critical peak event hours in 2012 (a reduction of 17%) but exhibited no statistically significant change in consumption during 2013 events. While the CPP-CPR group did exhibit larger average consumption levels than the control group used in this study, there is some evidence that this treatment group reduced usage during critical peak event hours while customers were on the CPR rate in 2012, but not while they were on the CPP rate in 2013.

5.3 Persistence of Load Impacts (Research Question 5)

As described in Section 4.3, we estimated persistence of response across events, and across hours within events.

Tables 5.5 through 5.8, along with Figure 5.10 show the results of our persistence analysis on an event-to-event basis. For this analysis we examine the behavior of individual treatment groups more closely, using the estimated group-event interaction effects from equation (2) - the $\beta_{jk}^{DB(k)}, \beta_{jk}^{DE(k)}$ and $\beta_{jk}^{DA(k)}$ coefficients.

Tables 5.5 and 5.6 show the estimated coefficient for each group and for each event in 2012,. This represents the average hourly kW reduction and percentage reduction as compared to the no-notification control group. Customer responses to critical peak events during 2012 were variable, with little evidence of persistence across events (see also Figure 5.10, below). Customers on the CPP rate in the first year tended to exhibit usage reductions during critical peak events that were larger in magnitude and more frequently statistically significant than customers on the CPR rate. We also note that for events in 2012, consumption by customers in rate and information treatment groups during the hours following the completion of a critical peak event was generally not statistically different from consumption by the no-notification treatment group.

Table 5.5. Estimated Group-Event Interaction Coefficients for 2012 events, in average kW reductions compared to no-notification control

	9/14/12			9/21/12		
Treatment	Before	During	After	Before	During	After
Flat Rate w/ Notification	-0.045**	-0.011	0.000	-0.093	-0.036	0.034
CPR-CPR	-0.049**	-0.078**	-0.035	-0.055**	-0.015	0.019
CPR-CPR w/IHD	-0.053	-0.147	0.050	-0.042	-0.021	0.046
CPP-CPP	0.023	-0.067	-0.007	-0.042**	-0.058*	0.062*
CPP-CPP w/ IHD	-0.028	-0.143***	-0.015	-0.109***	-0.097**	0.007
CPR-CPP	-0.019	-0.081	-0.029	-0.048**	-0.099***	-0.021
CPR-CPP w/ IHD	-0.048	-0.115**	-0.036	-0.105***	-0.083	-0.032

	9/25/12			10/5/12		
Treatment	Before	During	After	Before	During	After
Flat Rate w/ Notification	-0.037	-0.028	-0.019	-0.056**	-0.047	-0.009
CPR-CPR	-0.072***	-0.054	0.004	0.006	-0.043	-0.009
CPR-CPR w/IHD	0.057	-0.031	0.022	-0.057*	-0.075*	0.005
CPP-CPP	-0.037	-0.067*	-0.004	0.002	-0.075**	0.012
CPP-CPP w/ IHD	-0.087**	-0.092**	0.063	-0.087**	-0.091**	0.041
CPR-CPP	-0.075	-0.039	0.018	-0.013	-0.089**	-0.014
CPR-CPP w/ IHD	-0.025*	0.034	-0.032	-0.012	-0.060	-0.058

*note: *** p<0.01, ** p< 0.05, * p<0.1*

Table 5.6. Estimated Group-Event Interaction Coefficients for 2012 events, in percentage reductions compared to no-notification control

	9/14/12			9/21/12		
Treatment	Before	During	After	Before	During	After
Flat Rate w/ Notification	-5.05%	-1.21%	-0.05%	-10.41%	-4.00%	3.76%
CPR-CPR	-5.44%	-8.72%	-3.93%	-6.09%	-1.65%	2.16%
CPR-CPR w/IHD	-5.92%	-16.41%	5.55%	-4.64%	-2.34%	5.10%
CPP-CPP	2.57%	-7.46%	-0.78%	-4.70%	-6.43%	6.94%
CPP-CPP w/ IHD	-3.16%	-15.97%	-1.64%	-12.19%	-10.84%	0.73%
CPR-CPP	-2.15%	-9.07%	-3.19%	-5.29%	-10.98%	-2.32%
CPR-CPP w/ IHD	-5.33%	-12.82%	-3.97%	-11.70%	-9.21%	-3.59%

	9/25/12			10/5/12		
Treatment	Before	During	After	Before	During	After
Flat Rate w/ Notification	-4.10%	-3.10%	-2.17%	-6.25%	-5.22%	-0.96%
CPR-CPR	-8.05%	-6.00%	0.46%	0.72%	-4.81%	-0.95%
CPR-CPR w/IHD	6.35%	-3.44%	2.47%	-6.40%	-8.37%	0.51%
CPP-CPP	-4.09%	-7.46%	-0.41%	0.17%	-8.34%	1.33%
CPP-CPP w/ IHD	-9.68%	-10.25%	7.06%	-9.65%	-10.15%	4.55%
CPR-CPP	-8.31%	-4.33%	2.03%	-1.43%	-9.89%	-1.59%
CPR-CPP w/ IHD	-2.80%	3.78%	-3.57%	-1.32%	-6.71%	-6.49%

Table 5.7. Estimated Group-Event Interaction Coefficients for 2013 events, in average kW reductions compared to no-notification control

	7/5/13			7/15/13		
Treatment	Before	During	After	Before	During	After
Flat Rate w/ Notification	0.014	-0.102***	-0.004	-0.071**	-0.085**	-0.074
CPR-CPR	0.043	-0.035	0.055	-0.067*	0.024	-0.050
CPR-CPR w/IHD	0.065	-0.094**	0.050	-0.026	-0.076*	-0.032
CPP-CPP	0.020	-0.091**	0.039	-0.057	-0.020	-0.035
CPP-CPP w/ IHD	0.162***	-0.104**	0.000	0.047	-0.043	0.039
CPR-CPP	0.085*	0.027	0.088**	0.169***	0.044	-0.010
CPR-CPP w/ IHD	0.014	-0.139**	-0.054	0.101*	-0.006	0.037

	7/16/13			7/17/13		
Treatment	Before	During	After	Before	During	After
Flat Rate w/ Notification	-0.076**	-0.078**	-0.133***	-0.078**	-0.168***	-0.094***
CPR-CPR	-0.005	-0.016	-0.018	-0.021	-0.105***	-0.055
CPR-CPR w/IHD	0.038	-0.082*	-0.129***	-0.012	-0.179***	-0.044
CPP-CPP	-0.014	-0.053	-0.023	0.009	-0.072*	-0.039
CPP-CPP w/ IHD	0.058	-0.097**	0.050	0.037	-0.255***	-0.082*
CPR-CPP	0.233***	0.037	0.025	0.231***	0.017	0.092**
CPR-CPP w/ IHD	-0.007	-0.251***	-0.027	-0.003	-0.273***	0.032

	7/18/13			7/19/13		
Treatment	Before	During	After	Before	During	After
Flat Rate w/ Notification	-0.050	-0.109***	-0.122***	-0.036	-0.101***	-0.117***
CPR-CPR	0.000	-0.055*	-0.014	0.043	-0.071*	-0.054
CPR-CPR w/IHD	0.111***	-0.019	-0.020	0.023	-0.127***	-0.152***
CPP-CPP	0.015	-0.016	-0.074**	-0.011	-0.134***	-0.077**
CPP-CPP w/ IHD	0.013	-0.213***	-0.062	0.015	-0.231***	-0.100**
CPR-CPP	0.226***	0.024	0.037	0.179***	-0.103**	-0.093**
CPR-CPP w/ IHD	0.080	-0.134**	-0.106**	-0.028	-0.398***	-0.170***

	8/13/13			8/21/13		
Treatment	Before	During	After	Before	During	After
Flat Rate w/ Notification	0.034	-0.051	-0.022	-0.029	-0.037	-0.036
CPR-CPR	0.103***	0.027	0.035	0.036	-0.014	-0.016
CPR-CPR w/IHD	0.049	-0.035	0.047	-0.017	-0.073	-0.083
CPP-CPP	0.055	-0.034	0.002	-0.026	-0.104***	-0.059*
CPP-CPP w/ IHD	0.050	-0.019	0.024	0.026	-0.125***	-0.032
CPR-CPP	0.161***	-0.016	0.036	0.088**	-0.011	-0.026
CPR-CPP w/ IHD	0.061	-0.046	-0.033	-0.061	-0.132**	-0.019

	8/22/13			8/28/13		
Treatment	Before	During	After	Before	During	After
Flat Rate w/ Notification	-0.014	0.021	0.054	-0.036	-0.025	0.027
CPR-CPR	-0.031	0.049*	0.017	-0.007	0.002	-0.036
CPR-CPR w/IHD	-0.033	-0.096**	-0.089**	0.018	-0.076*	-0.068**
CPP-CPP	-0.052	-0.107***	-0.012	0.013	-0.037	-0.074
CPP-CPP w/ IHD	-0.018	-0.060	0.088**	-0.069	-0.165***	0.007
CPR-CPP	0.131***	0.108**	0.036	0.011	0.000	-0.013
CPR-CPP w/ IHD	-0.050	-0.015	0.028	0.059	-0.079	0.004

Table 5.8. Estimated Group-Event Interaction Coefficients for 2012 events, in percentage reductions compared to no-notification control

	7/5/13			7/15/13		
Treatment	**Before**	**During**	**After**	**Before**	**During**	**After**
Flat Rate w/ Notification	1.61%	-11.34%	-0.49%	-7.91%	-9.45%	-8.28%
CPR-CPR	4.82%	-3.90%	6.07%	-7.50%	2.63%	-5.61%
CPR-CPR w/IHD	7.25%	-10.47%	5.59%	-2.88%	-8.42%	-3.55%
CPP-CPP	2.21%	-10.09%	4.39%	-6.33%	-2.23%	-3.85%
CPP-CPP w/ IHD	18.07%	-11.63%	0.02%	5.18%	-4.80%	4.39%
CPR-CPP	9.46%	2.98%	9.76%	18.77%	4.85%	-1.15%
CPR-CPP w/ IHD	1.51%	-15.50%	-6.00%	11.20%	-0.67%	4.09%

	7/16/13			7/17/13		
Treatment	**Before**	**During**	**After**	**Before**	**During**	**After**
Flat Rate w/ Notification	-8.50%	-8.73%	-14.76%	-8.73%	-18.66%	-10.49%
CPR-CPR	-0.51%	-1.83%	-2.02%	-2.38%	-11.65%	-6.10%
CPR-CPR w/IHD	4.26%	-9.12%	-14.41%	-1.34%	-19.96%	-4.85%
CPP-CPP	-1.58%	-5.91%	-2.58%	0.95%	-7.99%	-4.35%
CPP-CPP w/ IHD	6.50%	-10.76%	5.56%	4.11%	-28.36%	-9.13%
CPR-CPP	25.99%	4.10%	2.75%	25.68%	1.91%	10.25%
CPR-CPP w/ IHD	-0.80%	-27.90%	-2.98%	-0.37%	-30.43%	3.57%

	7/18/13			7/19/13		
Treatment	**Before**	**During**	**After**	**Before**	**During**	**After**
Flat Rate w/ Notification	-5.59%	-12.18%	-13.56%	-3.96%	-11.21%	-13.02%
CPR-CPR	0.01%	-6.10%	-1.60%	4.80%	-7.96%	-5.96%
CPR-CPR w/IHD	12.41%	-2.13%	-2.18%	2.53%	-14.15%	-16.90%
CPP-CPP	1.62%	-1.83%	-8.19%	-1.27%	-14.96%	-8.61%
CPP-CPP w/ IHD	1.50%	-23.75%	-6.88%	1.69%	-25.69%	-11.18%
CPR-CPP	25.22%	2.66%	4.07%	19.95%	-11.44%	-10.32%
CPR-CPP w/ IHD	8.88%	-14.93%	-11.86%	-3.09%	-44.27%	-18.94%

	8/13/13			8/21/13		
Treatment	**Before**	**During**	**After**	**Before**	**During**	**After**
Flat Rate w/ Notification	3.80%	-5.69%	-2.49%	-3.21%	-4.13%	-4.00%
CPR-CPR	11.45%	3.03%	3.94%	4.05%	-1.53%	-1.79%
CPR-CPR w/IHD	5.47%	-3.95%	5.21%	-1.87%	-8.11%	-9.25%
CPP-CPP	6.14%	-3.83%	0.25%	-2.90%	-11.62%	-6.56%
CPP-CPP w/ IHD	5.58%	-2.14%	2.65%	2.87%	-13.93%	-3.54%
CPR-CPP	17.95%	-1.84%	4.05%	9.76%	-1.24%	-2.90%
CPR-CPP w/ IHD	6.82%	-5.12%	-3.69%	-6.83%	-14.69%	-2.07%

	8/22/13			8/28/13		
Treatment	**Before**	**During**	**After**	**Before**	**During**	**After**
Flat Rate w/ Notification	-1.59%	2.39%	5.99%	-4.01%	-2.74%	3.01%
CPR-CPR	-3.42%	5.42%	1.95%	-0.74%	0.24%	-4.05%
CPR-CPR w/IHD	-3.69%	-10.73%	-9.88%	2.00%	-8.49%	-7.52%
CPP-CPP	-5.83%	-11.93%	-1.36%	1.40%	-4.15%	-8.22%
CPP-CPP w/ IHD	-2.04%	-6.72%	9.84%	-7.72%	-18.40%	0.83%
CPR-CPP	14.54%	12.05%	3.99%	1.23%	-0.03%	-1.46%
CPR-CPP w/ IHD	-5.61%	-1.63%	3.09%	6.54%	-8.81%	0.46%

Tables 5.7 and 5.8 show the same information for the ten critical peak events declared in 2013. Again, we see very little evidence of a persistent response by any of the treatment groups, although the pure CPP-IHD group (i.e., those customers that were on the CPP with IHD for both years of the study) tended to exhibit larger reductions than other treatment groups.

Figure 5.10 shows estimated usage reductions during the fourteen critical peak events, in percentage terms relative to the no-notification control, for each of the rate and information treatment groups. Although there is wide variation in how different treatment groups responded during each event, we see evidence of a moderate response during 2012 events, although little consistency within treatment groups. We see more variability during 2013 events, and the statistical significance of during-event response for some groups (both in 2013 and across the two-year study horizon) appears to be dominated by a small number of events with a large magnitude of response. The relative importance of four to five events in July 2013 is most apparent for those customers on the CPP in 2013: the CPP-CPP group, the CPP-CPP-IHD group and the CPR-CPP-IHD group.

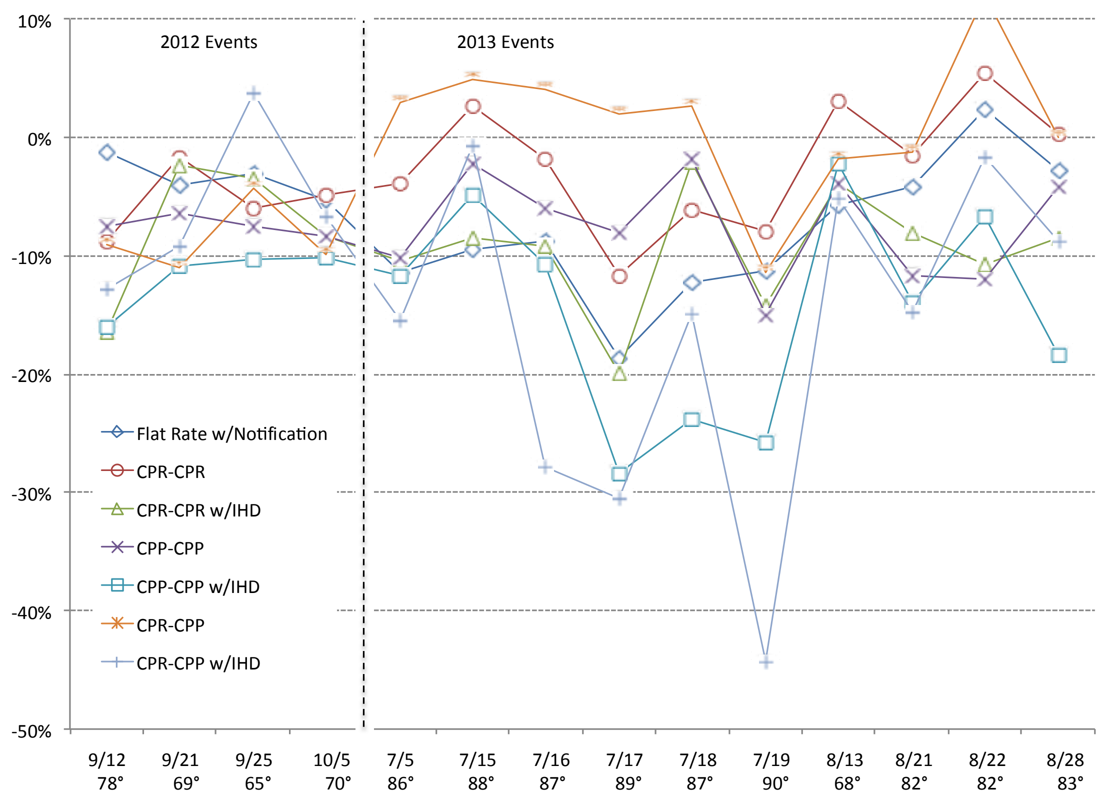

Figure 5.10. Average hourly load reductions, in percentage terms relative to the no-notification control group, for all treatment groups and events in 2013. Negative numbers indicate usage reductions relative to the control group. Figures below the dates indicate high temperatures, in degrees Farenheit.

Table 5.9 shows the results of our persistence analysis on an hour-to-hour basis within critical peak events. This analysis effectively addresses the question of whether, on average (and controlling for weather conditions), consumers in each of the rate and information treatment groups reduce average hourly kW loads by a uniform duration during the span of critical peak events. We note here that our persistence analysis does not explicitly break out the transition group (CPR to CPP); customers whose rate treatment transitioned after year one were assigned to the CPR group in year one and the CPP group in year two.

Persistence on an hour-to-hour time scale within events is measured using the coefficient, α_2 in equation (3), which indicates the mean hourly differences of hourly kW consumption with the average consumption between 12 – 1 pm during critical event days. We also control for weather conditions by interacting the hour and event indicators with the hourly heat index.

The results of our analysis, as shown in Table 5.9, suggest a strong persistence of response within events when averaged across all rate and information treatment groups. This is consistent with what we see visually in Figures 5.4 – 5.8. The α_2 values are shown in the lower portion of the table (where the treatment groups are interacted with the event-hours and weather variables). Any variations in persistence of response are small, amounting to 0.001 kW or less. This may suggest that consumers are not micro-managing electricity consumption during peak events, but rather are taking actions at a single point in time (such as adjusting thermostat settings) that would ultimately lower their consumption levels during critical peak events.

Table 5.9. Hour-to-hour persistence results.

Independent Variables	*Hour 13*	*Hour 14*	*Hour 15*	*Hour 16*	*Hour 17*
Hour * Event-hour Indicator * heat index	0.030***	0.034***	0.038***	0.036***	0.034***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
*Group * Hour * Event-hour indicators * heat index interaction terms*					
CPR	-0.001***	-0.001**	-0.001***	-0.001**	-0.001**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CPR with IHD	-0.001**	-0.002***	-0.002***	-0.001***	-0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
CPP	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CPP with IHD	-0.003***	-0.003***	-0.003***	-0.003***	-0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
No of Observations			26,427,323		

*note: *** p<0.01, ** p<0.05, * p<0.1*

The persistence analysis presented here has policy significance in two respects. First, our analysis of GMP customers suggests that utilities in Vermont should not count on customers responding in similar ways to critical peak events, even when those events are called under similar weather conditions. In other words, it is difficult to determine the capacity value of demand response in the GMP service territory, based on the demand response programs being evaluated in this study. The five consecutive events in July, for example, were called during a period of high humidity and temperatures in the 90s. We see neither evidence of a persistent response across this period nor evidence of significant response fatigue among any treatment group. Some customer groups (most notably the CPR-CPP group) actually increased consumption during this period. Some of the lowest response levels that we observed occurred during the August 22 event in 2013, when temperatures were in the low 80s. The following event, called six days later under similar weather conditions, saw higher levels of customer response from most treatment groups. Customer response to declared peak events was arguably more consistent during the 2012 events, which were called when temperatures were more moderate. Second, customers on the CPP rate during 2013 appear to have reduced usage more than other groups during the July 2013 heat wave. Some of these estimated reductions were large – more than 30% relative to the control group.

5.4 Financial Impacts of Peak-Time Usage Reductions (Research Question 6)

This section uses the regression results from Section 5.1, together with information on the rate treatments faced by each group, to estimate average bill savings during critical peak events. We note that in some cases the savings from reduced consumption during the critical peak event are offset by increased consumption during the periods before and after the event.

Figure 5.11 shows the average monetary savings per customer (per-event), calculated using equation (4). This incorporates any savings associated with usage reductions before the peak event; during the peak event period; and after the peak event. CPP customers who increased usage during these times will effectively see negative savings according to equation (4). The largest per-customer savings was again observed among IHD-equipped customers on the CPP rate (a bit more than $0.40 per event on average, or nearly $6 over fourteen events in 2012 and 2013), followed by IHD-enabled customers on the CPR rate and customers without IHDs on the CPP rate. The during-event savings dominate the bill impacts, since the incremental benefit of a one kW reduction is several times larger during the event, compared to the pre-event hours.

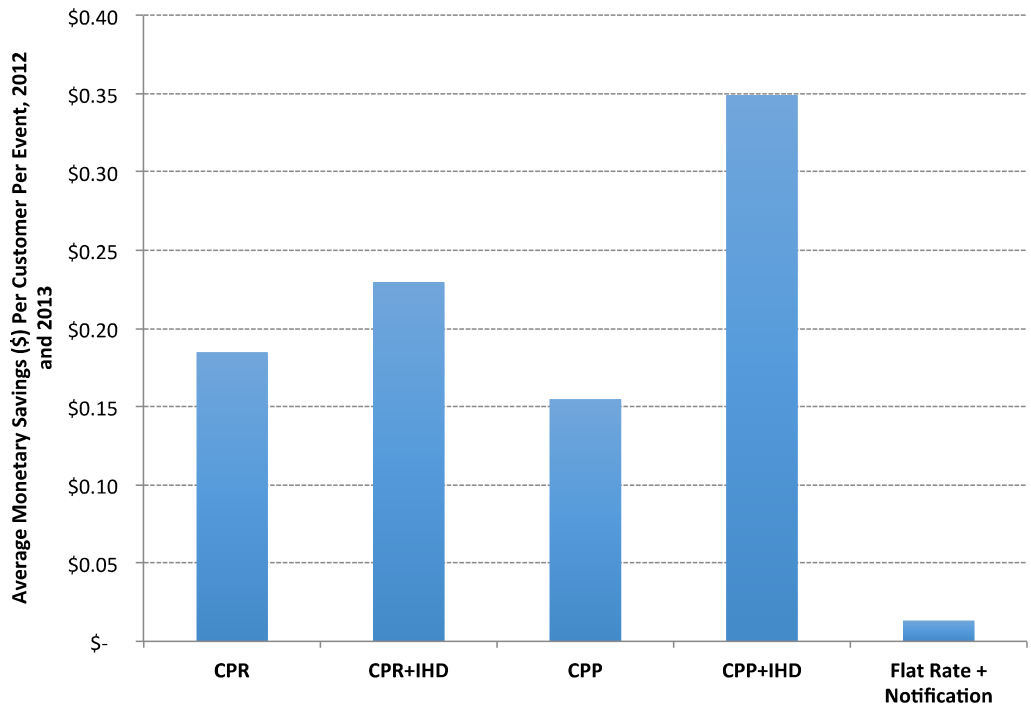

Figure 5.11. Average monetary savings by treatment group during critical peak events. The figures include the cost savings from reduced consumption during the event hours as well as costs from any increased consumption either before or after the peak event.

5.5 Monthly Energy Impacts of the In-Home Display (Research Question 7)

In this section we assess whether the presence of the IHD, which gives consumers continuous feedback on electricity usage (as long as the customer is paying attention to the IHD), has the effect of lowering electricity usage during periods other than declared critical peaks.

Our analysis compares monthly energy usage (monthly kWh) for customers with and without IHDs, during the periods before and after the IHDs were installed. We first construct a monthly kWh variable for each customer by summing the observed hourly average kW readings for each customer over the course of a month. The pre-IHD period is defined as March 2012 through July 2012, while the IHD period is defined as August 2012 through December 2013. As previously mentioned, IHDs were shipped out during the month of August but we do not have any specific data on when any particular customer received or installed their IHD (or whether they received or installed the IHD at all).

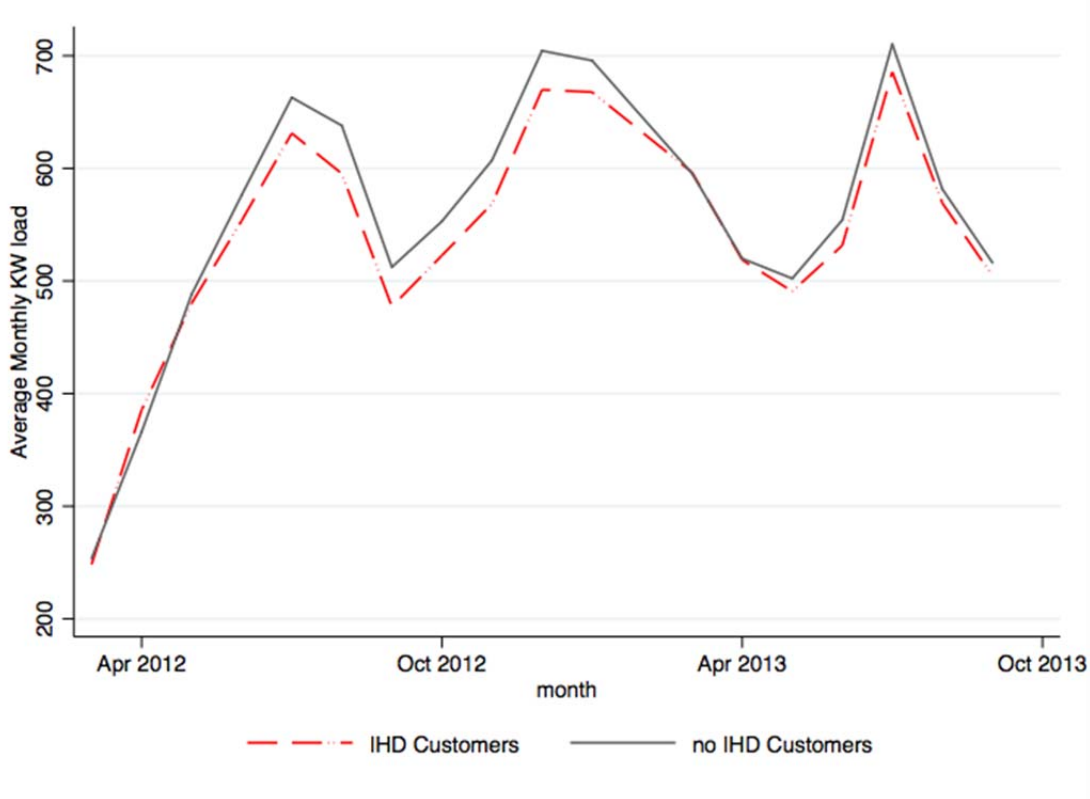

Figure 5.12. Average monthly consumption (kWh) for consumers with and without IHDs.

Figure 5.12 illustrates average monthly kilowatt-hour consumption for customers with and without the IHDs over the entire study period. (Note that we would not expect any differences in average monthly consumption until August 2012 when the IHDs were delivered to customers in the relevant treatment groups) Figure 5.13 provides more detail, showing average monthly kWh consumption for all treatment groups and the no-notification control group. The IHD-enabled groups exhibit a noticeable decline in average monthly consumption during and immediately following the period when the IHDs were delivered and when customers presumably installed and started using them. This consumption decline, however, does fade away after a few months.

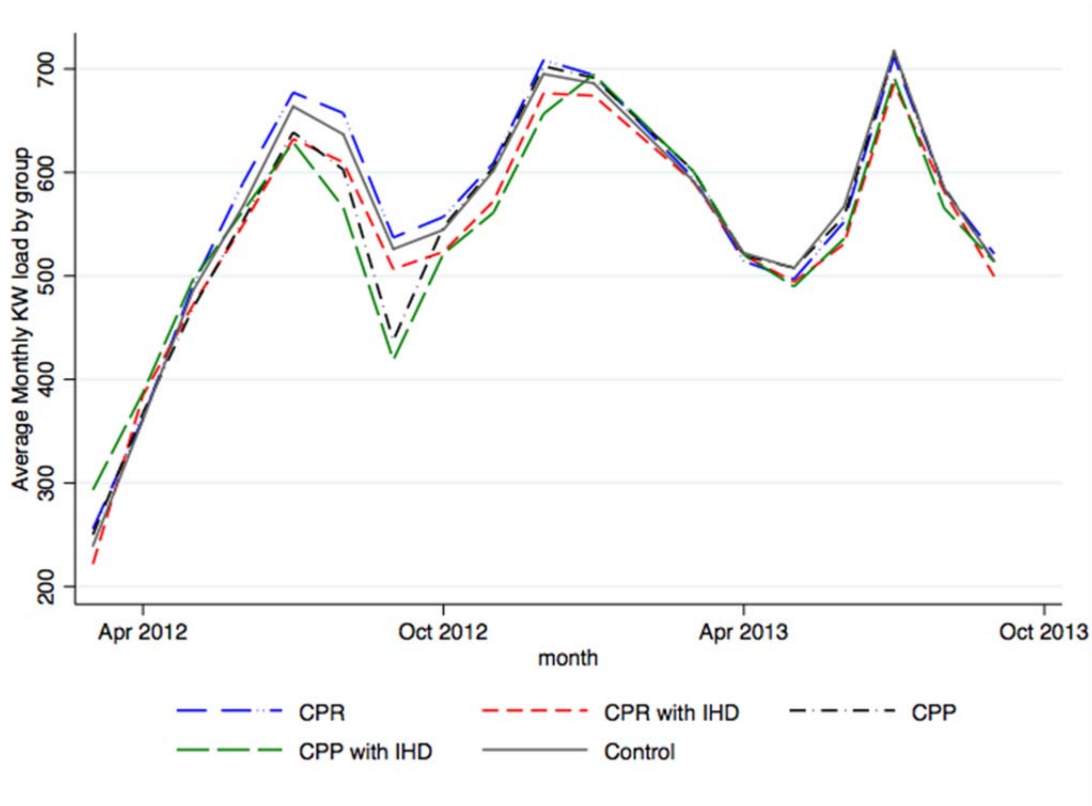

Figure 5.13. Average monthly consumption (kWh), broken down by treatment and no-notification control group.

We run a differences-in-differences type of panel regression using all customer data (including those who declined to participate) over the period March 2012 through December 2013. This regression specification is outlined in equation (5) in Section 4.5.

Table 5.6: Regression Parameters from Equation (6)

Variable	Parameter
Constant	780.389***
Monthly Cooling Degree Days	51.520***
IHD Indicator	-28.034***
IHD*AUG12	13.127***

* indicates significance at the α=0.1 level, **at the α=0.05 level, and *** at the α=0.01 level.

Table 5.6 shows the estimated regression parameters. All three coefficients are statistically significant at the 1 percent level. The regression indicates that on average, customers with IHDs have monthly energy (kWh) usage that is 28 kWh below the average usage for customers without IHDs, although during the post-August 2012 period this difference is effectively reduced by 13 kWh per month, yielding a net average reduction of approximately 15 kWh per month. As Figure 4.1 shows, however, this average masks the larger reduction in consumption observed around August 2012 and the subsequent increase in monthly consumption by IHD-enabled customers. If we evaluate these estimated savings at the Rate 1 energy charge of $0.148 per kWh, we get a 95 percent confidence interval for monthly savings among IHD customers of $0.44 to $3.44 per IHD-enabled customer per month.

6. Conclusions

The consumer behavior study run by Green Mountain Power during 2012 and 2013 aimed to evaluate the effectiveness of critical peak electricity pricing and the availability of real-time electricity consumption information in spurring consumers to reduce usage during periods of high system demand. The study was set up as a randomized control trial, involving seven treatment groups and one control group. All of the treatment groups received day-ahead notifications of critical peak events. Four of the treatment groups involved differential pricing during critical peak event periods – a critical peak rebate and critical peak pricing – with and without usage information feedback via an in-home display. Two additional treatment groups transitioned customers from the critical peak rebate in the first year of the study to the critical peak price rate in the second year of the study. A final treatment group was left on the regular (flat) residential rate but did receive notifications of critical peak events.

The principal objective of the study was to evaluate whether some combination of event-differentiated pricing and usage information feedback was effective in inducing customers to reduce peak demands during very high demand days in the summer season. While the per-customer energy savings from these critical peak events would be small over the course of a summer (because of the relatively small number of critical peak events called), effective response would imply that GMP could use critical peak pricing as a type of demand-response program in its resource adequacy assessments. Customers would thus benefit from reduced capacity charges paid to ISO New England, as well as reduced distribution capacity upgrade costs. A second motivation was to examine whether transitioning customers from a rebate-based rate to critical peak pricing rate would improve customer acceptance of higher rates during peak event periods (and lower rates during non-event periods), and would yield larger load reductions following the transition to the critical peak price (since customers would have already experienced critical peak events for a year with no risk of bills increasing).

Our analysis of the load reduction impacts associated with critical peak pricing in the Green Mountain Power service territory suggests six lessons for enhancing electric rate design in Vermont; for leveraging smart grid investments to reduce electricity costs in Vermont; and for utilities in other states considering electric rate design similar to that employed in the GMP Consumer Behavior Study. These lessons are summarized as follows.

Lesson 1: Critical peak pricing and critical peak rebates did elicit demand reductions during critical peak periods. We estimated that, after controlling for weather differences among critical peak events, customers in all rate and information treatment groups did reduce usage during critical peak events, relative to the no-notification control group. Hourly usage reductions across treatment groups (including the flat-rate + notification group) ranged from 0.05 kW to 0.07 kW (5.3% to 7.4%), with the exception of the CPP-IHD group, which exhibited hourly usage reductions of 0.125 kW (14%) during critical peak events. These reductions were all statistically significant. The CPP groups, however, exhibited statistically significant demand increases in the morning hours preceding the critical peak event. These demand increases were 0.03 to 0.04 kW in magnitude. These increases suggest that customers were shifting load from peak hours to off-peak hours. The CPR groups exhibited demand reductions that persisted beyond the event periods, but at smaller magnitudes (0.02 to 0.03 kW).

Lesson 2: Simple notification of critical peak demand periods can be as effective as some types of event-differentiated pricing. Our estimate of the demand reduction by the flat rate + notification group during critical peak events (6.5%) was larger than estimated reductions by the CPR group (5.3%) but smaller than our estimated reductions by the CPR+IHD and CPP (without IHD) groups (7.3% and 7.4%). Reductions by the flat rate + notification group were less than half as large as reductions from the CPP-IHD group (14%). Our findings suggest that if utilities are going to adopt critical peak programs as a form of demand response, critical peak pricing is the most effective option if accompanied by appropriate informational feedback. If utilities choose not to implement critical peak pricing, then simple notification of declared critical peak days may be just as effective as alternative rate structures.

Lesson 3: Transitioning customers from a rebate-based rate to a critical peak rate does not appear to be an effective way of increasing customer acceptance of critical peak pricing. During initial recruitment in 2011, customers agreed to take up critical peak pricing with an acceptance rate of 27% to 28%. The acceptance rate was very similar for both the CPP and CPP-IHD rates. 63% of the customers in the CPR-CPP transition group agreed to transition to the CPP in 2013, while 65% in the CPR-CPP-IHD group agreed to transition to the CPP in 2013. While the numbers are not directly comparable, since those customers in the transition groups got reminders from GMP regarding their rate treatment along with the invitation to switch to CPP, GMP's experience does not provide overwhelming evidence that a CPR to CPP transition improves customer acceptance rates.

Lesson 4: Transitioning customers from a rebate-based rate to a critical peak rate does not appear to be an effective way of increasing customer load response during critical peak events, relative to placing customers directly on critical peak rates. Evidence from GMP's pilot study indicates that the combination of rate and information feedback was a more important determinant of customer response to critical peak events than was the transition from a rebate to a critical peak price rate structure. Customers in the CPR-CPP-IHD group did improve the magnitude of their response during critical peak events in 2013 versus 2012 (6.2% reduction in 2012, when these customers were on CPR, to 12.4% reduction in 2013, when these customers transitioned to CPP), and the response by the transition group in 2013 was somewhat larger in magnitude than the response by the pure CPP group with the IHD (16.4% for the transition group with IHD versus 14.4% for the pure CPP-IHD group). We found some evidence that the transition group without the IHD reduced usage significantly during critical peak events called in 2012, but not during 2013.

Lesson 5: Leveraging existing smart grid infrastructure to provide informational feedback to customers can effectively induce demand reductions during critical peak periods. Based on GMP's pilot study, we observed larger demand reductions during critical peak events among customers given simple in-home devices, relative to those without IHDs. In 2013, customers in the pure CPR group with IHDs reduced usage by four times as much as CPR customers without IHDs. IHD-enabled customers in the pure CPP group reduced usage by twice as much as CPP customers without IHDs. While we initially observed that customers receiving IHDs at the beginning of the study had lower monthly energy usage (regardless of the occurrence of critical peak events), this energy reduction behavior faded within a few months. We note that while the study provides evidence of the effectiveness of IHDs in helping customers reduce usage during critical peak periods, any policy implications have two caveats. The first is that the study cannot say whether the IHDs were or would be worth their cost (the cost to equip a single GMP customer with the IHD was around $500 at the time that the study was implemented), nor do our results suggest any specific policy measure regarding who should be given IHDs and how they should be paid for. The second is that following the first year of the study many customers expressed confusion regarding how the IHD was supposed to work (and some reported never receiving the IHD in the first place). Educational assistance to customers receiving IHDs in any future technological rollout may alleviate some of the observed confusion and improve customers' use of technology.

Lesson 6: The rate and information treatments used in the GMP pilot did not induce a consistent response across multiple events, making the capacity value of critical peak demand reduction difficult to determine. As shown in Figure 5.10, customer response across individual events varied widely. No customer group exhibited a consistent or persistent response to critical peak events. There is some evidence that customers on critical peak pricing and those with IHDs reduced demand by larger magnitudes when events were called on hot days (when temperatures were in the mid 80°F range). Even within CPP groups, load reductions during a string of five consecutive critical peak days ranged from just a few percent to more than 35%. Perhaps more encouragingly, we did not find any evidence of "event fatigue" during this five-day period. In other words, we did not find any treatment group that exhibited relatively large reductions during the first one or two event days, with smaller reductions in subsequent days. (We also did not find any evidence that load reduction magnitudes increased over the five-day period.)

This lesson is of particular importance for the utility use of demand response programs to lower capacity-related costs. We found that the use of prices and information feedback alone provide insufficient motivation for consumers to reduce demands in any consistent way across multiple event periods. Based on GMP's experience during 2012 and 2013, neither critical peak pricing nor rebates are themselves sufficient to substitute for new capacity to meet resource adequacy requirements.