Residential Customer Response to Real-Time Pricing:
The Anaheim Critical-Peak Pricing Experiment*

by

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Abstract

This paper analyzes the results of a critical peak pricing (CPP) experiment involving 123 residential customers of the City of Anaheim Public Utilities (APU) over the period June 1, 2005 to October 14, 2005. Using a nonparametric condition mean estimation framework that allows for customer-specific fixed effects and day-of-sample fixed effects, I find that customers in the treatment group consumed an average of 12 percent less electricity during the peak hours of the day on CPP days than customers in the control group. There is also evidence that this reduction in consumption for customers in the treatment group relative to customers in the control group is larger on higher temperature CPP days. The impact of CPP events is confined to the peak periods of CPP days. Mean electricity consumption by customers in the treatment group is not significantly different from that of customers in the control group during the peak or off-peak periods of the day before or day after a CPP event. Much of the estimated consumption reduction of treatment consumers relative to control group consumers during peak periods of CPP days is due to reductions from a higher level of consumption by treatment group customers in non-CPP days. The consumption reductions paid rebates during CPP days are almost 7 times the reduction in consumption due to CPP events predicted by the treatment effects estimate, which provides strong evidence of an overly generous method for setting the reference level for peak period consumption relative to which customers are issued refunds during CPP days. The paper closes with a discussion of the challenges associated with implementing a CPP rate with a rebate mechanism as the default rate for residential customers.

1. Introduction

This paper analyzes the results of a critical peak pricing experiment involving 123 residential customers of the City of Anaheim Public Utilities (APU) over the period June 1, 2005 to October 14, 2005. During the late summer of 2004, a random sample of APU customers were selected to participate in the experiment. These customers were then randomly assigned into a treatment and a control group. Control group customers were charged according to the standard increasing-block, fixed-price schedule for APU residential customers. Customers in the treatment group paid according to the same APU residential tariff except during peak hours (noon to 6 pm) on critical peak pricing (CPP) days when these customers received a rebate of 35 cents/KWh for the amount they reduced their peak period consumption relative to their typical or reference level peak period consumption on non-CPP days.

Using a nonparametric conditional mean estimation framework with customer-level fixed effects and day-of-sample fixed effects, I compute the average difference in mean consumption between customers in the treatment and control groups on CPP days. Customers in the treatment group consumed an average of 12 percent less electricity during the peak hours of the day on critical peak pricing days than customers in the control group. I also find evidence that this reduction in consumption by treatment group customers is larger on higher temperature CPP days. The impact of CPP events is confined to the peak periods of CPP days. There is no discernable difference in mean consumption between the treatment and control groups during peak or off-peak periods of the day before or day after a CPP event.

Although the results of this experiment show a substantial reduction in consumption by the treatment group relative to the control group during the peak periods of CPP days, there are a number of features of this CPP experiment that complicate the process of inferring a demand

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response from the estimated average "treatment effect" of a CPP event. First, the rebate mechanism is based on the history of a customer's peak period consumption during non-holiday weekdays that are not CPP days during the sample period. The method used to compute the reference level of peak period consumption relative to which rebates are issued provides customers in the treatment group with a strong incentive to increase their consumption during peak-periods of non-CPP days. Second, customers in the treatment and control groups are subject to an increasing block tariff for their monthly electricity consumption. Each type of customer can purchase up to 240 kilowatt-hours (KWh) per month at 6.75 cents/KWh. The remainder of consumption in the month is charged at 11.02 cents/KWh. Finally, the CPP rebate mechanism guarantees that a customer's monthly bill does not exceed what the customer would pay under the standard increasing block tariff. A customer can only gain by reducing his consumption during the peak periods of CPP days. The customer is not punished with a higher monthly bill for failing to consume less than his reference level during the peak periods of CCP days, as would be the case if the customer was actually charged the sum of the fixed price and the rebate price for electricity consumed beyond this reference level during the peak periods of CPP days.

I formulate a dynamic model of customer behavior to understand the incentives created by this CPP rebate mechanism. Although I find no evidence in favor of pre-experiment period differences in the mean pattern of daily consumption across the treatment and control groups, the experiment period behavior of the customers in the treatment group is consistent with the predictions of this model. Specifically, I find that for non-holiday weekdays during the experiment period that are not CPP days, mean consumption for the treatment group is significantly higher than mean consumption for the control group during both peak and off-peak periods. This result is consistent

with the incentive that treatment group customers have to increase their reference level in order to obtain a higher rebate during CPP days.

I also find no significant difference in mean consumption for control group customers during peak periods of CPP days versus peak periods of non-CPP days. This result, combined with the treatment versus control peak period consumption results from the non-CPP day sample, is consistent with the view that roughly half of the 12 percent consumption reduction during peak periods of CPP days for the treatment group relative to the control group is due to a significantly higher experiment period consumption during peak periods of non-CPP weekdays by customers in the treatment group.

The difference between the average peak period reference level and the average peak period consumption during CPP days by treatment group customers is almost 7 times the reduction in consumption during CPP days predicted by the estimated treatment effect of a CPP day. This result implies that the vast majority of rebates paid for reductions relative to the customer's reference level for peak period consumption would occur without the incentives provided by the CPP program. This conclusion is supported by computing the reference level of consumption and the implied rebates during CPP days for customers in the control group. These customers receive rebates that are roughly 6 times the reduction in consumption during CPP days predicted by the treatment effects estimates. These results demonstrate that the financial viability of a CPP mechanism with refunds depends crucially on the method used to set a customer's reference level.

The existence of a mean consumption reduction associated with a CPP day is a necessary condition for universal critical peak pricing for residential customers. For this policy to have benefits that exceed the rebate costs, the savings in total wholesale energy purchase costs must be more than the total rebate payments made to CPP customers. It is relatively straightforward to

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estimate the reduction in wholesale energy purchase costs to serve customers on a CPP rate if this demand reduction exerts no impact on wholesale electricity prices. The estimated wholesale energy cost savings is equal to the average treatment effect times the total consumption of electricity by CPP customers in the absence of a CPP event multiplied by the average price of wholesale electricity during the peak period of the CPP day. At the current level of short-term wholesale energy market bid caps in US markets, the reduction in total wholesale electricity costs due to a CPP day is unlikely to be more than the total rebates paid to customers on a CPP plan. Therefore, whether CPP pricing for all residential customers has benefits that exceed the rebate costs for wholesale markets in the US depends on the extent to which the resulting reduction in consumption reduces the price of wholesale electricity. If this price reduction is large enough or applied to enough load, the reduction in wholesale energy costs to the retailer should be sufficient to cover the rebates paid to CPP customers during the peak period of a CPP day. Section 6 discusses three major factors influencing the financial viability of a CPP rate with a rebate for all residential customers

In spite of difficulties associated with designing a financially viable CPP program with a rebate for residential customers, I believe that this pricing plan is a politically acceptable approach to introduce residential customers to managing wholesale price risk. The results of the treatment effects analysis show sizable consumption reductions during peak periods of CPP days. If these percentage reductions could be obtained on a system-wide basis in California, this pricing mechanism would yield significant system reliability and market efficiency benefits.

2. Critical Peak Pricing Experimental Design

During the late summer and early autumn of 2004, a random sample of APU customers was chosen and subsequently randomized into treatment and control groups. The control group

customers received hourly meters, but were given no information about the critical peak pricing program. The treatment group customers were recruited through an enrollment letter sent to their home address telling the customer he or she had been selected to participate in APU's new "Spare the Power Days Rebate" pilot program. This letter emphasized that the program paid the customer to reduce his or her electricity consumption and that the customer could only save money from participating in the program. The letter stated, "If you can't reduce use on a Spare the Power Day, that's okay; you will just pay your normal bill amount. You can't lose!" This letter did not say that customers could opt out of the program.

This initial mailing also contained a fact sheet describing the major features of the program and a reply card that the customer was asked to send back to APU with their phone number or e-mail address in order to be notified of CPP days. These three documents are contained in Appendix A. Three weeks after the initial mailing, all customers who did not respond and had a valid phone number were contacted. All but a very small number, less than five, of the customers contacted by telephone agreed to participate in the experiment. A month later another letter was sent to the remaining treatment group customers that could not be contacted by telephone containing a Spare the Power Days magnet, the original fact sheet and the reply card. This letter is also contained in Appendix A.

This process ultimately resulted in 52 customers in the control group and 71 customers in the treatment group. By the last week of May of 2005, interval meters had been installed in all of the treatment group and control group residences and tested for their accuracy. These meters record a customer's consumption in each 15-minute interval of the day. In mid-May of 2005, customers in the treatment group were sent a final letter (included in Appendix A) reminding them of their participation in the CPP experiment.

To test the randomness of the process used to assign customers to the treatment and control groups I compare mean consumption of electricity by the treatment and control groups for each 15-minute interval of the day during the last three days of May 2005 before the start of the CPP experiment on June 1, 2005. These are the only days during May 2005 with 15-minute interval data available for all customers in the treatment and control groups.

Let CT_{itd} denote the consumption of electricity of customer i in 15-minute period t of day d from the treatment group and CC_{jtd} the consumption of electricity of customer j in 15-minute period t for day d from the control group. Figure 1 plots the average value of CT_{itd} and CC_{jtd}, over all customers and days for each 15-minute interval during last three days of the month of May 2005. If NC(t) is the total number of observations for the control group for the tth 15-minute interval and NT(t) is the total number of observations for the treatment group for the tth 15-minute interval, each value on the treatment group and control group curves are defined as follows:

$$\mu(CC(t)) = \frac{1}{NC(t)} \sum_{i,d \,\in\, NC(t)} CC_{itd} \quad and \quad \mu(CT(t)) = \frac{1}{NT(t)} \sum_{i,d \,\in\, NT(t)} CT_{itd}. \tag{1}$$

Let $Z(t) = \mu(CT(t)) - \mu(CC(t))$, the difference between mean consumption of the treatment group and mean consumption of the control group for 15-minute interval t. A consistent estimate of the standard error of Z(t) is equal to:

$$\sigma(Z(t)) = \sqrt{\frac{\sigma^2(CC(t))}{NC(t)} + \frac{\sigma^2(CT(t))}{NT(t)}} \tag{2a}$$

$$where \quad \sigma^2(CC(t)) = \frac{1}{NC(t) - 1} \sum_{i,d \,\in\, NC(t)} (CC_{itd} - \mu(CC(t))^2 \tag{2b}$$

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$$and \quad \sigma^2(CT(t)) = \frac{1}{NT(t) - 1} \sum_{i,d \,\in\, NT(t)} (CT_{itd} - \mu(CT(t))^2. \tag{2c}$$

Figure 2 plots Z(t) and the pointwise two-sided 95% confidence bound for the E(Z(t)), the expected value of Z(t). For virtually all of the 15-minute intervals, the 95% confidence bound for the expected value of the difference between the mean consumption of the treatment group and the mean consumption of the control group covers 0. If E(Z(t)) is equal to zero for all 96 intervals, then the 95% coverage probability of each of the 96 confidence bounds dictates that approximately $5 \approx$ 0.05*96 of the confidence bounds would fail to cover zero. Figure 2 demonstrates that less than 5 of the pointwise confidence intervals fail to cover zero. Consequently, these pointwise confidence bounds are consistent with the hypothesis that mean consumption for customers in the treatment group is equal to mean consumption for all customers in the control group for all 15-minute intervals throughout the day for the pre-experiment period. This result is consistent with the hypothesis that the process of selecting customers into the treatment and control groups for the CPP experiment is random.

Customers in the CPP treatment group were notified the day before a "Spare the Power Day" by telephone or e-mail, depending on their choice when they returned their enrollment reply card. All non-holiday weekdays are eligible to be "Spare the Power Days." Customers in the control group were not notified of "Spare the Power Days." Both sets of customers consumed according to the standard residential tariff of 6.75 cents/KWh for the first 240 KWh consumed each month and 11.02 cents/KWh for all monthly consumption beyond this monthly baseline amount. Customers in the CPP treatment group received a rebate at the end of the experiment if their average consumption during the peak period of noon to 6 pm for all critical peak days was less than their reference consumption during peak periods (noon to 6 pm) in non-CPP weekdays that were eligible

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to be CPP days. The customer's reference period consumption is computed as the average of the customer's three highest peak period consumption levels over all non-holiday weekdays that were not CPP days during the experiment period of June 1, 2005 to October 14, 2005. Off-peak period consumption is defined as the customer's total consumption during all hours of the day besides noon to 6 pm. Table 1 lists the 12 CPP event days ("Spare the Power Days") during the experiment period.

To derive expressions for a treatment group customer's total payments for electricity and total rebates over the experiment period, define the following notation:

q_{ism} = consumption within period i of day s of month m

$q_{sm} = (q_{1sm}, q_{2sm})$, where i=1 denotes the off-peak period and i=2 denotes the peak period

$q = (q_{sm}, s=1,...,S_m, m=1,...,M)$ = vector of peak and off-peak consumption for experiment period

p_{bb} = price of electricity at less than the monthly baseline level of 240 KWh (6.75 cents/KWh)

p_{ab} = price of electricity at greater than the monthly baseline level of 240 KWh (11.02 cents/KWh)

p_r = rebate during peak period of CPP day (35 cents/KWh)

I_{sm}^{CPP} = 1 if day s of month m is a CPP day and 0 otherwise

$I^{CPP} = (I_{sm}^{CPP}, s=1,...,S_m, m=1,...M)$ = vector of CPP day indicator variables for experiment period

I_{sm}^{CPPE} = 1 if day s of month m is a weekday or non-holiday (eligible to be a CPP day) and 0 otherwise

S_m = total number of days in month m of sample period

M = total number of months in sample period

The total payments, TP, for electricity for treatment and control customers during the experiment period is equal to

$$
\begin{aligned}
TP(q_{s,m} \mid s=1...,S_m,\ m=1,...,M) &= \sum_{m=1}^{M} I(240 - \sum_{i=1}^{2}\sum_{s=1}^{S_m} q_{ism} \geq 0) p_{bb}(\sum_{i=1}^{2}\sum_{s=1}^{S_m} q_{ism}) \\
&+ \sum_{m=1}^{M} I(\sum_{i=1}^{2}\sum_{s=1}^{S_m} q_{ism} - 240 > 0)[p_{bb}*240 + p_{ab}(\sum_{i=1}^{2}\sum_{s=1}^{S_m} q_{ism} - 240)],
\end{aligned}
\tag{3}
$$

where $I(X>c)$ is the indicator function for the event $(X>c)$. The total rebate paid to a treatment group consumer, TR, is equal to

$$
\begin{aligned}
&TR(q_{s,m},\ I_{sm}^{CPP} \mid s=1...,S_m,\ m=1,...,M) \\
&= I(q_{ref}(q) - \frac{\sum_{m=1}^{M}\sum_{s=1}^{S_m} I_{sm}^{CPP} q_{2sm}}{\sum_{m=1}^{M}\sum_{s=1}^{S_m} I_{sm}^{CPP}}) \left[\sum_{m=1}^{M}\sum_{s=1}^{S_m} (q_{ref}(q) - q_{2sm}) I_{sm}^{CPP} p_r\right],
\end{aligned}
\tag{4}
$$

where $q_{ref}(q)$ is equal to the average of the three highest peak period consumption levels during non-CPP non-holiday weekdays during the experiment period. This equation implies that a treatment customer must have an average consumption during the peak period over all CPP days that is less than $q_{ref}(q)$, the customer's reference level of consumption. Treatment customers receive a rebate equal to the sum of the difference between their reference level and their peak period consumption over all CPP days times p_r.

To compute $q_{ref}(q)$, define A(NCPP) as the set of CPP-eligible days that are not CPP days. This set of day-month pairs is defined as follows:

$$
A(NCPP) = \{(s,m) \mid I_{sm}^{CCPE}*(1 - I_{sm}^{CPP}) = 1,\ s=1,...,S_m,\ m=1,..M\}
\tag{5}
$$

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Define

$$q_{2(1)} = \max_{(s,m) \in A(NCCP)} q_{2sm}, \quad q_{2(2)} = \max_{(s,m) \in A(NCCP) - (s(1),m(1))} q_{2sm}, \qquad (6a)$$

where $(s(1),m(1))$ are the values of s and m associated with $q_{2(1)}$, and

$$q_{2(3)} = \max_{(s,m) \in A(NCCP) - (s(1),m(1)) - (s(2),m(2))} q_{2sm}, \qquad (6b)$$

where $(s(2),m(2))$ are the values of s and m associated with $q_{2(2)}$. The values, $q_{2(k)}$, k=1,2, and 3, are

the 3 highest values of q_{2sm} over (s,m) pairs that are in the set $A(NCPP)$. In terms of this notation

the reference level is defined as:

$$q_{ref}(q) = \frac{1}{3} \sum_{k=1}^{3} q_{2(k)}. \qquad (6c)$$

As the above discussion clarifies, the total payment, TP, and total rebate, TR, are complex nonlinear

functions of q, the vector of consumption during the peak and off-peak periods each day during the

experiment and the entire time series of the indicator variable that day s of month m is a CPP day.

This nonlinear budget constraint invalidates the existence of a standard demand function for

electricity which relies on a linear budget constraint. Specifically, standard demand functions are

derived from the optimization problem:

$$max_{x \geq 0} U(x) \text{ subject to } \sum_{i=1}^{N} p_i x_i \leq M \qquad (7)$$

where $U(x)$ is the household's utility function and p_i the price of good i and x_i is the consumption

of good i, $x = (x_1, x_2, ..., x_N)$, and M is total expenditure. The optimized value of x_i as a function of

the vector of prices, $p = (p_1, p_2, ..., p_N)$, and total expenditure, M, is $x_i^*(p,M)$, the household's demand

for good i. The structure of the rebate mechanism faces the household with a nonlinear multiperiod

budget constraint over the duration of the experiment, which implies that a demand function for peak

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or off-peak electricity in the usual sense does not exist. A more complex model is required to recover a consistent estimate of the customer's price response to a CPP event. This model is outlined in the next section and its implications for customer behavior are explored.

3. A Dynamic Model of Electricity Consumption Under CPP with a Rebate

This section outlines a dynamic model of electricity demand under CPP with a rebate to illustrate a number of incentives faced by customers in the treatment group. The first incentive is caused by the existence of a before-baseline price for electricity and an after-baseline price for electricity each month. The second incentive is the result of basing a CPP customer's reference level on his or her consumption during peak periods of the days eligible but not chosen to be CPP days during the experiment. The final incentive arises because the rebate price only applies to consumption below the reference level. Consumption beyond the customer's reference level during the peak period of a CPP day has the same financial consequences it would have during a non-CPP day.

Let $U(q_{1sm}, q_{2sm}, z_{sm}, T_{sm})$ denote the customer's utility of consuming q_{1sm} kWhs during the off-peak period, q_{2sm} during the peak period and z_{sm} units of a composite of all other goods during day s of month m. I also assume that the utility the customer achieves from consuming this bundle depends on T_{sm}, the average temperature during day s of month m. Each day s of month m of the sample period the consumer is assumed to choose $(q_{1sm}, q_{2sm}, z_{sm})$ to maximize the sum of utility over the time remaining in the experiment, subject to the intertemporal budget constraint that the amount spent on electricity and the composite commodity, z, over the sample period is less than or equal to M. To simplify the discussion of the incentives treatment customers face under this CPP program,

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I assume the household has perfect foresight about CPP days and daily temperatures for the entire sample period.

The customer's dynamic choice problem can be written as:

$$\max_{\{q_{sl}\}_{s=t,\ldots,S_m,\ l=m,\ldots,M}} \sum_{n=0}^{M-m} \sum_{r=0}^{S_n-t} U(q_{1,t+r,m+n}, q_{2,t+r,m+n}, z_{t+r,m+n}, T_{t+r,m+n})$$

$$\text{subject to } TP(q) - TR(q, I^{CPP}) + \sum_{m=1}^{M} \sum_{s=1}^{S_m} z_{s,m} = M. \tag{8}$$

I assume that the price of z is equal to one for the entire experiment.

Following Browning (1991), re-write this problem in terms of its profit-function representation as

$$\max_{\{q_{sl}\}_{s=t,\ldots,S_m,\ l=m,\ldots,M}} r_{tm} \sum_{n=0}^{M-m} \sum_{r=0}^{S_n-t} U(q_{1,t+r,m+n}, q_{2,t+r,m+n}, z_{t+r,m+n}, T_{t+r,m+n})$$

$$- TP(q) + TR(q, I^{CPP}) - \sum_{m=1}^{M} \sum_{s=1}^{S_m} z_{s,m} \tag{9}$$

where r_{tm} is the inverse of the marginal utility of total expenditure (intuitively, the dollar price of one unit of utility) during day t of month m that causes the intertemporal budget constraint to hold. The first-order conditions for choosing off-peak and peak consumption during day t of month m can be written as:

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$$r_{tm} \frac{\partial U(q_{1tm}, q_{2tm}, x_{tm}, T_{tm})}{\partial q_{1tm}} = \frac{\partial TP(q)}{\partial q_{1tm}} \qquad (10)$$

$$r_{tm} \frac{\partial U(q_{2tm}, q_{2tm}, x_{tm}, T_{tm})}{\partial q_{2tm}} = \frac{\partial TP(q)}{\partial q_{2tm}} - \frac{\partial TR(q, I^{CPP})}{\partial q_{2tm}} \qquad (11)$$

From equation (3), $\dfrac{\partial TP(q)}{\partial q_{1tm}}$ and $\dfrac{\partial TP(q)}{\partial q_{2tm}}$ equal to either p_{bb} or p_{ab} depending on the total consumption

in the month up to day t of month m. From equation (4), $\dfrac{\partial TR(q, I^{CPP})}{\partial q_{2tm}}$ equals $-p_r$ if day t of month

m is a CPP day, $\dfrac{\partial TR(q, I^{CPP})}{\partial q_{2tm}} = \dfrac{\partial q_{ref}(q)}{\partial q_{2tm}} p_r$ if it is not a CPP day but is eligible to be one, and

$\dfrac{\partial TR(q, I^{CPP})}{\partial q_{2tm}} = 0$ if it not eligible to be a CPP day. This yields the following three first-order

conditions for the case that day t is a CPP-eligible day, the customer has not yet consumed 240 KWh

in the month, and the customer will receive a rebate at the end of the experiment:

$$r_{tm} \frac{\partial U(q_{1tm}, q_{2tm}, z_{tm}, T_{tm})}{\partial q_{1tm}} = p_{bb} \qquad (10a)$$

$$r_{tm} \frac{\partial U(q_{2tm}, q_{2tm}, z_{tm}, T_{tm})}{\partial q_{2tm}} = p_{bb} + p_r \qquad (11\text{-CPP})$$

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$$r_{tm} \frac{\partial U(q_{2tm}, q_{2tm}, z_{tm}, T_{tm})}{\partial q_{2tm}} = p_{bb} - \frac{\partial q_{ref}(q)}{\partial q_{2tm}} p_r \qquad \text{(11-NCPP)}$$

A similar set of first-order conditions holds with p_{ab} replacing p_{bb}, if the household has consumed more than 240 KWh in the month before day t of month m. Because $\dfrac{\partial q_{ref}(q)}{\partial q_{2tm}}$ is greater than or equal

to zero during non-CPP days that are eligible to be CPP days, the customer faces an effective price of electricity less than or equal to p_{bb}, and therefore has an incentive to increase his consumption during this peak period because of the incentives provided by the CPP program. Equation (11-CCP) shows that during CPP days the customer faces an effective price greater than p_{bb} and therefore has an incentive to reduce his consumption if he will receive a rebate.

To understand the intuition behind equation (11-NCPP), recall that the household can consume an additional KWh of electricity in a peak period of the day early in the month for 6.75 cents/KWh. If this increases by 1 KWh any of the $q_{2(k)}$ (for k=1,2, or 3) that enter the household's reference level, $q_{ref}(q)$, used to compute its rebate for all 12 CPP periods, the household can earn a rebate of 35 cents/KWh times 12, the number of CPP days, divided by 3 (because q_{ref} is the average of the three highest values of peak period consumption during CCP-eligible days that are not CPP days). This implies a total rebate of \$1.40 for a 6.75 cent expediture, which provides a very high rate of return to the household on consuming additional electricity to increase the $q_{ref}(q)$. Even if the customer purchases this additional KWh to increase his $q_{ref}(q)$ at the above-baseline price of 11.07 cents/KWh, he still earns more than ten times this amount in rebates, assuming that he is eligible to receive a rebate.

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4. A "Treatment Effects" Approach to Assessing the Impact of CCP Events

This section abstracts away from the many complications associated with modeling the customer's total-utility-maximizing pattern of electricity consumption in peak and off-peak periods during the CPP experiment. I focus on estimating the "treatment effect" associated with a CPP event on the peak and off-peak period consumption of treatment households relative to the control households. As the model of the previous section demonstrates, part of the estimated reduction in consumption for treated households during CPP days could be due to the incentive caused by the rebate mechanism to increase peak period consumption during CPP-eligible days that are not CPP days. By doing so, the household receives a larger rebate. Following the presentation of the treatment effects estimation results and an investigation of their sensitivity to various modeling assumptions, I present evidence supporting the view that a significant fraction of the estimated treatment effect is due to this incentive to increase the customer's reference level.

The standard treatment effects estimation framework relies on the assumption that assignment to the treatment and control groups is random. Figures 1 and 2 are consistent with random assignment of customers to the treatment and control groups. I compute a non-parametric estimate of the mean treatment effect of a CPP day on both peak and off-peak consumption using the following specification for peak and off-peak period consumption:

$$\ln(q_{jt}) = \alpha_j + \lambda_t + \beta \ Treat(j)*CPP(t) + \epsilon_{jt}, \quad (t=1,..,T, \ i=1,...N) \tag{12}$$

$\ln(q_{jt})$ is the natural logarithm of consumption of customer j during day t, Treat(j) is equal to 1 if customer j is in the treatment group and zero otherwise, CPP(t) is equal to 1 if day t is a CPP day and zero otherwise. The α_j, j=1,...,123 are customer-level fixed effects and the λ_t, t=1,...135 are day-of-sample fixed effects. The customer-level fixed-effects control for persistent differences in peak

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period and off-peak period consumption across customers over time and the day-of-sample fixed effects control for all persistent differences in consumption across days. The day-of-sample fixed effects account for weather, and other common factors impacting all APU customers during a given day. Figure 3 plots the day-of-sample fixed effects for the peak period regression results and the average daily temperature at the Fullerton airport. The day-of-sample fixed effects closely follow the pattern of average daily temperature over the sample, although there are noticeable differences in the two time series at certain points during the experiment.

Because all of the regressors in equation (12) are indicator variables, the OLS estimate of β is the mean difference in consumption between the treatment and control groups during CPP days. An alternative interpretation of the estimate of β can be obtained by taking the difference between expected value of equation (12) on a CPP day (t^*) and a non-CPP day (t) for a customer in the treatment group. This yields $E(\ln(q_{jt^*}) - (\ln(q_{jt}))|\text{Treat(j)}=1) = \lambda_t + \beta$. Repeating this process for customer k in the control groups yields $E(\ln(q_{kt^*}) - (\ln(q_{kt}))|\text{Treat(k)}=0) = \lambda_t$. Consequently, taking the difference between $E(\ln(q_{jt^*}) - (\ln(q_{jt}))|\text{Treat(j)}=1)$ and $E(\ln(q_{kt^*}) - (\ln(q_{kt}))|\text{Treat(k)}=0)$ yields

$$E(\ln(q_{jt^*}) - (\ln(q_{jt}))|\text{Treat(j)}=1) - E(\ln(q_{kt^*}) - (\ln(q_{kt}))|\text{Treat(k)}=0) = \beta. \qquad (13)$$

Consequently, the estimate of β obtained from applying ordinary least squares to equal (12) is often called the difference-in-difference estimate of the treatment effect. Note that the difference between $E(\ln(q_{jt^*}) - (\ln(q_{jt}))|\text{Treat(j)}=1)$ and $E(\ln(q_{kt^*}) - (\ln(q_{kt}))|\text{Treat(k)}=0)$ for any j in the treatment group and any k in the control group and any CPP day t is equal to β, so that it is a nonparametric treatment effect of a CPP day because it does not rely on any functional form assumption for the impact of other covariates.

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Table 2 presents the results of estimating (12) for daily peak and off-peak consumption. To make my inferences as robust as possible to misspecification of the properties of the ϵ_{it} over time and customers, I compute standard errors using the approach described in Arellano (1987). Re-writing equation (7) by stacking all observations for a given individual into a single vector yields

$$\mathbf{y_i} = \mathbf{X_i}\boldsymbol{\beta} + \Lambda + \boldsymbol{\iota}_T\boldsymbol{\alpha_i} + \boldsymbol{\epsilon_i} \tag{14}$$

where $\mathbf{y_i} = (\ln(q_{i1}), \ln(q_{i2}), ...\ln(q_{iT}))'$, $\boldsymbol{\iota}_T = (1,1,...,1)'$, $\Lambda = (\lambda_1, \lambda_2,...,\lambda_T)'$, $\boldsymbol{\epsilon_i} = (\epsilon_{i1}, \epsilon_{i2}, ...\epsilon_{iT})'$ and $\mathbf{X_i}$ = (Treat(i)*CPP(1),Treat(i)*CPP(2),...,Treat(i)*CPP(T))'. Arellano's procedure computes a consistent estimate of the covariance matrix of $(\boldsymbol{\beta}',\Lambda')'$ that allows each $\boldsymbol{\epsilon_i}$ vector to have a different positive definite covariance matrix Σ_i. This implies that these standard errors are robust to arbitrary forms for the Σ_i across customers and each Σ_i allows for arbitrary forms of autocorrelation of the ϵ_{it} over time for a given customer. These standard errors provide very conservative measures of the precision of the estimates of $(\boldsymbol{\beta}',\Lambda')'$.

Table 2 also reports estimates of equation (12) assuming that the α_i are random effects uncorrelated with the λ_t and Treat(i)*CPP(t). The estimate of β obtained from the random effects estimation procedure is nearly identical to the estimate obtained from the customer-level fixed-effect estimator. A test of the hypothesis that the probability limit of the fixed effects estimates of $(\boldsymbol{\beta}',\Lambda')'$ is equal to the probability limit of the random effects estimates of $(\boldsymbol{\beta}',\Lambda')'$ yields no evidence against the validity of the null hypothesis. The value of the test statistic is substantially less than the 0.05 critical value of a χ^2_{136} random variable. This hypothesis testing result provides further evidence in favor of the validity of the procedure used to select households into the treatment and control groups for the CPP pricing experiment. If the selection into the treatment and control groups was non-random, we would expect some correlation between the regressors and the α_i.

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The estimates of β reported in Table 2 imply that treatment group customers consume an average of approximately 12 percent less electricity during the peak period of CPP days than control group customers. This estimate is statistically significantly different from zero for both the fixed-effect estimates that use the conservative Arellano (1987) method for computing standard errors and the more efficient random effects estimator (under the assumption that these random effects are uncorrelated with the regressors).

Based on the results of specification tests for autocorrelated error terms, I explored specifications for ϵ_{it} which assume it follows a second-order autoregressive process of the form

$$\epsilon_{it} = \rho_1 \epsilon_{it-1} + \rho_2 \epsilon_{it-2} + \nu_{it}. \tag{15}$$

As shown in Table 1, the estimate of β did not change appreciably after accounting for the autocorelation in ϵ_{it}, although the estimated precision of the estimate of β did improve.

I also explored whether the treatment effect of a CPP event depended on the temperature during that day. For this analysis I used Ln(Temp(t)), the natural logarithm of the daily average temperature during day t at the Fullerton airport shown in Figure 3. I then estimated the regression:

$$\ln(q_{jt}) = \alpha_j + \lambda_t + \beta \ Treat(j)*CPP(t) + \delta Treat(j)*CPP(t)*Ln(Temp(t)) + \epsilon_{jt}, \tag{16}$$

Table 3 reports the fixed effects estimates of β and δ in equation (11) with the Arellano (1987) standard errors, the random effects estimates, and the fixed effects feasible generalized least squares estimates with errors that follows an AR(2) process. All of these results recover a positive estimate of β and a negative estimate of δ. These coefficients estimates are very similar across the three estimation procedures. These all imply that the absolute value of the predicted reduction in peak period consumption by customers in the treatment group is larger during higher temperature CPP days. A ten percent higher temperature during the day predicts a 7 percent larger reduction in

consumption during a CPP day for the treatment group relative to the control group. Although the magnitudes of the estimates are similar across the models estimated, none of the coefficient estimates are as precisely estimated as the values for β in Table 2. Nevertheless, these results are suggestive of larger percent consumption reductions in response CPP days by the treatment group during higher temperature days.

The declaration of a CPP day appears to have no impact on off-peak period consumption for treatment customers versus control customers. Table 2 performs the same regressions using the natural logarithm of off-peak consumption as the dependent variable. All of the coefficient estimates associated with Treat(i)*CPP(t) are small in absolute value and very imprecisely estimated. These results are consistent with the view that any impact of CPP days is confined to the peak period of the CPP day. The reduction in consumption during peak periods of CPP days does not appear to show up as higher consumption in off-peak periods of the same day.

I now investigate the impact of CPP days on consumption in neighboring peak and off-peak periods. To do this, I augment equation (12) as follows:

$$\ln(q_{jt}) = \alpha_j + \lambda_t + \beta \ \text{Treat(j)*CPP(t)} + \gamma \ \text{Treat(j)*CPP(t-1)} + \epsilon_{jt} \qquad (17a)$$

and

$$\ln(q_{jt}) = \alpha_j + \lambda_t + \beta \ \text{Treat(j)*CPP(t)} + \gamma \ \text{Treat(j)*CPP(t+1)} + \epsilon_{jt.} \qquad (17b)$$

Equation (17a) is used to determine if a CCP event the previous day predicts a change in consumption by treatment versus control customers during the peak period or off-peak period of the following day. For example, one might expect that a customer that reduces her consumption by a substantial amount in the peak period of day t may systematically consume more during the off-peak or peak period of the following day. Table 4 presents estimates of equation (17a) for both peak and

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off-peak consumption and finds no evidence for the hypothesis that any of the consumption reduction due to a CPP event in day t, shows up as systematically higher consumption in the peak or off-peak period of day t+1. The estimates of γ for equation (17a) for both peak and off-peak consumption are not statistically significantly different from zero.

Equation (17b) attempts to determine if in response to a day-ahead notification of a CPP day, customers in the treatment group alter their electricity consumption during the current day. Table 4 provides little evidence of a change in consumption in anticipation of a CPP event the following day. The estimates of γ for equation (17b) for peak and off-peak consumption are not statistically significantly different from zero.

I also investigated whether customers in the treatment group increased their consumption during CPP-eligible days that are not CPP days in order to increase their reference levels. These actions increase the likelihood they will receive a rebate and amount of the rebate if they do. I first restricted the sample of observations to CPP-eligible days that are not CPP days and ran the following regression:

$$\ln(q_{jt}) = \lambda_t + \beta \text{Treat}(j) + \epsilon_{jt}, \tag{13}$$

for both peak and off-peak consumption. Table 5 presents the results of these regressions. Customers in the treatment group consume approximately 7 percent more during peaks periods of CPP-eligible days that are not CPP days and 14 percent more during the off-peak periods of these days than customers in the control group. These results suggest that close to half of the 12 percent reduction in peak period consumption of treatment customers relative to control customers during CPP days may be due to the incentive for higher consumption during non-CPP days that are eligible to be designated CPP days. A surprising aspect of these results is the magnitude of the difference

in mean consumption between the treatment and control groups during the off-peak period of CPP-eligible days. Both of these results suggest that there is significant promise associated with estimating the dynamic model described in the previous section.

5. Customer Behavior Under the CPP Pricing Experiment

This section summarizes the behavior of customers in the treatment and control groups during the period of the CPP pricing experiment. For virtually all customers in the treatment group, the CPP pricing experiment was a very financially rewarding experience. All customers in the treatment group with more than 130 days of meter readings during the sample period received rebates. However, there was considerable heterogeneity among customers in the total rebates they received. A number of customers received total rebates over the period of the experiment in excess of $50 and one customer received a rebate of over $100. Another important conclusion from the experiment is that the vast majority of rebates appear to have been paid for by consumption reductions during CPP days that treatment customers would have made without the financial incentives provided by the CPP event. One explanation for this result is the method used to set the reference level of peak period consumption was too generous. The other explanation is the incentive effect of CPP customers to increase their consumption during the peak hours of non-CPP days to increase their reference level.

Figures 4-T and 4-C plot the total electricity bill before rebates for all customers in the treatment and control groups with more than 130 days of meter readings. There are a total of 31 customers in the control group and 57 in the treatment group that met this requirement. These plots show a roughly similar distribution of total bills before rebates over the experiment period for the treatment and control group. Figures 5-T and 5-C plot the total amount paid for electricity

purchased at the before-baseline price of 6.75 cents/KWh by each customer during the experiment period. For these two figures and all remaining figures, customers in the treatment and control groups are listed in the same order as given in Figures 4-T and 4-C. Figure 6-T and 6-C show the total amount paid for electricity purchased at the after-baseline price for both the treatment and control groups. There are several customers in the treatment and control groups that do not purchase any electricity at the after-baseline price during the period of the experiment.

Figure 7-T plots the total rebate paid to each of these treatment customers. There are a number of customers that received sizeable rebate payments. Figure 8-T plots the ratio of each customer's total rebate over the experiment period to the customer's total bill over the experiment period. Virtually all customers received rebates that were more than 10 percent of their total bill during the experiment. One customer received a total rebate equal to 40 percent of his total bill during the experiment period.

To assess the generosity of the process used to set the reference level of consumption, Figure 9-T plots the total amount of KWh that were paid rebates over the sample period for each customer in the treatment groups. I call these "Paid for Consumption Reductions" that the CPP experiment actually paid for. For a number of customers, these consumption reductions are enormous, implying either that the process used to set the reference level was overly generous and/or that these customers clearly understood the incentives to increase their reference level of consumption. The results presented in Table 5, imply that the second explanation is likely to be true for customers with a total peak period reduction above 100 KWh.

For comparison, Figure 10-T plots an estimate of the total KWh that were not consumed as a result of all CPP events during experiment for these treatment group customers. This "Predicted

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Consumption Reduction" figure is computed using the following procedure. Let $X(j)$ equal total

consumption during the 12 CPP periods by customer j. Assuming that 0.12 is the average peak

period consumption reduction for a CPP event, then $X(j)*(0.12/0.88)$ is equal to the predicted total

consumption reduction from declaring CPP days. This equation follows from the logic that if $Y(j)$

is the customer's total peak period consumption if there were no CPP events during these days and

$X(j)$ is the observed consumption with these CPP events, then the treatment effects estimate implies

that $X(j) = 0.88*Y(j)$, or $X(j)/ 0.88 = Y(j)$. The treatment effect estimate implies the predicted

reduction in $Y(j)$ as a result of CPP day, is $Y(j)*0.12$, which yields the above result.

As should be clear from comparing Figure 10-T to Figure 9-T, for many treatment group

customers, the amount of electricity that was paid the rebate (the Paid for Consumption Reduction)

was dramatically less than the amount that was predicted to be reduced (the Predicted Consumption

Reduction) by the treatment effects estimate for all of the CPP days during the experiment. The total

Paid for Consumption Reductions over all of these treatment group customers divided by the total

Predicted Consumption Reductions for these same customers yields 6.8. This implies that customers

were paid almost 7 times more per KWH for their demand reductions than would be predicted by

the estimated average consumption reduction in response to a CPP day. This result highlights the

importance of the process used to set the customer's reference consumption level. Setting too high

of a reference level makes it virtually impossible for a CPP program to be self-financing in the

sense that the total wholesale energy purchase costs saved exceeds the total rebates paid to achieve

them.

To assess the extent to which the results in Figures 9-T and 10-T are due to setting the

reference level too high or the outcome of the incentives for customers in the CPP treatment group

have to increase their reference level, I computed the reference level for customers with more than 130 days of observations in the control group following the same algorithm used to compute the reference level for customers in the treatment group. Although customers in the control group were not notified of CPP days or eligible to receive rebates, I used the same formula applied to the treatment group customers to compute the rebate these customers would have received for their actual consumption during CPP days. Because these customers did not receive a rebate, they had no incentive to reduce their consumption on CPP days. They also had no incentive to increase their consumption on non-CPP days that were eligible to be CPP days in order to increase their refund amount. I also computed a Predicted Consumption Reduction using the estimated treatment effect of 12% applied to the actual consumption of each of the control group customers during the 12 CPP days during the sample period. I use 0.12 in this case because I observe the consumption in the absence of the incentives of CPP events for the control group, which is Y(j) in the earlier notation. Figure 9-C plots the total difference between each customer's reference level and actual consumption during CPP days–Paid for Consumption Reductions. Figure 10-C plots the Predicted Consumption Reduction for the 12 CPP days for each control group customer. These two figures show the same dramatic difference between the KWh reductions paid for with rebates (that weren't actually paid) and the predicted reduction in peak period consumption implied by the average treatment effect of a CPP day that appear in Figures 9-T and 10-T. Figure 7-C plots the rebates customers in the control would have received for their actual consumption during CPP days given their reference level. These rebates are slightly smaller than the rebates actually paid to the treatment group customers. This is consistent with a significant treatment effect associated with a CCP day for the treatment group relative to the control group.

The differences in the level of the two variables–Paid for Consumption Reductions and Predicted Consumption Reductions–across customers in the control group is not as pronounced as it is for customers in the treatment group. In particular, the ratio of the total amount of "Paid for Reductions" divided by the total amount of "Predicted Reductions" is equal to 5.9, compared to 6.8 for the treatment group. This suggests that the vast majority of the rebate payments made to treatment group customers were for reductions in consumption relative to their reference level that they would have undertaken without the incentives of the CPP program.

Combining these results with the estimation results from the previous section leads to the conclusion that a significant fraction of the Predicted Consumption Reductions during CPP days by customers in the treatment group is due to higher consumption by these customers during the peak periods of non-CPP days. A rough estimate is that approximately half of the predicted consumption reduction is due to this increase in consumption during non-CPP periods. However, estimation of the dynamic model customer electricity demand outlined in Section 3 is necessary to provide a theoretically valid estimate of the magnitude of this effect.

These results also underscore the importance of the process used to set the reference level for customers on the CPP rate. The approach used in the APU experiment appears to be much too generous. A topic for future research is how to set this reference level. Estimates of the dynamic model of electricity demand in Section 3 can provide very useful input into the design of the mechanism used to determine the reference level.

6. Factors Influencing the Net Benefits of Universal CPP for Residential Consumers

This section discusses the major factors influencing the net benefits of a universal CPP program with a rebate for residential consumers. There are three major factors that determine the

financial viability of universal adoption of CPP pricing for residential consumers within a given geographic area. The first concerns the number of customers and size of their peak demand relative to the wholesale market over which prices are set. The second relates to the methodology used to set the reference level relative to which rebates are paid. The final issue concerns the magnitude of the price cap on the short-term wholesale market.

The reason that the number of residential customers on a CPP pricing program impacts the financial viability of universal CPP for residential customers is because the decision to declare a CPP day can impact day-ahead and real-time wholesale prices. Declaring a CPP day for residential customers with an aggregate peak demand that is a very small fraction of the peak demand for the wholesale market is unlikely to have much of an impact of day-ahead or real-time electricity prices. Under these circumstances, the major source of savings to the retailer from offering a CPP rebate is the reduction in wholesale energy purchase costs from serving these CPP customers. This is likely to be the case for APU, which has a peak demand of 550 MW with approximately 25% of its load from residential customers. A 12 % load reduction from 25% of its load amounts to a peak demand reduction of approximately 3% or 16.5 MW. This reduction in peak demand is unlikely to reduce the day-ahead or real-time price in the California ISO control area.

The same conclusion does not hold if CPP pricing is adopted as the default rate for all residential load in California. Residential demand is approximately 30% of total demand in California, and a 12% reduction in statewide residential demand on a statewide peak of approximately 50,000 MW implies a peak demand reduction of 3.6% or 1800 MW. This consumption reduction is likely to exert significant downward pressure on day-ahead and real-time prices, particularly during high-demand load periods when expensive-to-operate generation units

are needed to meet demand and certain suppliers possess substantial unilateral market power to raise prices in the day-ahead and real-time markets.

Given the levels of forward contracting for energy that currently exist in California, the ability to reduce system demand by roughly 4% with a day-ahead notice can substantially mitigate the volatility in short-term energy prices. This has the additional benefit of reducing the expected profits to suppliers from selling in the short-term energy markets. This, in turn, reduces the price at which they are willing to enter into fixed price forward contracts with load-serving entities. Consequently, the presence of a substantial amount of load on a CPP program can reduce both short-term energy prices and long-term contract prices that retailers pay to serve CPP customers and other customers on fixed-price tariffs. This is the so-called multiplier effect of having some fraction of customers on a CPP program. The benefit of their efforts to reduce electricity demand and wholesale prices, to the extent they are successful, are shared by all customers.

However, the more customers there are on the CPP rate or other rates that require them to pay prices that vary with real-time system conditions, the greater is the impact of their behavior on market prices and the greater are the aggregate benefits of their actions on reducing wholesale energy payments to customers facing retail prices that do not vary with real-time system conditions. Computing how much the actions of CPP customers impact short-term prices is not as straightforward. Computing the impact of these actions on long-term contract prices is even more complex. Finally, quantifying the extent to which all other customers will be able to capture these price reductions in their wholesale energy costs is also very difficult. Nevertheless, all three of these factors are extremely important sources of benefits to the universal adoption of CPP for residential customers.

A final issue that mitigates against the need for a large number customers on the CPP program in order to achieve significant short-term and long-term price reduction benefits is the use of locational marginal pricing (LMP) to sell wholesale electricity to retailers. If retailers pay the LMP at their location for their wholesale energy needs, then small changes in the demand in their local market can have a substantial impact on LMPs in the day-ahead and real-time market at their location in the network, even if the system-wide load-weighted average LMP is virtually unaffected by this change in local demand. This logic highlights an important shortcoming in US wholesale markets that use LMP to charge retailers for the electricity they purchase to serve their load obligations according to some average price over a large geographic area. The upside of this market rule is that retailers in costly-to-serve locations are able to pay an average price over a large geographic area. The downside is that these retailers have little ability to influence this average price with reductions in demand for electricity of the magnitude implied by the estimated CPP treatment effect, which limits the benefits these retailers can receive from universal adoption of CPP with rebates for residential customers.

The process used to set the reference level is another key determinant of the financial viability of universal CPP rates with rebates for residential customers. The APU experiment provides an excellent example of the financial consequences of setting the reference level too high. The above calculations show that APU paid an average of 7 times more per KWh for the load reductions achieved during CPP days than the rebate amount. This means than instead of 35 cents/KWh, APU paid almost $2.50/KWh for the actual load reductions achieved during the peak period of CPP days. At this price per KWh of load reduction, it is unlikely that any CPP rebate program would be financially viable in the sense that the reductions in wholesale energy purchase

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costs to the retailer are greater than the total dollar amount of rebates paid to customers on the CPP rate.

Any mechanism for setting the reference level is likely to pay more per KWh for actual load reductions than the stated per KWh rebate for reductions relative to the customer's reference consumption level. However, it does seem very possible to achieve a ratio of "Paid for Consumption Reductions" to "Predicted Consumption Reduction" that is significantly less than 7 to 1. There are a number of options for the process used to determine a CPP customer's reference level. One promising approach is for the customer to buy their reference level by choosing to pay according to a lower fixed price during peak and off-peak days in exchange for a lower CPP reference level that makes rebates less likely and pays less dollars in rebates in spite of a very high cents/KWh rebate payment. Alternatively, a customer wanting a very high reference level would have to pay for it through a higher fixed price during peak and off-peak days and a lower cents/KWh rebate payment. A major challenge associated with this "buy your reference level" approach is setting the trade offs between the fixed price of electricity, the CPP rebate price, and level of the customer's reference level.

A final issue that impacts the financial viability of universal CPP for residential customers is the level of the bid cap on the wholesale market. The current level of the bid cap in the California ISO real-time market is $400/MWh. At this level of the bid cap, the maximum amount that retailers can save from reducing demand by 1 KWh is 40 cents/KWh, which is approximately equal to the effective price paid for electricity during a CPP day that occurs before a customer has crossed its monthly baseline. At the current bid cap in the eastern US markets of $1000/MWh, the maximum savings to a retailer from a 1 KWh reduction is $1/KWh, which significantly increases the potential

financial benefit to the retailer from offering a CPP rate, even if the load reductions by the CPP customers do not impact the market-clearing price in the day-ahead or real-time markets. Even at this bid cap, the current APU CPP rebate mechanism is not likely to be financially viable. However, if the ratio of "Paid for Consumption Reductions" to "Predicted Consumption Reductions" is in the range of 2 to 1, then a program that implements a CPP event when the day-ahead price is expected to be above $900/Mwh could be self-financing. The expected rebate payments would be less than the expected wholesale energy cost reductions during CPP event days.

It is hard to deny that universal CPP in a wholesale market with a substantially higher bid cap than $1,000/MWh or no bid cap at all has positive net benefits. However, recent events in US electricity markets make it unlikely that it will be possible to raise bid caps above $1000/MWh in the near future. In addition, the recent trend in a number of US markets to implement capacity payments mechanisms that limit the level and volatility in short-term energy prices further reduces the potential benefits from universal CPP for residential customers. Many analysts argue that these capacity payment mechanisms result in too much new generation capacity on a system-wide basis, which significantly depresses short-term wholesale energy prices and the value of price-responsive final demand. In addition, these capacity payments represent a significant share of total electricity costs to final consumer that they cannot avoid by consuming less electricity.

7. Concluding Comments

CPP with a rebate mechanism represents a potentially attractive way to introduce final consumers to the benefits of responding to retail prices that vary with real-time system conditions. The experience of the APU pricing experiment points out a number of potential problems for retailers that decide to implement these programs. The first is how to set the customer's reference

level to avoid paying for reductions relative to the reference level that the customer would make without the CPP rebate incentive. The second issue concerns how to set the level of the rebate payment and the reference level to have a reasonable assurance that the total amount paid out in rebates is less than the reductions in the retailer's total wholesale electricity purchase costs that are made possible by the consumption reductions during the peak periods of CPP days by consumers on the CPP program.

Although customers in the APU program clearly have an incentive to increase their peak period reference level in order to increase the rebate payment they receive for reducing their consumption during peak periods of CPP days, this aspect of the program is not a significant concern if the total cost of the predicted demand reductions were not very large. What is most valuable from a system reliability and market efficiency perspective is the ability to reduce overall system demand or demand at a specific location in the network on very short notice. Specifically, the ability to achieve a 50% reduction in consumption relative to an inflated level of consumption in all CPP-eligible non-CPP days is superior to a 10% reduction in consumption from a reference level that does not reflect this incentive.

Consequently, it may be optimal to choose a process for determining a customer's reference level that has some incentive to inflate consumption in non-CPP days in order to obtain a larger and more reliable consumption reduction during peak periods of CPP days. This aspect of the design of CPP programs is another topic for future research.

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Table 1: Spare the Power Days During Experiment Period June 1, 2005 to October 14, 2005
07/13/05
07/21/05
07/22/05
08/03/05
08/05/05
08/25/05
08/26/05
10/05/05
10/06/05
10/12/05
10/13/05
10/14/05

Table 2: CPP Treatment Effect Estimates Under Different Assumptions				
	Natural Log of Peak Period Consumption in KWh		Natural Log of Off-Peak Period Consumption in KWh	
	Coefficient Estimate	Standard Error	Coefficient Estimate	Standard Error
Variable Name	Fixed Effects*			
Treat(i)*CPP(t)	-0.1215	0.0579	0.0138	0.0316
	Random Effects			
Treat(i)*CPP(t)	-0.1207	0.0308	0.0144	0.0189
	Feasible Generalized Least Squares**			
Treat(i)*CPP(t)	-0.1462	0.0505	0.0118	0.0220
*Arrellano (1987) covariance matrix used, **Estimates computed using Cochrane-Orcutt procedure assuming AR(2) errors. All regressions include 135 day-of-sample fixed effects.				

Peak Period = noon to 6 pm
Off-Peak Period = all other hours of the day

Table 3: Temperature Dependent CPP Treatment Effects Under Different Assumptions		
Variable	Coefficient	Standard Error
	Fixed Effects*	
Treat(i)*CPP(t)	2.9869	1.7184
Treat(i)*CPP(t)*Ln(Temp(t))	-0.6894	0.3878
	Random Effects	
Treat(i)*CPP(t)	2.9927	1.6510
Treat(i)*CPP(t)*Ln(Temp(t))	-0.6905	0.3677
	Feasible Generalized Least Squares**	
Treat(i)*CPP(t)	2.1326	1.4345
Treat(i)*CPP(t)*Ln(Temp(t))	-0.5058	0.3233

*Arrellano (1987) covariance matrix used, **Estimates computed using Cochrane-Orcutt procedure assuming AR(2) errors. All regressions include 135 day-of-sample fixed effects.

Table 4: Leads and Lags in CPP Treatment Effects		
Dependent Variable: Log of Peak Period Consumption Fixed Effects with Time-of-Day Dummies*		
Variable	Coefficient	Standard Error
Treat(i)CPP(t)	-0.1269	0.0532
Treat(i)*CPP(t-1)	0.0172	0.0469
Dependent Variable: Log of Off-Peak Period Consumption Fixed Effects with Time-of-Day Dummies*		
Treat(i)*CPP(t)	0.0142	0.0258
Treat(i)*CPP(t-1)	0.0018	0.0292
Dependent Variable: Log of Peak Period Consumption Fixed Effects with Time-of-Day Dummies*		
Treat(i)*CPP(t)	-0.1278	0.0555
Treat(i)*CPP(t+1)	0.0175	0.0328
Dependent Variable: Log of Off-Peak Period Consumption Fixed Effects with Time-of-Day Dummies*		
Treat(i)*CPP(t)	0.0091	0.0298
Treat(i)*CPP(t+1)	0.0195	0.0197

*Arrellano (1987) covariance matrix used.

Table 5: Consumption Differences for Treatment and Control Customers During Non-CPP Days		
Variable	Coefficient Estimate	Standard Error
Dependent Variable: Log of Peak Period Consumption Day-of-Sample Fixed Effects for All Non-CPP Days		
Treat(i)	0.0675	0.0195
Dependent Variable: Log of Off-Peak Period Consumption Day-of-Sample Fixed Effects for All Non-CPP Days		
Treat(i)	0.1406	0.01467

Figure 1: Average Daily Load Shape at 15-Minute Intervals for Treatment and
Control Groups During Pre-Sample Period

red=control group   blue=treatment group
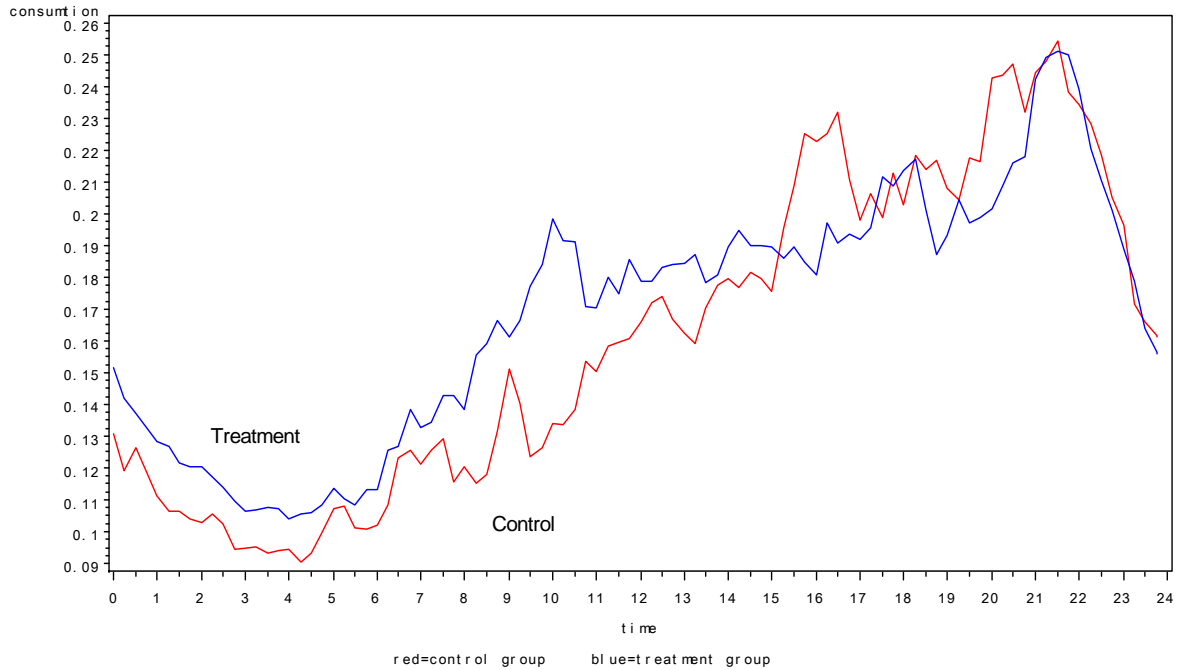
Figure 2: Pointwise 95% Confidence Intervals for Pre-Experiment Difference
Between Mean Consumption of Treatment and Control Group
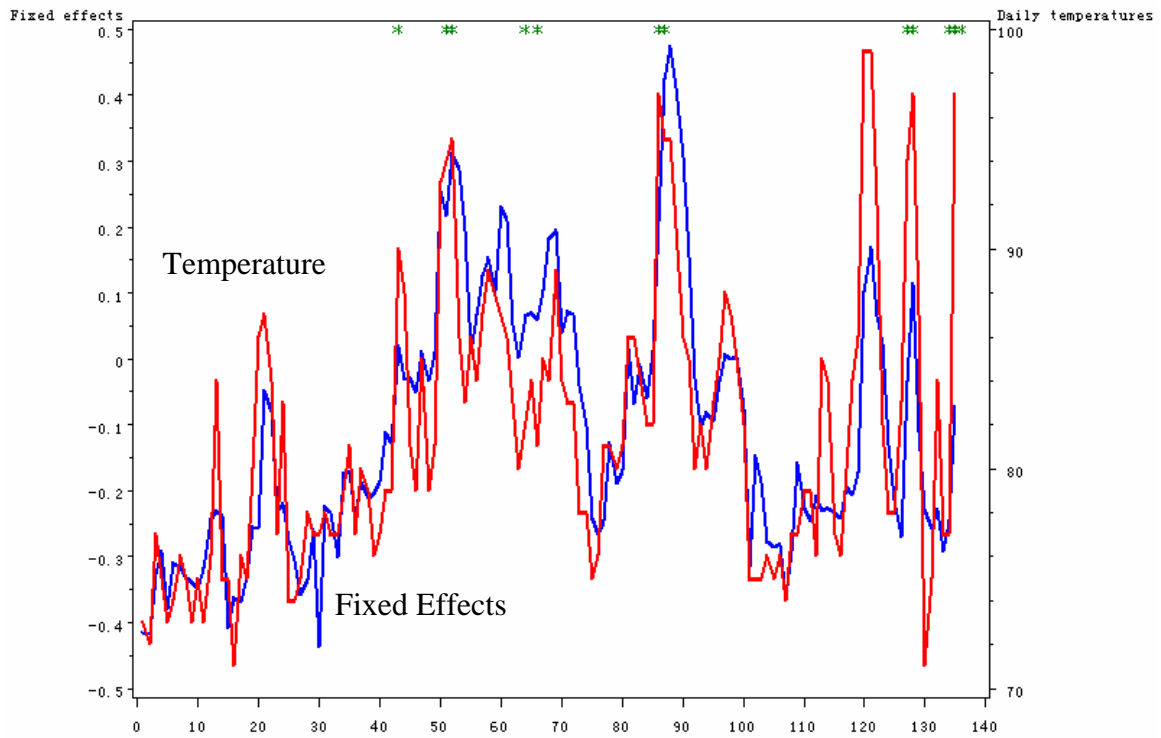for 15-Minute Intervals Throughout the Day
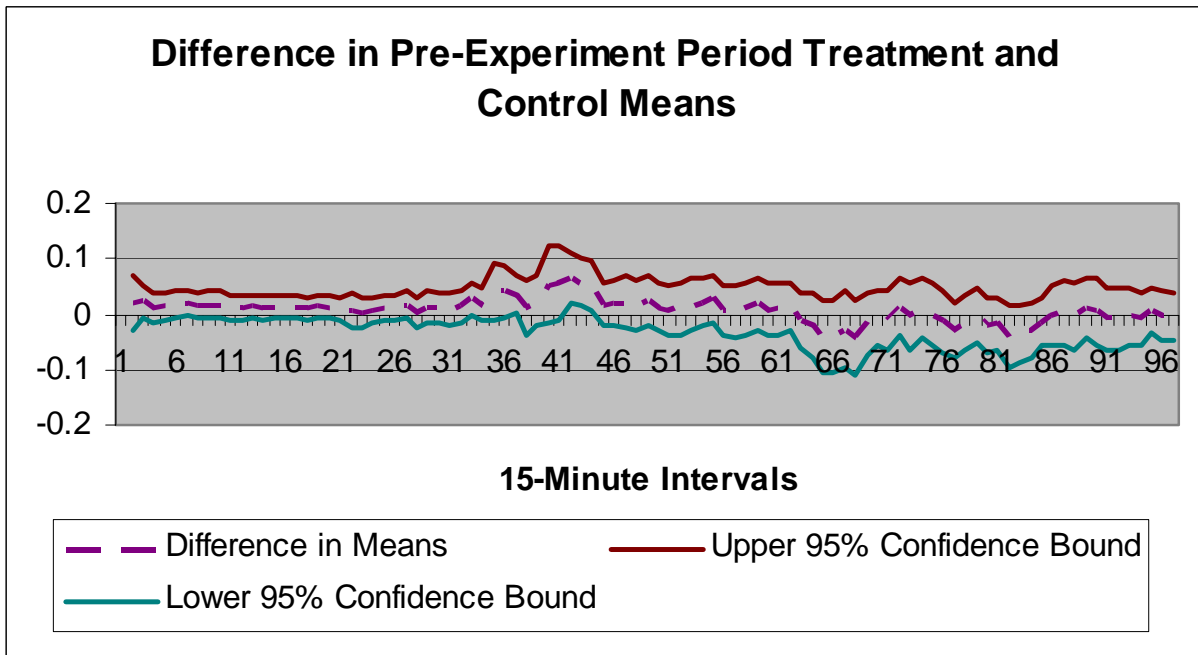
Figure 3: Comparison of Day-of-Sample Fixed Effects and Average Daily Temperature

Red Line = Average Daily Temperature at Fullerton Airport, Blue Line = Day-of-Sample Fixed Effects, Green Stars = Critical Peak Pricing Days

Figure 4-T

Total Bill for Each Customer Before Rebate ($)

Treatment Group

Figure 4-C

Total Bill for Each Customer Before Rebate ($)

Control Group

Figure 5-T

Total Expenditure Before Monthly Baseline

Treatment Group

Figure 5-C

Total Expenditure Before Monthly Baseline

Control Group

Figure 6-T

Total Expenduture After Monthly Baseline

Treatment Group

Figure 6-C

Total Expenditure After Monthly Baseline

Control Group

Figure 7-T

Total Rebate

Treatment Group

Figure 7-C

Total Rebate

Control Group

Figure 8-T

(Total Rebate)/(Total Bill)

Treatment Group

Figure 8-C

(Total Rebate)/(Total bill)

Control Group

Figure 9-T

Paid for Consumption Reduction

Treatment Group

Figure 9-C

Paid For Consumption Reduction

Control Group

Figure 10-T

Predicted Consumption Reduction

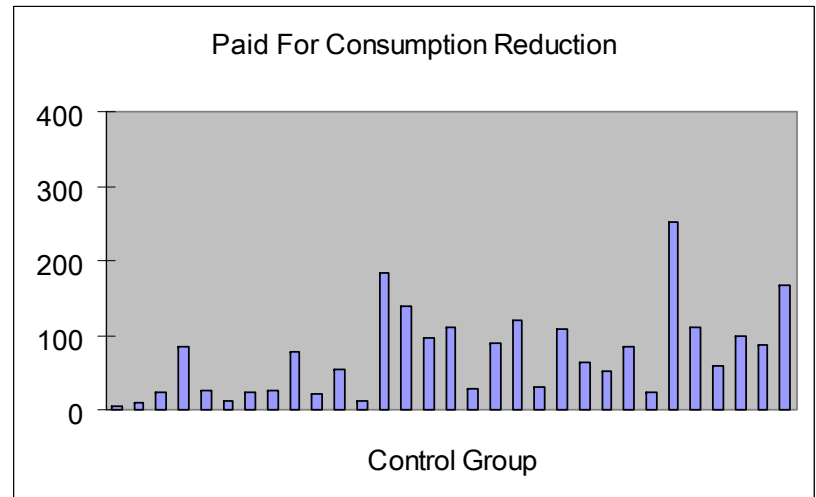Treatment Group

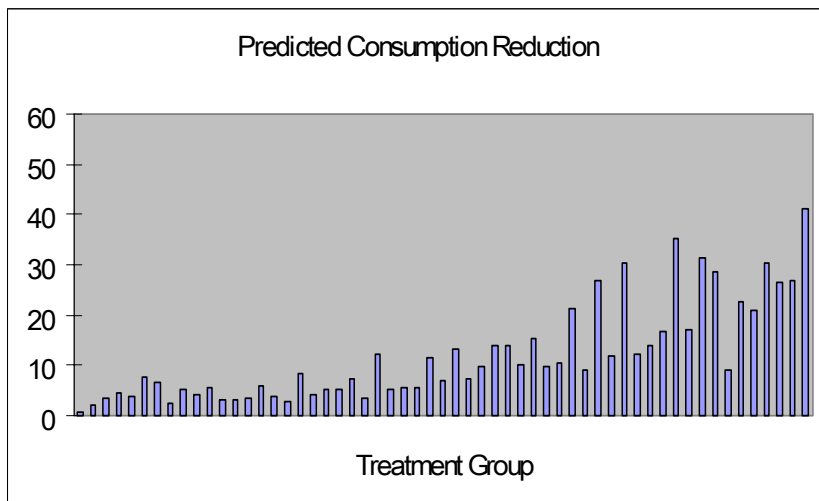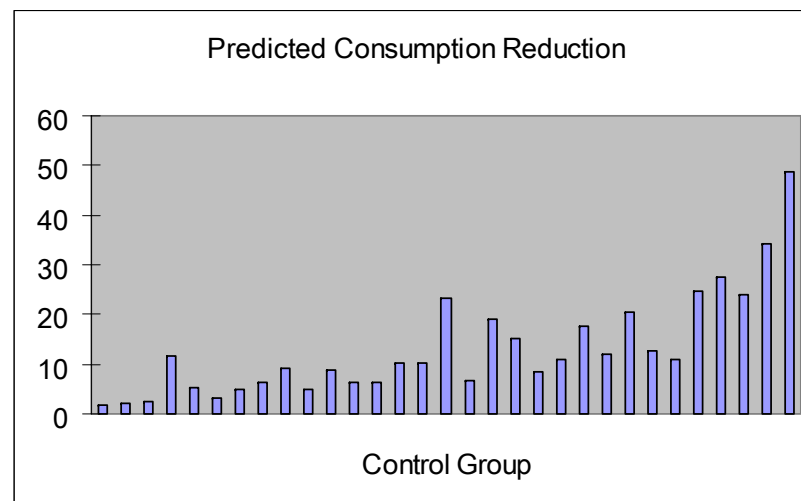
Figure 10-C

Predicted Consumption Reduction

Control Group

Appendix A: Anaheim CPP Experiment Materials

August 4, 2004

Sample Customer
123 Main Street
Anaheim, CA 9xxxx

Dear Sample Customer,

You have been selected for Anaheim Public Utilities' new Spare the Power Days *Rebate* pilot program. This is an energy-conservation program that lets you save a few dollars on your summer bills while helping keep your rates down and your environment clean.

The rebate program works by *paying you* for reducing your electric use a few afternoons during the summer on "Spare the Power Days." These are typically those days when temperatures are high and electricity use soars. If our customers can use a little less power on Spare the Power afternoons – noon to 6 p.m. – we can operate our power plants less and reduce air emissions. This is strictly a *rebate* program; you can SAVE money as you benefit your community and the environment.

To measure how much you conserve and to calculate your **rebate**, we need to install a special "smart meter" on your home.* This meter will measure when you use electricity and send the data to our office each day. We will tell you the day before each Spare the Power Day by calling your home using an automated system or by sending you an e-mail, if you prefer.

You now pay 11 cents per kWh for each kWh you use beyond the lifeline amount. But, we'll *pay you* 35 cents for each kWh you save on a Spare the Power Day. The rebate will be calculated as the amount you reduce your usage from noon to 6 p.m. on Spare the Power Days times 35 cents per kWh.

Customers in similar programs typically make one or two changes, such as shutting off lights, doing laundry at other times, and raising thermostats a few degrees or turning off air conditioners for a time. Running pool pumps and heaters before noon or after 6 p.m. is another good option. If you can't reduce use on a Spare the Power Day, that's okay; you will just pay your normal bill amount. You can't lose!

See the attached Fact Sheet for more information. Please complete the enclosed enrollment card and send it back to us in the enclosed postage-paid envelope.

Thank you for participating in this important program.

Ken Noller
Interim General Manager
Anaheim Public Utilities

* - Please note that we may be unable to install the smart meter at some customer locations for technical reasons; such customers will be unable to participate at this time.

Spare the Power Days Information

Please fill out the information below and return this card in the postage-paid envelope.

Phone Number: Please enter the phone number below for us to call you to notify you the day before Spare the Power Days.

Phone Number: $($ _____ $)$ _____

                        Area Code

Email Address: Please enter your email address for us to contact you with more program information.

Email Address: _____

☐ **Email Notification:** Check here if you prefer that we use email to notify you of Spare the Power Days

CPPf RES

Spare the Power Days Rebate Program
Fact Sheet

Who

Who is participating?
One hundred fifty Anaheim Public Utilities customers have been selected randomly to participate in the Spare the Power Days Rebate pilot program. If the program is successful, it may be offered to other customers.

Who is operating the program?
We have hired eMeter Corporation of Redwood City, CA to help us operate the pilot, and economists at Stanford University will help us evaluate it.

Whom do I call with questions?
Feel free to call customer support at **877-363-8371** with any questions or e-mail at **support@emeter.com.**

What

What is the Spare the Power Days Rebate program?
Spare the Power Days is an energy-conservation program that pays our customers to reduce electricity use on a few afternoons (called "Spare the Power Days") each summer . Your total rebate is calculated as the amount you reduce your usage on Spare the Power afternoons times 35 cents per kWh.

Do I need to do anything?
You don't need to do anything on the program. If you don't conserve on Spare the Power Days, you simply won't earn any rebates and will pay your normal bill amount. You may also choose to reduce usage on some Spare the Power days and not on others.

What special equipment do I need?
You don't need any special equipment. We will install a "smart meter" on your home to keep track of how much electricity you use on Spare the Power Days so we can calculate your rebates. The smart meter will send the data back to us over a wireless data link. There is no charge for this smart meter.

What else is part of the program?
We will contact you for a short survey to find out more about your energy usage, such as what appliances you own. This will help us evaluate the program.

Why

Why is Anaheim Public Utilities doing this pilot?
We are testing this program as part of our continuing efforts to improve service to our customers. If our customers can use a little less power on Spare the Power afternoons, we can operate our power plants less and reduce air emissions. As the amount of energy used by our customers grows over the years, we might need fewer new power plants to meet that growth. This would save money and help reduce pollution.

How

How will I know about Spare the Power Days?
We will notify you by telephone or e-mail, your choice.

How should I reduce electricity use?
You can reduce electricity use on Spare the Power Days by changing when you do your laundry, turning off lights or other appliances during the afternoon, or using less air conditioning. Some customers schedule errands or shopping so they are out of the house during Spare the Power afternoons.

When

When are Spare the Power Days?
Spare the Power Days only occur on weekdays. They are usually the hottest days of the summer, when air conditioning and other electricity use soars.

What hours should I reduce usage?
Rebates are calculated on your usage reductions between noon and 6 p.m.

When will I know about Spare the Power Days?
We will notify you by 5 p.m. the afternoon before a Spare the Power Day. Unless it's on a Monday; then, we will let you know by 5 p.m. on the Friday before.

When will I get my rebate?
We will add up all your rebates and pay you once at the end of the summer, in October.

When will the pilot end?
The pilot will run through the end of September 2005.

Where

Where can I get more information about this program?
Online at www.anaheim.net/utilities/Spare, by phone at 877-363-8371, or by email at support@emeter.com.

Where can I get more information about other Anaheim Public Utilities energy-efficiency programs?
More information is online at www.anaheim.net/utilities.

September 3, 2004

«Cust_name»
«Addr_1»
«City», «St» «Zip_code»

Dear «Cust_name»,

I'm writing to remind you of your participation in the Anaheim electricity rebate program and ask for your help as we work to keep rates down. As I mentioned in my recent letter to you, you can save on your bill by reducing usage on "Spare the Power Days." Since it's a rebate program, you can't lose.

See the enclosed magnet and Fact Sheet for more information.

We need your correct phone number or email address to notify you the day before Spare the Power Days so you can save. Please call us at 877-363-8371 (se habla español) to verify your phone number or complete the enclosed card and send it back in the postage-paid envelope.

Again, thank you for participating in this important program.

Ken Noller
Interim General Manager
Anaheim Public Utilities

May 15, 2005

«Cust_name»
«Addr_1»
«City», «St» «Zip_code»

Dear «Cust_name»,

I'm writing to remind you of the Anaheim electricity rebate program and ask for your help as we work to keep rates down. As I mentioned in my letter to you last fall when we started the program, you can save on your bill by using less power between noon and 6 p.m. on "Spare the Power Days." We'll calculate your savings and put the rebate right on your bill at the end of the summer.

We will call or email to notify you the day before Spare the Power Days so you can save. There will be approximately ten Spare the Power Days between June 1 and October 1. See the enclosed magnet and Fact Sheet for more details. Please call us at 877-363-8371 (se habla español) with any questions.

Again, thank you for participating in this important program.

Marcie L. Edwards
General Manager
Anaheim Public Utilities