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Residential implementation of critical-peak pricing of electricity

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Abstract

This paper investigates how critical-peak pricing (CPP) affects households with different usage and income levels, with the goal of informing policy makers who are considering the implementation of CPP tariffs in the residential sector. Using a subset of data from the California Statewide Pricing Pilot of 2003-2004, average load change during summer events, annual percent bill change, and post-experiment satisfaction ratings are calculated across six customer segments, categorized by historical usage and income levels. Findings show that high-use customers respond significantly more in kW reduction than do low-use customers, while low-use customers save significantly more in percentage reduction of annual electricity bills than do high-use customers – results that challenge the strategy of targeting only high-use customers for CPP tariffs. Across income levels, average load and bill changes were statistically indistinguishable, as were satisfaction rates – results that are compatible with a strategy of full-scale implementation of CPP rates in the residential sector. Finally, the high-use customers earning less than

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$50,000 annually were the most likely of the groups to see bill increases – about 5% saw bill increases of 10% or more – suggesting that any residential CPP implementation might consider targeting this customer group for increased energy efficiency efforts.

Keywords: electricity rates, residential electricity, demand response

1. Introduction

Between May 2000 and June 2001, peak wholesale prices on the California spot electricity market sustained record highs, and capacity shortages were frequent. While factors leading up to the onset of the California electricity crisis are complex, there is reasonable consensus that the lack of real-time response by retail demand was a major contributor to its severity and duration (Borenstein, 2002; Jurewitz, 2002; Woo, 2001; Woo et al., 2003). Since that time, increasing real-time demand response to electricity price changes by strengthening the real-time price link between wholesale and retail markets has become an explicit policy goal at both state and national levels. In California, policy makers have set a goal for 2007 of meeting 5% of peak demand with a price-responsive load (California Energy Commission, 2004). At the national level, the Energy Policy Act of 2005 states that it is now “the policy of the United States that time-based pricing and other forms of demand response…shall be encouraged, the deployment of such technology and devices that enable electricity customers to participate in such pricing and demand response systems shall be facilitated, and unnecessary barriers to demand response participation in energy, capacity and ancillary service markets shall be eliminated.”

Historically, utilities have used two strategies to reduce residential peak load: direct load-control (DLC) programs and time-of-use (TOU) tariffs. Direct load-control programs, which have existed in California since the early 1980s, offer households recurring monthly bill credits in exchange for utility control of large electrical end uses, most commonly central air conditioning. One reason for the popularity of DLC programs is that, unlike price-based demand response programs, DLC programs are feasible with the existing metering infrastructure.

While effective in providing load relief when warranted by capacity shortage, DLC programs may be seen as inequitable for three reasons. First, DLC programs are voluntary, offering fixed financial incentives for unmeasured load reductions. This encourages adverse selection that results in "free riders" – participants who provide little to no load relief during load-control events, but still benefit as much as do those providing significant load reductions. Second, although customers without central air conditioning do not cause system peak demand surges on hot days, they are not eligible for program benefits. Third, when payments to participants exceed system benefits, these same customers must suffer higher electricity rates to pay for the bill savings enjoyed by the program participants.

The other common residential peak reduction strategy in use today is voluntary TOU pricing. TOU tariffs typically have high peak prices on weekday afternoons and lower off-peak prices for the remaining hours of the week. Experimentation with TOU rates in the residential sector indicates that TOU prices flatten load shapes by decreasing usage in the high-price periods and increasing usage in the low-price periods (Atkinson, 1979; Caves and Christensen, 1980; Caves et al., 1984; Herriges et al., 1984). The shortcoming of TOU tariffs is that they do not provide additional incentives to reduce demand further on days when the system is most stressed, because they reflect only long-term average expectations of daily peak marginal costs (Crew et al., 1995).

The potential shortcomings of DLC programs and TOU tariffs, combined with the decreasing cost and increasing functionality of electricity meters, have prompted growing interest in encouraging peak reductions through dynamic rates. By more closely linking short-term wholesale and retail electricity prices, tariffs based on dynamic rates provide the reliability benefits of peak load reductions, while improving the allocation of electricity procurement costs among residential customers with diverse demands (Borenstein, 2002; Braithwait and Faruqui, 2001; Hirst, 2002; Kueck et al., 2001).

More than any other retail electricity rate structure, real-time pricing (RTP) closely tracks time-dependent marginal wholesale costs. Hourly RTP tariffs have been implemented successfully for large industrial and commercial firms (Taylor et al., 2005). Notwithstanding the long-run efficiency benefits of RTP (Borenstein, 2005), policy makers generally consider hourly RTP too complex for small electricity users and are thus reluctant to allow residential customers to face the inherently volatile wholesale market. An exception to this generalization can be found in Illinois, where state legislation has recently prompted the first RTP option for residential customers (2006).

Where dynamic rates are being considered, but RTP is deemed infeasible for residential customers, a reasonable alternative is critical-peak pricing (CPP). CPP tariffs augment a time-invariant or TOU rate structure with a dispatchable high or "critical" price during periods of system stress. The critical price can occur for a limited number of discretionary days per year, or when system or market conditions meet pre-defined criteria. Participating customers receive notification of the dispatchable high price, typically a day in advance, and in some cases are provided with automated control technologies to support efficient load drop. Because all of the prices in a CPP rate are preset, CPP is not as economically efficient as RTP; this same characteristic, however, also makes CPP politically more appealing, because it diminishes the potentially large price risk associated with RTP.

Empirical evidence supports the view that CPP can achieve significant load reductions during critical periods. In California, households supplied with sophisticated end-use controls dropped an average of 41% of baseline load (i.e., load that would have occurred absent the CPP price signal) over 2-hour hot-weather CPP events. In the absence of end-use controls, households dropped an average of 13% of baseline load over 5-hour hot-weather CPP events (Herter et al., 2006).

While the effectiveness of residential CPP in California to deliver load reduction appears certain, there is an on-going debate as to whether to implement CPP, because how to do so remains controversial. The objective of this paper is to provide empirical evidence that aids in the decision about which, if any, CPP implementation schemes might be considered for the residential sector.

The analysis described here uses data from 457 residences, determined to be representative of California households (see Appendix), that participated in the California Statewide Pricing Pilot (SPP) of 2003 and 2004. Average load changes during summer events, annual bill changes, and post-experiment satisfaction values are calculated across six customer segments, categorized by historical usage and income level.

The analysis shows that high-use customers respond significantly more, in kW reduction, than do low-use customers, while low-use customers save significantly more, in percentage reduction of annual electricity bills, than do high-use customers. For equity reasons, these results challenge the strategy of targeting only high-use customers for CPP tariffs.

Across income levels, average load and bill changes were statistically indistinguishable, as were satisfaction rates – results that are compatible with a strategy of full-scale implementation of CPP rates in the residential sector. Finally, the high-use customers earning less than $50,000 annually were the most likely of the groups to see bill increases – about 5% saw bill increases of 10% or more – suggesting that any residential CPP implementation might consider targeting this customer group for increased energy efficiency efforts.

2. The CPP implementation problem

The three primary criteria for designing sound rate structures are capital attraction, consumer rationing, and fairness to ratepayers (Bonbright et al., 1988). Capital attraction, or meeting revenue requirements, can be accomplished through proper design of nearly any tariff structure, including those based on time-invariant, TOU, CPP or RTP rates. The consumer rationing objective requires rates that assign resources to those who value them above the marginal cost of their provision. If, in the short term, this demand exceeds supply, then resources should be assigned to those who value them the most. In theory, CPP rates that are designed to more closely reflect short-term wholesale electricity costs meet this criterion better than do time-invariant or TOU rates, but not as well as do RTP rates. The final objective, fairness to ratepayers, obligates utilities to distribute revenue requirements fairly among ratepayers, such that equals are treated equally, and unequals are treated unequally. Under time-invariant rates, customers with low peak to off-peak ratios subsidize those with high peak to off-peak ratios. Thus, this third objective can better be met through rates that more closely reflect time-varying wholesale costs, because they more accurately apportion costs according to the hour and day of use.

Where CPP and RTP tend to fall into doubt is in the "practical" attributes of "simplicity, certainty, convenience of payment, economy in collection, understandability, public acceptability, and feasibility of application" (Bonbright et al., 1988). Where these attributes are uncertain or not met, two strategies are commonly used to enhance them. Dynamic tariffs can be targeted to those customer segments likely to have a high demand response. Alternatively or at the same time, the tariff might be offered as a "voluntary" or "default" (rather than mandatory) tariff, allowing customers to "opt in" or "opt out" of the new tariff. These policy decisions are discussed in greater detail in the next two sub-sections.

2.1. *Full-scale vs. targeted tariffs*

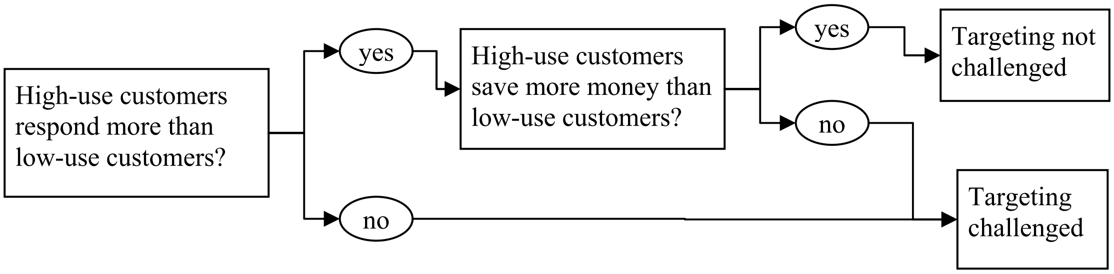
To improve cost effectiveness, CPP tariffs can be required of or offered to only those customers who are most likely to contribute load relief. This is typically seen as a win-win situation, providing utilities with improved cost effectiveness and participants with lower bills. For example, consumer advocates in California have proposed that CPP rates be targeted to the largest residential users of electricity, who, they say, are likely to have the greatest demand response and greatest bill savings, thus improving customer acceptance, reducing adverse bill impacts, and improving cost effectiveness in comparison to a class-wide rate.

While this strategy is intuitively appealing, the implied relationships between customer size, demand response and bill effects are not obvious. Before deciding whether targeting is an appropriate strategy, one should first determine whether the customer class can be easily divided into meaningful segments that respond differentially. Given significantly different response rates, one must then ascertain the differential bill impacts of these same customer segments. If customers that are more responsive benefit financially, while those that are less responsive lose financially, targeted implementation might be a sound strategy, all else being equal. If these relationships do not hold, however, equity concerns might discount the use of targeting to improve cost effectiveness.

This decision process is illustrated in Figure 1, which shows the combined effect of customer response and bill savings on the decision to target tariffs to only high-use customers. If high-use customers do not respond more than low-use customers in absolute terms, then targeting will not improve the cost effectiveness of the tariff. If high-use customers respond significantly more and save proportionally less on their electricity bills than do low-use customers, the use of targeting to improve cost effectiveness is challenged by equity issues. If high-use customers respond significantly more and save proportionally more on their electricity bills than do low-use customers, then the use of targeting to improve cost effectiveness is not challenged by these criteria – which is not to say that targeting is recommended. That is, meeting the criteria is a necessary but not sufficient condition for recommending the use of targeting, since a cost-effective response by low-customers, no matter how small, might still warrant full-scale implementation.

This study does not include an explicit cost effectiveness analysis, which requires that the energy cost savings exceed the CPP implementation costs. Where local distribution companies have already decided to install an advanced metering infrastructure (AMI), incremental costs include billing and marketing costs. The costs avoided by CPP implementation include energy and capacity cost savings due to household load reduction. Given the complexities specific to each potential tariff design and implementation (Baskette et al., 2006), this issue is well beyond the scope of the present study.

Figure 1. Decision process for customer targeting



2.2. *Mandatory vs. default or voluntary tariffs*

If the primary objectives of implementing CPP are customer rationing and fairness to ratepayers, without respect to customer acceptance or cost effectiveness, then full-scale mandatory CPP participation seems the obvious choice. Under this scheme, all customers face the same high prices during critical hours, irrespective of customer characteristics. This implementation scheme is generally considered politically difficult, inviting strong objection because of the significant departure from the *status quo* of the time-invariant tariffs that now exist in California (Hartman et al., 1991).

When low or uncertain customer acceptance levels foretell potential political backlash from full-scale mandatory implementation, rates offered on a voluntary (opt in) or default (opt out) basis can be safer alternatives. In both cases, customers are given at least one rate choice besides CPP, allowing those that are unhappy with the new tariff to choose another. In the case of voluntary tariffs, customers must actively choose to switch or "opt in" to the new CPP tariff. In the case of default tariffs, customers are automatically placed on the new tariff, and must actively choose to switch or "opt out" to an alternative tariff that mimics the *status quo*.

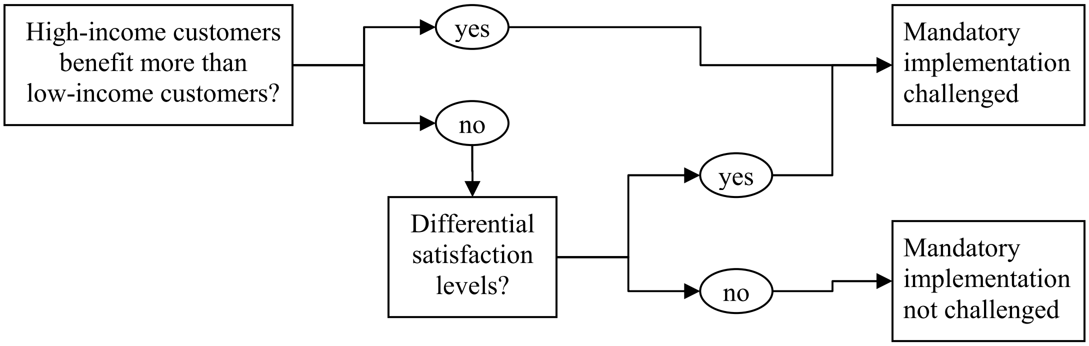
The tradeoff between default and voluntary tariffs is mainly one of participation rates. In California, the initial opt-in rate for the SPP was 20% with a sign-up bonus. At the end of the pilot, about half of these CPP participants chose to remain on the CPP rate in absence of a participation payment, suggesting a voluntary participation rate of less than 10% for CPP tariffs. In Washington State, time-differentiated tariffs offered on an opt-out basis enjoyed participation rates of about 90% (Faruqui and George, 2003).

The potential costs of increased customer acceptance for default or voluntary CPP tariffs with respect to mandatory CPP tariffs are twofold. First, peak-demand reductions are almost certainly lower than what could be achieved with 100% participation. Second, voluntary CPP tariffs could encourage adverse self-selection such that households with low peak to off-peak ratios benefit from time-varying rates, while those with high peak to off-peak ratios benefit from time-invariant rates (Hartway et al., 1999; Horowitz and Woo, 2006). This situation might cause shortfalls in a utility's cost recovery or violate the primary objective of fairness to ratepayers unless the tariff alternatives properly reflect risk premiums. Furthermore, while default and opt-in tariffs might have better initial customer acceptance, high overall satisfaction rates for both the SPP and the Washington rates provide evidence that long-term customer satisfaction might hinge more on the structure of the rate and customer service than the initial subscription circumstances.

Although the choices among mandatory, default and voluntary rates are complex, one of the important factors needed to guide this decision is expected customer acceptance of the proposed new tariff. If customer acceptance is expected to be high, the relative benefits of mandatory implementation might warrant its consideration. If customer acceptance is expected to be low or to vary substantially across important customer segments, default or voluntary tariffs might be safer policy choices. Ultimately, perceived bill effects might also affect the sustainability of a tariff through longer-term customer acceptance; thus some policy makers require evidence that customer bill impacts will not be large.

Figure 2 illustrates some of the conditions influencing decisions about mandatory implementation. The decision involves weighing the administrative ease and demand-response benefits of mandatory tariffs against the potential customer backlash. If high-income customers are likely to save significantly more on their electricity bills than low-income customers, then welfare considerations could make mandatory implementation politically difficult. At the same time, if certain customer segments are more dissatisfied with the program than are other customer segments, potential customer backlash might preclude mandatory implementation. If neither adverse bill effects nor satisfaction levels differ across customer segments, mandatory implementation is not challenged. This is not sufficient evidence, however, to recommend mandatory implementation either, since such a decision must take into consideration economic and political considerations not addressed here.

Figure 2. Decision process for mandatory implementation



3. Approach and Results

To shed light on the implementation choices described above, this paper uses load, billing and satisfaction data from 457 residential CPP customers, shown to be representative of the California population (see Appendix), to answer the following questions.

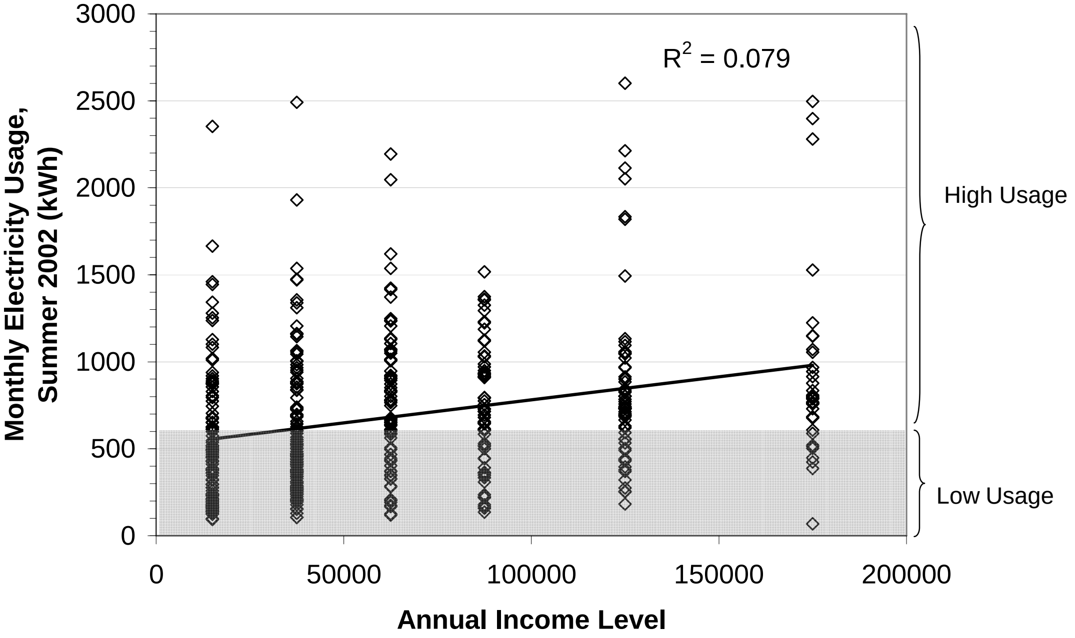
1. *Does response to CPP events vary across household types?* If all households provide an equal amount of load relief, targeting does not have the potential to improve the cost effectiveness of the rate.
2. *Do electricity-bill impacts vary across household types?* The answer to this question depends on the structure of the pre-existing tariff and the new CPP tariff. CPP rates are designed to be revenue neutral, meaning that bills will not change for non-responding households with a usage pattern identical to the

class average. Revenue neutrality, however, does not perfectly preempt adverse bill impacts. Customers with high peak to off-peak consumption ratios relative to the class average are likely to see a bill increase if they do not respond to the higher peak and critical-peak prices. If adverse bill impacts are focused on particularly sensitive customer classes, for example low-income households, mandatory CPP might be viewed as being regressive, and thus politically unsustainable. In addition, favorable bill impacts on low-use households would challenge the strategy of targeting only high-use customers.

3. *Does customer satisfaction with CPP vary across household types?* Previous studies have shown relatively high customer satisfaction with the CPP rates tested in the SPP (Momentum Market Intelligence, 2004). If this high customer acceptance is not distributed equally across all household types, a mandatory implementation scheme might be considered undesirable.

Given the interest in usage and welfare effects, both historical electricity usage and income levels are used to divide the residential class. Although electricity consumption is generally presumed to increase with income, an exploratory analysis of the relationship between usage and income indicates that, in the sample of 457 SPP customers, income levels explain less than 8% of household electricity consumption (Figure 3). In this sample, at least, a substantial number of low-income households are high-use customers and a substantial portion of high-income households are low-use customers.

Figure 3. Historical monthly summer usage and income



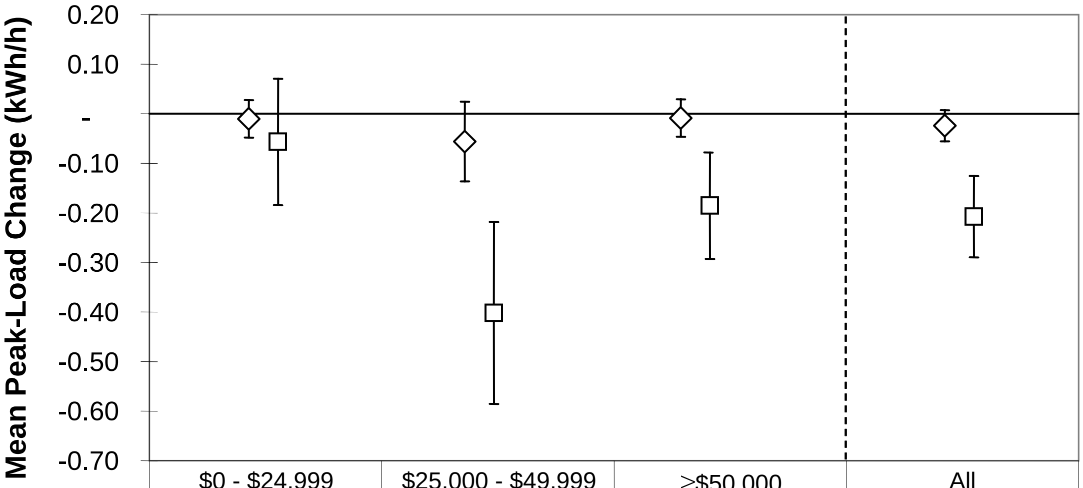
Historical usage values, provided by the three California utilities, are average monthly kWh usage values measured during the summer of 2002. Income levels are taken from a survey distributed in 2003, before the SPP began. Participants chose from six possible household income levels: less than $25,000, $25,000 to $49,999, $50,000 to $74,999, $75,000 to $99,999, $100,000 to $149,999, and $150,000 or more. For analytical purposes, these values were recoded as $15,000 for the lowest income level, $175,000 for the highest income level, and at the range mid-points for the remaining income levels.

The low correlation (R^2 = 0.079) between income and historical summer usage suggests that the analysis requires a finer delineation of customers ,prompting a division of the data sample into the six groups shown in Table 1. The remainder of this section presents the mean satisfaction, response, and bill-change values for each group based on empirical evidence from the SPP experiment.

3.1. Does response to CPP events vary across household types?

Load reduction during CPP events is critical for a tariff implementation where demand response is a stated policy goal. Previous analysis of SPP data has reported significant load reductions during CPP events (Herter et al., 2006). Determination of whether a CPP tariff targeted to high-use customers might be more cost effective than a full-scale tariff implies investigating how load reductions vary across customers with different historical consumption levels. Further division by income-level categories provides initial insight into whether low-income homes might be disproportionately affected by CPP rates. The results of the analysis are presented in Figure 4.

Figure 4. Mean household kW change across 12 CPP events, July through September 2004



	$0 - $24,999	$25,000 - $49,999	≥$50,000	All
◇ Low use	-0.010	-0.056	-0.009	-0.024
□ High use	-0.057	-0.402	-0.185	-0.208

Mean peak-load change is the average difference between the actual and baseline loads, where baseline load is an estimate of the load that would have occurred in the absence of a CPP event. Actual and baseline loads are estimated for each customer using regression techniques described in (Herter, 2006).

Figure 4 shows that kW response differs substantially between customers using less than 600 kWh per summer month and those using at least 600 kWh per summer month. Overall, kW response by low-use customers (shown by the diamond pattern) is not statistically different from zero, while high-use customers (shown by the square pattern) reduce loads by a statistically-significant amount during CPP events ($\alpha = 0.05$, the standard adopted throughout the paper). This provides evidence that, given similar per-customer administrative and marketing costs, a rate targeted at high-use customers has the potential to be more cost-effective than a full-scale program.[1]

In the low-use category, response levels are statistically indistinguishable across the three income levels. In the high-use category, the low-income ($0-$24,999) and middle-income ($25,000-$49,999) responses do not differ significantly from the high-income (≥$50,000) response. These results provide preliminary evidence that low-income and middle-income customers might not be unduly disadvantaged by CPP rates, since they respond as much as or more than do high-income customers at the same usage level. This finding is preliminary because load reduction during CPP events is only part of the bill-change equation. Differences in daily load shapes are likely to have a more pronounced effect on bill changes than will load changes occurring just a few times per year. To further investigate this issue, the following section addresses bill changes by customer type.

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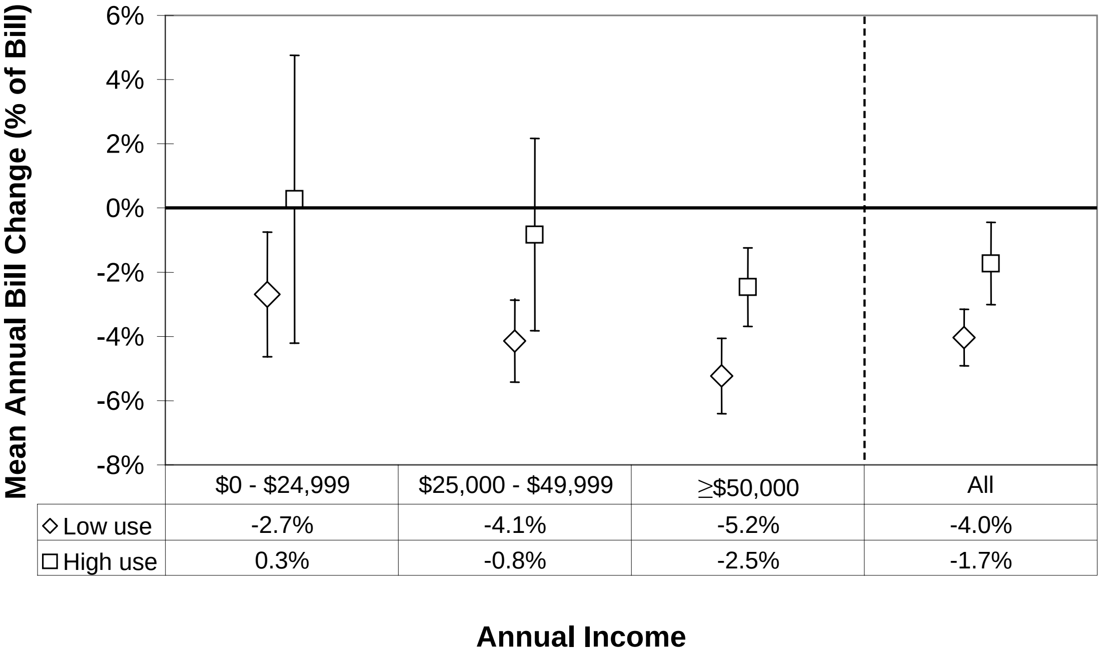
[1] An analysis of differential administrative and marketing costs is beyond the scope of this analysis.

3.2. Do electricity-bill impacts vary across household types?

Knowledge of distributional bill impacts or the lack thereof is a critical input into the initial decision of whether and how to implement CPP. This information is important because bill-change estimates help identify potential winners and losers. A CPP design that benefits a few at the expense of many has little chance of customer acceptance and regulatory approval.

Using calculations provided by the SPP sponsoring utilities, the bill-change value used in this analysis is calculated as $(x-y)/y$, where x is the dollar amount of the CPP bill and y is the dollar amount that would have been billed under the otherwise applicable tariff, given the same usage. The results, presented in Figure 5, show that the overall mean bill change for both high and low-usage customers is significantly less than zero ($\alpha = 0.05$), meaning that, on average, the SPP participants save money through CPP rates. Moreover, low-usage customers save proportionally more money on a CPP tariff than do high-usage customers. Across income levels, mean bill-change values are statistically indistinguishable. These results imply that (1) customers, on average, save money on CPP rates, (2) low-usage customers save proportionally more than do high-use customers, and (3) savings are statistically indistinguishable across income levels.

Figure 5. Mean annual change in electricity bills



	$0 - $24,999	$25,000 - $49,999	≥$50,000	All
◇ Low use	-2.7%	-4.1%	-5.2%	-4.0%
□ High use	0.3%	-0.8%	-2.5%	-1.7%

Bill change is the utility-calculated difference between the average monthly bills sent out between October 1, 2003 and September 30, 2004 under the CPP tariff and what would have been billed under the old tariff given the same consumption pattern, divided by the latter. Thus, this variable represents the percentage bill change under the new tariff with respect to the old tariff.

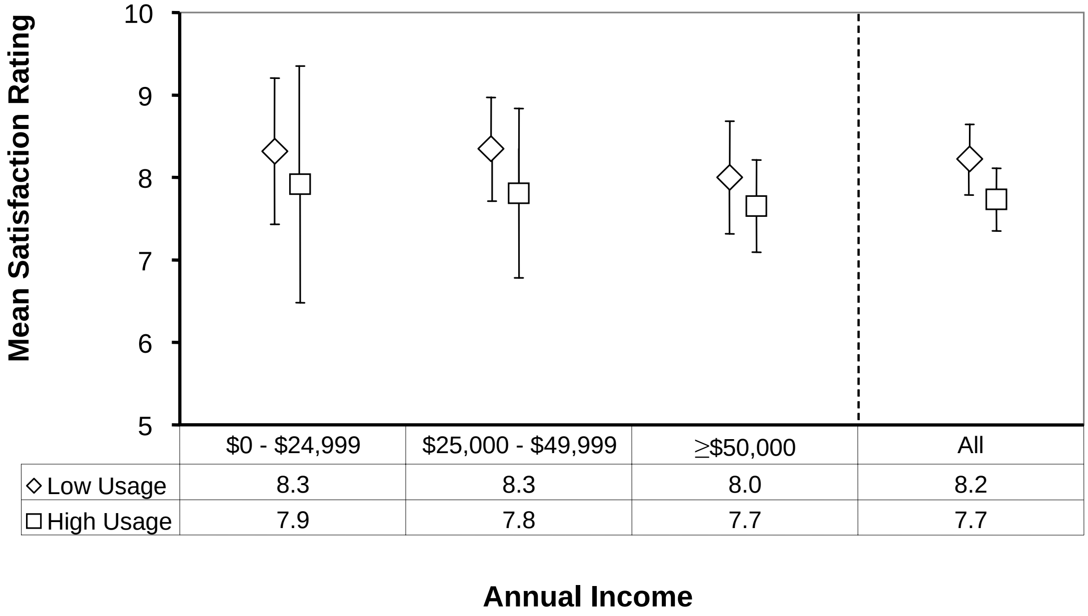
While the results in Figure 5 affirm that CPP does not cause adverse bill impacts on average, they also imply that some customer types are more likely to see a bill increase due to CPP implementation. In particular, the insignificant bill savings for the low-income ($0-$24,999) and middle income ($25,000-$49,999) customer segments in the high-use category warranted further investigation. A closer look at the individual billing data showed that 5.0% of these customers saw bill increases of more than 10%. Based on these findings, future CPP rate policies might consider providing assistance to these customers for appliance and building efficiency measures.

3.3. Does customer satisfaction with CPP vary across household types?

In planning a new tariff, it is important to test customer reaction to its implementation. Low customer acceptance can engender public and political backlash, while high customer acceptance can mean smooth adoption. Unfortunately, asking people how they might react to a hypothetical rate is unlikely to provide accurate answers.

For this analysis satisfaction ratings given by customers actually exposed to CPP rates were used as predictors of acceptance levels. Figure 6 shows the average satisfaction ratings for the six groups of customers, organized by usage and income level. The average ratings, ranging from 7.7 to 8.3 out of a maximum of 10 points, are slightly higher for low-use customers than for high-use customers, but the difference across usage is statistically insignificant. Likewise, satisfaction ratings across income levels are statistically indistinguishable. These results imply that customer satisfaction with CPP tariffs is high and does not vary significantly across income or usage levels.

Figure 6. Mean customer satisfaction ratings from a post-experiment survey



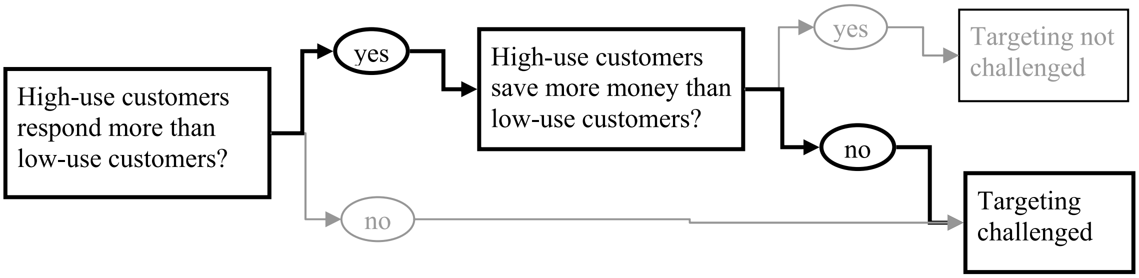
	$0 - $24,999	$25,000 - $49,999	≥$50,000	All
◇ Low Usage	8.3	8.3	8.0	8.2
□ High Usage	7.9	7.8	7.7	7.7

The variable satisfaction is taken from a post-experiment survey of about one-third of the CPP participants. This variable contains responses to the question: “Overall, how satisfied are you with the new pricing program?” Respondents were directed to rate the program using a number between 1 and 10, where 1 was “very dissatisfied” and 10 was “very satisfied.”

4. Conclusions

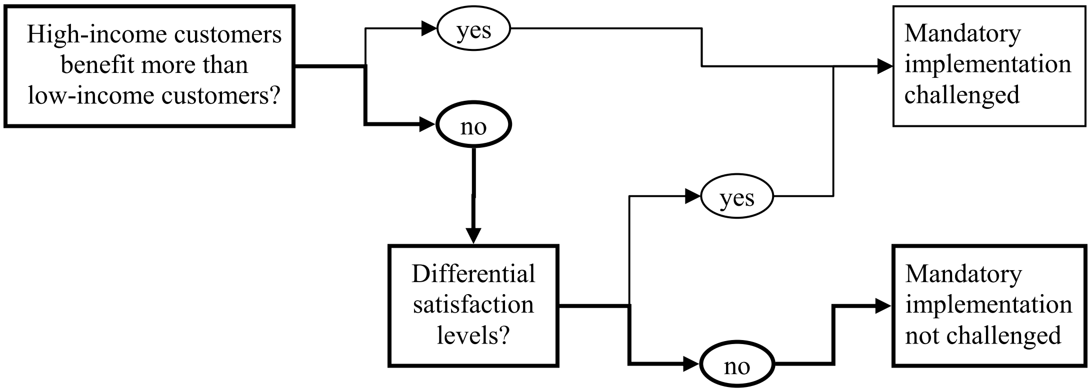
We conclude by applying the empirical evidence presented above to analyze the choices of tariff implementation. The analysis of load change during CPP events presented here indicates that high-use customers respond significantly more than do low-use customers. On average, low-use customers (those using on average less that 600 kWh during summer 2002 months) dropped 0.024 kWh/h during CPP events, while high-use customers (those using on average at least 600 kWh during summer 2002 months) dropped 0.208 kWh/h during CPP events. In contrast, the analysis of CPP customer bill change indicates that low-use customers saved an average of 4.0% on their electricity bills, while high-use customers saved an average of only 1.7%. These results suggest that targeting high-use customers to improve the cost effectiveness of CPP tariffs is challenged by equity concerns: those who would benefit most from the tariff should not be excluded from participation or marketing efforts (Figure 7).

Figure 7. Results for the targeting decision



The bill-savings analysis also showed that on average low-income customers did not pay more under CPP tariffs, and that savings across income levels were statistically indistinguishable. In addition, satisfaction rates across all customer segments were uniformly high, averaging between 7.7 and 8.3 out of a maximum of 10. Combined these results are compatible with a policy of mandatory implementation (Figure 8). This does not, however, imply that mandatory implementation is recommended by these results, since economic and political considerations, which differ from jurisdiction to jurisdiction, are not addressed here.

Figure 8. Results for the mandatory implementation decision



Moreover, the bill savings of the two lowest-income levels in the high-use group were statistically indistinguishable from zero, while the remaining six groups showed statistically significant savings. To offset this disparity, those considering full-scale CPP rates might focus efficiency and education efforts on high-use, low-income customers.

The overall conclusion from the above analysis is that CPP can be considered for a voluntary, default or mandatory electric tariff implementation without concern for differential impacts by income or electricity usage. As a voluntary tariff, care should be taken to ensure minimization of cross-tariff subsidies, since those expecting to pay more on CPP rates are likely to choose to remain on time-invariant rates. Although the voluntary pilot study investigated here received uniformly high satisfaction ratings across customer segments, consideration of a mandatory CPP tariff should be particularly wary of customer and political backlash. Consideration of CPP as a default tariff, having elements of both mandatory and voluntary tariffs, must address both of these issues.

There is no obvious reason to think that the group *comparisons* and major conclusions presented in this paper would not hold outside the pilot – to different implementation schemes (e.g. default or mandatory), geographic areas and seasons. In contrast, one should be cautious in extrapolating the specific *values* indicated in this paper. Although the customer sample used in this analysis has been shown to be representative of the California population based on measured variables (see Appendix), there might still be unmeasured variables distinguishing participants from non-participants. For example, there was no attempt to define or measure any variable, for example "agreeableness" or "responsiveness," that might predispose customers to participate in the pilot, respond to prices, and give the program a high satisfaction rating. Thus, extrapolation of these values to a voluntary program within California is supportable, but extrapolation of these values to any other implementation scheme or geographic area should be done with caution.

Finally, the focus of this paper has been the implementation of CPP tariffs. This does not imply that CPP should be implemented to the exclusion of other pricing and capacity rationing mechanisms. For example, RTP and properly designed reliability-differentiation mechanisms can provide important contributions to system operations while simultaneously providing increased customer choice (Chao and Wilson, 1987). Thus, consideration of CPP implementation should occur in the context of a broader demand response portfolio.

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Appendix: The Statewide Pricing Pilot and Data

The Statewide Pricing Pilot (SPP) was a result of a joint Rulemaking proceeding between the California Energy Commission and the California Public Utilities Commission. The SPP was designed and implemented with the help of all three investor-owned utilities in California: Pacific Gas and Electric Company, Southern California Edison, and San Diego Gas and Electric Company. The full pilot study exposed about 2500 residential and small commercial customers to experimental rates for 15 months beginning in July 2003.

The experimental sample was stratified by four climate zones and three building types. Each zone number roughly reflects the climate severity, where Zone 1 has the mildest climate, with relatively low summer temperatures, and Zone 4 has the most extreme climate, with very high summer temperatures. The three building-type strata considered in the experimental design were multi-family homes, single-family high-use homes, and single-family low-use homes.

Potential participants were randomly selected from within each stratum. They were then sent enrollment packages and promised a total participation incentive payment of $175 over the course of the experiment. About 20% of the customers accepted the invitation to participate, 15% declined to participate, and the remaining 65% were unreachable or otherwise excluded. Subsequent analyses using mean comparison and Heckman correction indicated that the final sample was a representative cross section of California residents by appliance holdings, income, education, and 16 other measured variables (Charles River Associates, 2004). Furthermore, over the course of the experiment, the turnover rate of the treatment groups (21%) was similar to the turnover rate for the primary control groups (22%), suggesting that the CPP rate itself was not responsible for the account changes (Charles River Associates, 2005).

Each experimental CPP tariff consisted of a two-period fixed TOU rate with a third "critical-peak" period that could be imposed with a one-day advance notice by telephone. Up to 15 critical-peak events could be called during the year, 12 during summer and 3 during winter. The underlying TOU peak price was 2 to 3 times the off-peak price, and the critical-peak price was between five and ten times the off-peak price. Both the TOU peak and critical-peak periods were 2 p.m. to 7 p.m.

All SPP participants were linked to one of 58 California weather stations that recorded hourly temperature values. Each participant was also supplied with a new electricity meter that collected usage values at 15-minute intervals. The new time-varying rates were put into effect on July 1, 2003.

Although the full pilot study ran from July 2003 through September 2004, the load change data are limited to those based on values collected between July 1, 2004 and September 30, 2004, so that the results are more indicative of an established summer program. The analytic sample used in this study is a subset of the 518 residential SPP participants who were on the CPP tariff without end-use controls for at least 30 days in the summer of 2004 (Herter, 2006). The subset includes the 457 households for which hourly loads, historical usage and income data are available.

The dataset used in this analysis includes: *kw_change*, the average hourly load change during summer 2004 events (Herter, 2006); *bill_change*, the average monthly percentage electricity-bill change for the year preceding September 30, 2004; *income*, reported annual income level; *usage02*, historical summer electricity consumption; and *satisfaction*, the program satisfaction rating for each of the 151 customers in the analytic sample that also answered the post-pilot survey. The final measures to be used in this analysis are shown in Table A1 along with a short description and summary statistics for each.

Table 1. Analytic sample

	Sample	
	N	%
Less than 600 kWh/mo	214	47%
$0 - $24,999	72	16%
$25,000 - $49,999	68	15%
≥$50,000	74	16%
At least 600 kWh/mo	243	53%
$0 - $24,999	37	8%
$25,000 - $49,999	47	10%
≥$50,000	159	35%
Total	457	100%

Table A1. Data description

Variable	Data type	Description	N	Share (%)	Unweighted Mean	SD
kw_change	Real	Difference between average peak baseline and actual electricity use (kWh/h) across the 12 event days	457	100	-0.12	0.51
bill_change	Real	Difference between bill under CPP tariff and what would have been the bill under the old tariff.	457	100	-$2.07	$7.62
usage02	Real	Average daily summer 2002 electricity use (kWh)	457	100	22.4	14.4
satisfaction	Integer	Rating from 1=”very dissatisfied” to 10=”very satisfied”	151	33	8.0	2.0
income1	Boolean	Annual income $0 to $24,999	109	24		
income2	Boolean	Annual income $25,000 to $49,999	115	25		
income3	Boolean	Annual income ≥$50,000	233	51		
		Total	*457*	*100*		