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Using Incentive Preserving Rebates to Increase Acceptance of Critical Peak Electricity Pricing

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2547 Channing Way
Berkeley, California 94720-5180
www.ucei.org

Using Incentive Preserving Rebates to Increase Acceptance of Critical Peak Electricity Pricing

Robert Letzler

Federal Trade Commission, Bureau of Economics
600 Pennsylvania Ave Stop NJ-4136
Washington, DC 20580

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Abstract

Low consumer opt-in rates prevent dynamic electricity pricing programs, like Critical Peak Pricing (CPP), from achieving their potential. Customers who received significant incentives to participate in CPP pilot programs use less power when electricity is expensive, report high satisfaction levels, tend to stay on dynamic pricing, and often save 10% or more. However, roughly 99% of customers reject opportunities to switch to CPP. This paper presents evidence that imperfections in common consumer decision making heuristics drive reluctance to enroll. Incentive Preserving (IP) Rebates change the presentation of CPP to address these heuristics. Incentive Preserving Rebates reframe scarcity “events” as opportunities to get rebates rather than as periods of extremely high prices. Incentive Preserving Rebates change neither CPP’s marginal incentives nor each customer’s total annual payments. An analysis of California pilot program data suggests Incentive Preserving Rebates are feasible.

1 Introduction

Low consumer opt-in rates prevent dynamic electricity pricing programs, like Critical Peak Pricing (CPP), from achieving their potential. This project uses insights from behavioral economics to explain consumer resistance and proposes addressing resistance with Incentive Preserving (IP) Rebates that do not change CPP’s incentives or annual per customer revenues. IP rebates add revenue neutral charges and credits to a CPP rate that regulators can tailor to meet local needs.

Typical, time-invariant, pricing charges the same price per kilowatt during high and low cost hours. Dynamic rates create incentives to better manage electricity consumption by varying prices to reflect the substantial intertemporal variation in electricity cost.

CPP is a simple dynamic rate that is attractive for residential customers and captures some variations in power cost. CPP rates announce a schedule of peak and offpeak periods and prices. Some CPP rates designate “shoulder” periods between peak and offpeak. CPP allows utilities to designate about 1% of all hours as critical, scarcity periods which invoke a significantly higher rate. Policy makers in places including California, the District of Columbia, Georgia, and Missouri have either run pilot tests of residential CPP or authorized residential CPP programs.

Critical Peak Pricing (CPP) works. CPP reduces customer usage during higher-priced, peak periods and the highest-priced critical periods. CPP customers typically save money and report high satisfaction levels. Indeed, the majority of customers who received \$175 to participate in a California CPP experiment chose to stay on CPP at the conclusion of the experiment.(Faruqui and George, 2005; Charles River Associates)

Consumers, however, resist signing up for CPP. Mailings offering Florida customers a CPP rate that saves participants an average of \$90 a year got a 1.3% opt-in rate (White, 2006). Customers are more receptive to baseline-rebate programs that create similar incentives by rewarding customers whose critical-period power use is below a “baseline” level. These customers, who resist CPP but are open to rebate programs with the same average bill, appear to have preferences about aspects of rate presentation that affect neither peak-period incentives nor total bills.¹

Residential CPP will generally be an opt-in program until it develops a track record that justifies making it the default. Hence, this project seeks to present CPP in a way that elicits good enrollment choices when shown side by side with the status-quo, time invariant rate.²

Psychological and economic factors affect both customer’s enrollment choices and participants’ consumption. People’s use of simplified decision making rules (“heuristics”) in specific situations causes predictable deviations from expected-utility maximizing decision making.³ This project focuses on psychology at the opt-in stage and on incentives for participants because decision making heuristics appear to cause important mistakes in enrollment decisions.⁴

¹Section 2 describes rational reasons for consumers to prefer time-invariant pricing, but observes low participation rates even among consumers whose use patterns mean they would save under dynamic pricing without changing their consumption.

²CPP’s initial opt-in status is a political reality, but the strand of literature that suggests that IP rebates might work also reports that changing defaults or forcing people to decide can lead to considerably better choices in areas like retirement savings. See Choi et al. (2003) for an overview. Wood (2002a,b) discusses making dynamic pricing the default to increase participation. Helping customers make better enrollment choices may not only increase the benefits of opt-in programs but also build a track record to inform discussions of making dynamic pricing the default.

³For reviews of this literature, see e.g. Rabin (1998); DellaVigna (2009) while Kahneman and Tversky (2000) collects many classic articles.

⁴Many customers overestimate their distaste for change, exhibiting “projection bias” (Loewenstein et al.,

Several heuristics that many potential customers use to consider programs with occasional extreme prices, such as conventionally-presented CPP, will make customers irrationally wary of enrolling. Many people code outcomes as gains or losses relative to an anticipated (“reference”) outcome and give greater weight to losses in their decisions (Kahneman and Tversky, 1979). CPP delivers subtle savings by lowering prices most of the time while notifying customers about critical prices so high that many customers spend more to get less than they would during an ordinary period and experience both expenditure and consumption losses.⁵ Despite this, experience suggests that a majority of customers would reduce their total annual bills by switching to CPP and responding. Savings from small price reductions nights, mornings, and weekends more than offset any bill increases during rare, but visible critical events. People’s heuristics, however, tend to overweight the high-priced periods and may not notice the gains, making potential customers too apprehensive. Concentrating losses and diffusing gains repels loss-averse customers if they “narrowly bracket,” meaning that they consider power costs one bill cycle – or day – at a time, rather than over the long term (Thaler, 1999; Read et al., 1999). CPP also repels customers who find it unfair to raise the price of air conditioning on the hottest days (Kahneman et al., 1986). This paper introduces Incentive Preserving Rebates which change the presentation of CPP to avoid these biases.⁶

IP rebates present potentially threatening critical events as opportunities to earn rebates through sacrifice. They sidestep loss aversion by presenting critical periods as opportunities to gain rebates as opposed to periods when high prices cause losses. IP rebates address narrow bracketing by moving many of the benefits of dynamic pricing into the visible critical periods when they ask participants to reduce consumption. IP rebates address consumers’ perception that is unfair to raise the cost of power on hot days by selling them the right to use power at the usual price and then compensating customers who sacrifice. IP rebate

⁵California pilot customers reduced usage 12% during critical events that more than doubled prices (Faruqui and George, 2005; Charles River Associates; Herter et al., 2007).

⁶Appendix D generalizes IP rebates to complement a wide family of dynamic pricing programs. This project presents them in the context of CPP because CPP is a simple, illustrative, and policy relevant application.

customers pay a fixed amount each month to buy rights to use a preset quantity of power at the usual price during each critical event. If customers use less power during an event than they had rights to, they get a rebate for the value of the unused rights. This project aspires to offer most customers a rebate during every month containing an event. Incentive Preserving (IP) rebates make CPP appear less threatening but change neither the total annual bill nor marginal incentives.⁷

To see how this works, consider a rate with a 60 cent per kWh critical period opportunity cost and a 24 cents per kWh peak price. The right to use one, 60-cent, critical-period kWh at the usual price of 24 cents is worth 36 cents. The owner of a right can use its value for power or a rebate. Customers who exhaust their rights during an event pay the full price of 60 cents for each additional kWh. We can offer a customer the right to 8 kWh at the usual price during each of 15 events per year if we charge the customer \$3.60 (which buys 10 kWh of rights) each month. This customer pays the exact value of the rights they receive because $15 \text{ events} \times 8 \text{ kWh of rights} \times 36 \text{ cents each} = \$43.20 = 12 \text{ months} \times \3.60 .

The analysis below identifies constraints on desirable IP rebate implementations. An analysis of California data finds that utilities can identify offers that satisfy these constraints using readily available information about customer location and aggregate consumption. This paper further confirms the feasibility of satisfying those constraints for most customers even if it assigns broad categories of customers the same rights level. Offering everyone in a neighborhood the same number of rights will reduce (misinformed and fruitless) customer attempts to profit by increasing their rebate eligibility and (confused) beliefs that the program is unfair because a neighbor got more rights. Offers to categories are easier for regulators and utilities to analyze and discuss.

Section 2 offers background on dynamic pricing, section 3 describes the psychology of consumer resistance, section 4 describes how to use rebates to improve the presentation

⁷Adding IP rebates to CPP may lead to slight changes in power consumption because IP rebates charge a few extra dollars during some months and return those dollars as bill reductions in other months which creates income effects.

without affecting incentives, section 5 and 6 proves that these changes do not affect incentives or revenues, section 7 compares incentive preserving (IP) rebates to other rates, especially baseline-rebate rates, and section 8 uses California CPP data to explore IP rebates' feasibility.

2 Background: dynamic pricing

Providing incentives for customers to use less electricity during scarcity periods has the potential to save billions of dollars (Borenstein, 2005) and to facilitate the integration of wind generation.

Few utilities have successfully implemented dynamic pricing – largely because utilities have not presented dynamic pricing in ways that consumers find attractive (Barbose et al., 2004). For example, Florida and Illinois programs encountered consumer resistance to residential dynamic pricing.⁸ Gulf Power offers GoodCents Select residential CPP in Florida. Gulf Power and its parent, the Southern Company, are considered leaders in marketing and customer service. The Community Energy Cooperative's (now CNT Energy) Energy-Smart Pricing Plan offers Illinois residences real time prices. Both notify customers of high priced periods. The two retailers report that most customers who sign up save money, are satisfied, and stay enrolled. But both programs get roughly 1% sign up rates.

Some consumer resistance is rational. Customers who use a large proportion of their power during peak periods would pay more under CPP. The transaction costs of responding to price signals could deter some customers.⁹ Gulf Power's Good Cents Select program saves participants an average of \$90 a year (White, 2006), and reduces transaction costs by automating response with a “set it and forget it” thermostat (Gulf Power). However, conventional economic reasons cannot explain the high rejection rate among customers who

⁸Large commercial and industrial customer resistance is also a problem. Commercial and industrial customers are beyond the scope of this project because large consumers employ analysts to analyze economic decisions, unlike most small customers. Large customers may also suffer principal agent problems.

⁹Practitioners and scholars are working to address both the distributional and transaction cost issues (see e.g. Borenstein (2007a); Wright et al.).

use a larger-than-average proportion of their power off peak and would save money on CPP even if they did not respond to price signals.

Recruiting new customers is a different challenge than retaining existing customers. Recruiting appears to be the more difficult challenge. Retention involves customers who have experienced CPP's implications for their total bills, lifestyles, decision making heuristics, and preferences. Recruiting involves customers who know significantly less. Further, programs that 1) allows customers to learn to respond and what they saved; 2) rewards the majority of responsive participants with savings; and 3) limits the use of potentially onerous consecutive event days and critical events during the dinner hour are likely to retain more customers.¹⁰ Gulf Power, the Community Energy Cooperative, and California's Statewide Pricing Pilot have high customer retention rates. This project addresses an aspect of recruiting, namely resistance among consumers who stand to gain from participation.

3 Psychological explanations of customer resistance.

CPP delivers subtle benefits by modestly lowering prices most of the time while it occasionally inflicts visible losses during critical events when the average customer uses less power, but pays more in total for it. A variety of psychological theories suggest that presenting subtle gains and visible losses will repel consumers.

- “Narrow bracketing” consumers base their decision on short term outcomes like a single month's bill or afternoon's cost rather than the appropriate long term outcomes like annual or lifetime costs (Thaler et al., 1997; Read et al., 1999). Customers who know they can achieve a flatter than average load shape are almost certain to come out ahead on CPP in the long term but risk occasional losses. If the common risk

¹⁰Limiting dinner hour residential events is consistent with the Ramsey pricing intuition that pricing high elasticity products accurately has great social value, while raising prices on low elasticity goods transfers cash without changing consumption much. Air conditioning empty houses during the afternoon and empty offices during the evening are high elasticity goods. Occupied houses' evening power demand is likely to be less elastic.

perception heuristics (described below) repel these customers, narrow bracketing is part of the explanation.

- A reference dependent, loss averse customer codes outcomes as gains or losses relative to an anticipated (“reference”) outcome. Loss averse consumers put roughly twice as much emotional magnitude on a loss relative to the reference point than on the same sized gain. (Kahneman and Tversky, 1979) Reference dependent loss aversion makes paying more to buy less during an event seem quite painful.
- Studies of choice under risk also suggest that consumers often consider just the worst case rather than the whole outcome distribution. (March and Shapira, 1987; Lopes, 1987)

These three theories suggest that consumers are too concerned about critical events.

Research confirms that consumers notice and fear critical events:

- “The Super Peak rate period was especially anxiety producing.” It “created strong apprehensions about the size of the monthly energy bills ” (Focus Pointe, 20)
- A focus group participant worried about, “Having to depend on some telephone message that my rates are going to double the next day because it’s a peak day,” because “if I miss the message ... it could cost me a lot of extra money.” and later in the same focus group, a participant worries that, “If your son comes home in the middle of the day and turns on the air conditioner, you could easily end up with another \$50 on your bill” (King and Harper-Slaboszewicz, 2006).
- “Customers were already prepared to spend the current amount each month.... So, they were not strongly motivated to ... lower [their bill]. At the same time, a much higher monthly bill would become a serious problem, one that customers were strongly motivated to avoid. That mentality [often drove] ... the decision to refuse participation.” (Focus Pointe, 18-19)

3.1 Addressing biases relevant to electricity pricing

Making critical events an opportunity to earn rebates can sidestep resistance from these heuristics:

- Rebate opportunities present critical events as opportunities to gain through sacrifice rather than as losses.¹¹
- Offering rebates during critical events that prompt people to sacrifice consumption addresses narrow bracketing.
- Rebates will typically improve outcomes on both the costliest days and costliest months.¹² Improving these outcomes makes the offer more attractive to customers who focus on the worst case. Appendix A documents how CPP with Incentive Preserving Rebates' (CPPIPR) lowers the highest monthly bills in climates where customer use peaks when electricity is scarcest.

Members of a residential customer focus group considered conventional real time pricing and a similar rate presented with rebates. When asked to name rate features they liked, most customers mentioned rebates. (King and Harper-Slaboszewicz, 2006) Further, retailers' and utilities' widespread use of rebates suggests that rebates might be viable.

¹¹ Using IP rebates to reframe critical events as opportunities rather than threats could make customers less responsive to critical events. Loss aversion can create an "endowment effect" that makes customers demand far more to give up mugs that they have just been handed than a control group is willing to pay for mugs that they do not have (Kahneman et al., 1991). However, an experimental rebate program prompted Anaheim customers to significantly reduce critical period use despite any electricity endowment effect (Wolak, 2006). Critical Peak Pricing with Incentive Preserving Rebates (CPPIPR) might outperform conventional CPP if the benefits of increased enrollment outweighed the costs of an endowment effect.

¹²Critical events happen disproportionately during seasons when the average customer's highest demand season and receiving their highest bills. Critical Peak Pricing with Incentive Preserving Rebates dampens seasonal variations for these customers. However, it may not have this effect for customers whose local climate or seasonal consumption patterns deviate from their electric system's average.

3.2 Other consumer perception challenges: price comparison rules and fairness

Two additional factors may affect consumer reaction to CPP. First, marketing scholars find a tendency to choose the option with the greater number of prices or scenarios that compare favorably (Redden and Hoch, 2005). Customers who use this favorable price counting heuristic would avoid CPP rates that sets two of three prices above the time invariant price despite the fact that the higher prices apply during less than 20% of all hours. Gulf Power splits the offpeak period into “medium” and “low” priced periods, both of which are lower than the time invariant price. Doing so deals with this heuristic. Critical period rebate opportunities may compare favorably to the time invariant rate, while the high critical price compares unfavorably. This reframing of critical periods is decisive for people who decide between time invariant pricing and three price level CPP by choosing the rate with more favorable prices.

Second, many consumers find it unfair to raise prices to deal with a shortage stemming from a demand-increasing shock. They find conventional, economically efficient price rationing unfair. Critical periods often raise air conditioning prices when hot weather makes power scarce. A study of an analogous situation found that most consumers consider it unfair to increase prices to manage a blizzard-induced snow shovel scarcity.(Kahneman et al., 1986). Gulf Power seems to acknowledge this concern when it assures customers that its critical price, “[R]eflect[s] the actual cost of producing electricity during those periods.” IP rebates address the fairness question by presenting critical periods as a way to profit through sacrifice.

3.3 Behavioral interventions’ effectiveness

Studies show that adjusting options’ presentation, information about results, and the timing of choices relative to costs and benefits can improve consumer choices in areas like retirement

savings and investment choices. For example, employees who got the option to precommit to increase their retirement plan contribution rate when they got their next raise saved more (Thaler and Benartzi, 2004). Lab experiments show that customers choose higher yielding, but riskier investments when they only get aggregated performance information which forces them to broadly bracket (Gneezy and Potters (1997); see also Gneezy et al. (2003); Thaler et al. (1997)). Behavioral economists suggest that choice architects should seek ways to improve biased consumers' choices without affecting rational consumers' choices because errors and biases are common, not universal (Camerer et al., 2003; Sunstein and Thaler, 2003; Thaler and Sunstein, 2009). This paper's approach is consistent with their view because it not only preserves CPP's good incentives but also presents those incentives in ways that reflect how consumers decide.

4 Improving presentations while preserving incentives

This section presents critical events as opportunities to gain while preserving marginal incentives and charging each customer the same total annual amount the underlying CPP rate would have charged for the same consumption pattern.

4.1 Revenue neutral rebates that preserve marginal incentives

Incentive preserving rebates transform the presentation of CPP while preserving CPP's revenue streams and marginal incentives.

IP rebates make critical events into opportunities for customers to gain by selling each customer rights to a block of power at the regular price during critical events and rebating the value of unused rights. Setting the right rebate value per kWh gives customers the right incentives to choose between using their rights and cashing them in. Each customer pays a fixed monthly fee to buy these rights. For example, a customer might pay \$5 a month to buy the rights to a \$4 bill reduction during each of 15 events a year.

Fixed transfers of cash or property rights can adjust bills while maintaining the right marginal incentives. Versions of this insight underlie the Coase Theorem, hedging in financial markets, and cap-and-trade pollution policies. CPP sets critical prices and the annual number of events in advance, meaning there is no risk and no need for a risk premium in the price of the right to use a kWh during each event.

We can make these transfers of rights revenue neutral for each customer – by using every penny the customer paid for rights either for power or for a rebate.¹³ The rate in Table 1 has customers contribute \$135 per year to get rights worth \$135 per year. Customer-level revenue neutrality makes it impossible for a customer to profit by strategically manipulating the number of rights the utility assigns them. Hence, switching a customer from a time-invariant rate to CPPIPR creates only the desired incentive to shift use away from peak and critical periods. Revenue neutrality makes it costless for designers to offer customers rights to more (or less) power than they would have used in the absence of a critical event. This freedom allows rights assignments that give most customers rebates and that give the same number of rights to broad classes of customers. Revenue neutrality means that CPPIPR rates deliver the same revenue levels, transparency, and predictability as CPP.¹⁴ Further, customer level revenue neutral rebates create no cross subsidies, making CPPIPR as equitable as the underlying CPP rate.

Achieving account-level revenue neutrality requires policies that, for example, refund the value of rights purchased for events that were never called and that balance customer rights purchases and redemptions when customers enter and exit the program mid-fiscal-year.

Appendix B discusses these details.

¹³Achieving revenue neutrality requires paying interest to equate the net present value of the dollars each customer pays to the net present value of the rights that they get later in that calendar year. I omit this straightforward but small and tedious adjustment for brevity.

¹⁴CPP and CPPIPR raise identical revenue assuming that customers behave identically under them. Note 11 discusses endowment effects that might cause CPPIPR customers to use more critical period power. If the critical price equaled the utility’s marginal cost of critical-period power, then changes in critical period consumption would be revenue neutral. If the critical price diverged from the utility’s costs, changes in critical period consumption would affect the utility’s revenues. Regulators often address uncertainty about utility revenue because utilities face uncertainty about weather-driven demand, fuel costs, and economic conditions.

Table 1: Examples of rates. The IP rebate offer here is appropriate for a high use customer with air conditioning in a hot climate.

Price Period	Times in effect	Price per kWh			
		Time Invariant Rates	CPP	CPPIPR	
Low	weekdays before 2PM; after 7PM; all day weekends & holidays	14.6 cents	12 Cents	initial price	beyond 450 kWh/mo.
				14.5 cents	12 cents
High	Weekdays 2:00PM-6:59PM	14.6 cents	24 Cents	26.5 cents	24 cents
Critical	Announced with a telephone call at least 24 hours in advance	14.6 cents	60 Cents	First 25KWh: 24 cents; 36 cent rebate for every kWh you save. Additional kWh after the first 25: 60 cents	

There are several equivalent ways to describe the rebate program. One attractive description is that consumers own the right to buy a limited amount of power at the hour’s usual (reference) price during each event.

Customers can cash in an unused kWh of rights for the value of access to a kWh of critical period power at the peak price, which is the difference between the peak and critical prices. Customers on the rate in table 1 get \$9 worth of rights during each critical event, which lets them access up to 25 kWh of power for 24 cents each instead of 60 cents and cash in unused rights for a rebate of 36 cents per kWh. Figure 1 shows the equivalence of the \$9 fixed credit and 25 regular-priced-critical-kWh presentations while section 5 proves their equivalence.

Presentation matters: Loss-averse customers may be more receptive to the “usual-price” explanation (shown in table 1) than to the “fixed-credit” presentation. Customers who have rights to buy all of their critical period power at the usual, peak price (likely, the reference price) experience no losses in their mental accounts. Presenting economically identical incentives as a high price and a fixed credit creates offsetting gains and losses, but loss-averse

Offering a choice between a lower nominal price or the right rebate for the first q_R kWh is equivalent to giving each customer a fixed bill credit and charging the full critical price

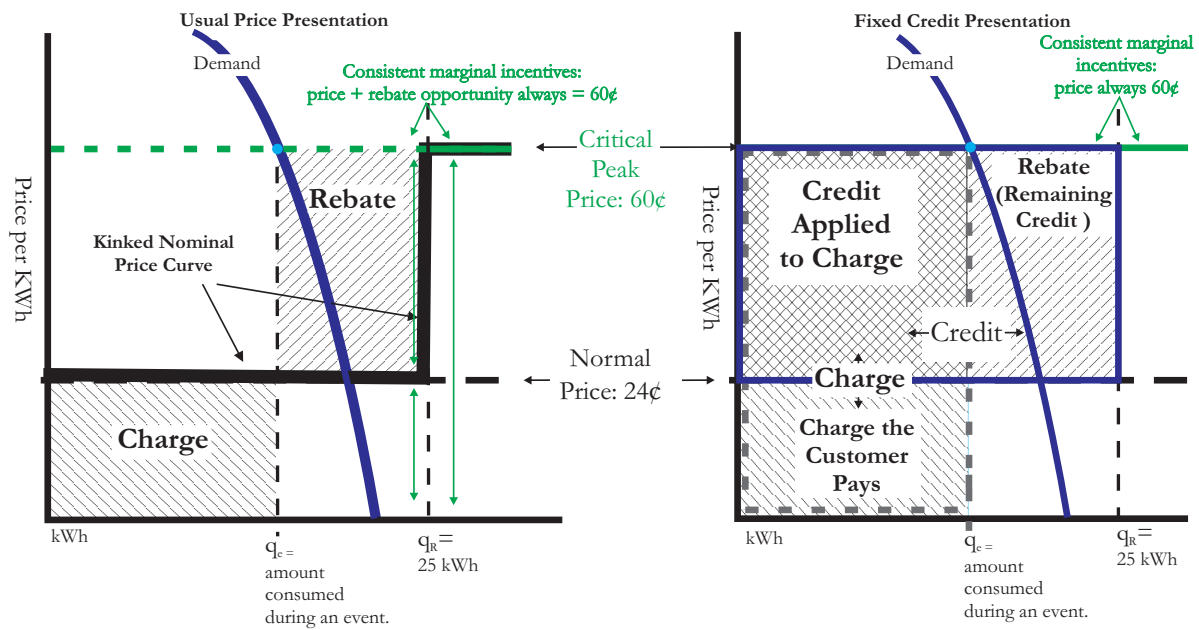


Figure 1: Presenting IP rebates as the right to choose between power at the usual price or a rebate during each event is equivalent to presenting it as a fixed credit during each critical event. Both presentations keep the marginal incentives equal to the critical peak price.

customers put more weight on losses than gains and may perceive the offsetting gains and losses as a net loss.^{15, 16}

This presentation of IP rebates preserves CPP's marginal incentives by keeping the sum of the price of the marginal unit and any foregone rebate equal to the CPP price for that time period. It is efficient and fair that all customers face the same CPP incentives to use power regardless of whether they are eligible for a rebate. Table 1's rate creates a 60 cent per kWh opportunity cost as the sum of the 24 cent payment and a 36 cent forgone rebate for customers with rebates and charges 60 cents per kWh to customers who have exhausted their rights.

4.2 Bundling rights with power purchases

Selling customers a fixed, monthly block of rights for a fixed fee is a simple, effective funding mechanism that does not change customers' incentives. However, the marketing literature reports that customers are averse to paying fixed fees but are more receptive to almost identical incentives presented as quantity discounts (Ho and Zhang, 2004). An alternative to fixed fees that strongly resembles the quantity discounts in Ho and Zhang (2004) is to bundle rights with the first few units of power that each customer uses each month and to increase the price of those units by the value of the bundled rights. For example, bundling 2.5 cents of rights with each customer's first 200 kWh per month can replace the \$5 per month fixed fee in section 4.1's example.

Bundling does not change consumers' incentive to buy power since IP rebates' customer-level revenue neutrality returns every cent that customers pay for bundled rights.¹⁷ We aspire to have each customer buy all of the power with bundled rights each month to ensure that each customer buys the rights their rate promised. If the rate fails to offer a customer the

¹⁵We could use a model like Koszegi and Rabin (2006) to formalize this.

¹⁶Prospect theory suggests that customers will have diminishing marginal sensitivity to gains which will further diminish the perceived difference in size between the gain from the full credit presented by the fixed-credit presentation and the smaller rebate emphasized by the usual-price presentation.

¹⁷Appendix C.1 proves this.

rebates that it promised because the customer did not fully purchase their rights, customers may experience the kind of unexpected loss that the rate structure is designed to avoid.

It is desirable to keep offpeak power bundled with rights less expensive than the time invariant rate so 3-period CPPIPR rates compare favorably to time invariant rates during both off peak and critical periods. This is attractive to customers who simply count the number of periods during which one rate outperforms another (Redden and Hoch, 2005). It also lets marketers claim that CPP with Incentive Preserving Rebates (CPPIPR) offers lower prices more than 80% of the time – as Gulf Power does (Gulf Power).

Collecting money for rights each month and returning it during critical events reschedule a significant part of CPP’s savings. CPP delivers subtle savings offpeak, year round. CPPIPR visibly delivers many of those benefits during critical events. Table 2 compares the proportion of customer bills that come from peak, offpeak, and critical periods under time invariant, CPP, and CPPIPR rates. This change in the timing of charges over the year may cause small, likely negligible, income effects.

Table 1 shows how offer letters might explain CPPIPR to consumers.¹⁸ In this example, the time invariant rate is 14.6 cents per kWh. CPP Customers CPP pay more – a 24 cent per kWh “high rate”– non-holiday weekday afternoons. CPP customers pay less – a 12 cent per kWh “low rate”– during the remaining, “off peak,” periods. More than 85% of hours are offpeak. The utility can notify customers that a (typically peak) period will be critical, raising prices 36 cent per kWh.¹⁹ Roughly 1% of hours are critical.

This example CPPIPR rate is CPP modified three ways:

1. The customer’s first 450 kWh per month come bundled with 2.5 cents of rights.
2. The customer has the right to access up to 25 kWh of power during an event at the

¹⁸The CPP rate in table 1 on page 13 is based on Pacific Gas and Electric’s “low ratio” experimental CPP rate (Pacific Gas & Electric, c). These CPP and CPPIPR rates would raise the same amount of money as the time invariant rate did for the consumption pattern of customers on time-invariant rates in California’s Statewide Pricing Pilot.

¹⁹If critical periods increase the price for any time period by a constant amount, like 36 cents per kWh, then calling critical events during an “offpeak” period has the same revenue implications as doing so during a peak period. This provides infrastructure to call an “offpeak” critical event should the need arise.

Table 2: Annual bills: This reports the annual total bill that three rates would have charged for California CPP pilot customers’ use patterns; and reports the percentage of those bills that come from the offpeak, peak, and critical periods. CPP and CPPIPR generated lower bills than time-invariant rates would have for these CPP customers. The average CPP customer would have saved \$30 on a CPP or CPPIPR rate relative to buying the same quantity on a time-invariant rate. IP rebates delivered most of those \$30 in savings as rebates during critical periods. Data: California State Wide Pricing Pilot CPP customers, described in section 8.3.1, CPPIPR benchmark offers described in section 8.3.5.

	offpeak	peak	critical	annual total bill
Time Invariant (% of bill and total kWh’s used)	84.6%	14.1%	1.3%	\$939
CPP	71.4%	23.8%	4.8%	\$909
CPPIPR	77.6%	24.9%	-2.4%	\$909

usual (typically high) price for that period. If the customer uses less than 25 kWh during the event that lasts 5 hours or less, he also earns a 36 cent per kWh rebate for the difference between their 25 kWh of rights and their actual use. For example, a customer who used 20 kWh during a critical afternoon would get a \$1.80 rebate on $5kWh = 25kWh \text{ of rights} - 20kWh \text{ used}$.

3. CPP puts a ceiling over the number of critical periods, while CPPIPR put a floor under the number of rebate opportunities. CPP allows the utility to designate no more than e.g. 1% of all hours as critical, while CPPIPR requires that customers get rebate opportunities equivalent to declaring 1% of all hours as critical periods. Appendix B.2 details this.

4.3 Psychological evidence about consistent rebates

CPPIPR rates aspire to sell customers enough rights that most customers receive rebates during each billing cycle containing an event (i.e. receive “consistent rebates”) because customers dislike paying critical prices and experiencing bill spikes and because selling customers more credits neither affects utility revenue nor distorts incentives.²⁰

²⁰Analogously, the US income tax system is tuned so many citizens withhold too much and get refunds.

Maximizing the number of customers getting rebates has potential downsides. IP rebates may induce customers to accept improved air conditioning management incentives, but reduce their awareness of air conditioning’s costs. Customers might misinterpret rebates as signals that they managed their peak use well.²¹

5 Proof: rights to regular-priced power are equivalent to incentive-preserving fixed credits

This section proves that IP rebates preserve marginal incentives for the interior case in which customers buy all the bundled rights, while appendix C extends the proofs to the general case. The next few sections consider critical period incentives during the hours the during which the program changes costs and typically consider total charges at the monthly, billing cycle level.

An IP rebate rate gives customers rights to get up to q_R of power at the normal price, typically P_H , during a critical event when they would otherwise face the critical price, P_C . Further, if during event e they use a quantity $q_e < q_R$ they get a rebate of $P_C - P_H$ per unit for their unused rights, $q_R - q_e$. Writing this out and multiplying through shows that this is mathematically equivalent to offering each customer a fixed credit, R , that reduces bills by $R = (P_C - P_H)(q_R)$ during each event.

²¹Comparative signals like “7 out of 10 of your neighbors earned significantly bigger rebates than you did last month.” might avoid this misinterpretation. Yoeli (2009) and Ayres et al. (2009) report on the use of peer comparisons to get people to change their energy use in a demand response field experiment and a company’s energy efficiency program respectively.

$$\begin{aligned}
TC_e^{CPPIPR} &= P_H q_e - (P_C - P_H)(q_R - q_e) \\
&= P_H q_e - P_H q_e + P_C q_e - (P_C - P_H)(q_R) \tag{1}
\end{aligned}$$

$$\begin{aligned}
&= P_C q_e - (P_C - P_H)(q_R) \\
&= P_C q_e - R \tag{2}
\end{aligned}$$

Equation 2 makes it clear that CPPIPR customers face the same price, P_C , during an event as CPP customers do, but get a lower bill because they receive a fixed credit of R . Equation 1 shows that the two formulations are equivalent because the sum of the usual price P_H and the forgone rebate, $P_C - P_H$ is equal to the critical price, P_C .²²

The balance of this analysis describes IP rebates as providing a fixed credit, R to both simplify its notation and emphasize the unchanged marginal incentive.

6 Proof: account-level revenue equivalence

This section shows that CPPIPR generates total annual bills identical to the underlying CPP rate.

Consider a CPP rate with three periods: low-priced, offpeak periods (denoted “ L ”), higher-priced, peak hours (“ H ”), and the highest-priced, critical hours (“ C ”). The customer uses Q_i kWh during period i during a billing cycle. The period-specific prices are P_L, P_H , and P_C . The monthly CPP bill, TC_m^{CPP} , is:

$$TC_m^{CPP} = P_C Q_C + P_L Q_L + P_H Q_H$$

IP rebates add charges and credits to CPP that sum to zero. The rate bundles rights with the first Q_B kWh. The rights increase each kWh’s value and price by a markup, \mathcal{M} .

²²Customers who use $q_e > q_R$ pay P_C for their marginal power use. That equivalence proof is analogous and omitted for brevity.

This section shows that CPPIPR generates total annual bills identical to the underlying CPP rate in the interior case where customers buy $Q_m \geq Q_B$ kWh in each month m , buying all the rights the rate offers them, namely $\mathcal{M}Q_B$ per month in order to receive power rights worth R during each of the rate's N_C events.²³ Appendix C considers the analogous general case that maintains revenue neutrality even if customers buy less than the planned $\mathcal{M}Q_B$ worth of rights in some months.

Consider a rate that calls N_C critical events per year. Revenue neutrality requires that the amount the customer pays through the purchase of marked up units equal the value of the rights the customer gets back, formally that $12\mathcal{M}Q_B = N_C R$.

In the well-behaved case, a customer's total monthly bill, TC_m^{CPPIPR} , in a month with $N_m \leq N_C$ events will be:

$$TC_m^{CPPIPR} = \mathcal{M}Q_B - N_m R + TC_m^{CPP} = \mathcal{M}Q_B - N_m R + P_C Q_C + P_L Q_L + P_H Q_H$$

The total annual CPPIPR bill, TC_a^{CPPIPR} , is simply the sum of the monthly CPP bills, TC_m^{CPP} , plus exactly offsetting rights and charges. We can see this by computing the total annual CPPIPR bill, rearranging terms, and recalling that $12\mathcal{M}Q_B = N_C R$ and that the total number of critical events $N_C = \sum_{m=1}^{12} N_m$, as follows:

$$\begin{aligned} TC_a^{CPPIPR} &= \sum_{m=1}^{12} [\mathcal{M}Q_B - N_m R + P_C Q_C + P_L Q_L + P_H Q_H] \\ &= 12\mathcal{M}Q_B - N_C R + \sum_{m=1}^{12} [TC_m^{CPP}] \\ &= 0 + \sum_{m=1}^{12} [TC_m^{CPP}] \end{aligned}$$

²³Appendix A details the way IP rebates tend to reduce seasonal bill variation when they raise CPP bills by up to $\mathcal{M}Q_B$ each month and return that money during (typically peak season) events.

7 Comparing IP rebates to other rebate approaches

This section compares CPPIPR to other rates, including baseline-rebate approaches. Baseline-rebate rates calculate a personalized, baseline demand level from each customer’s consumption history and then offer rebates to customers who use less than their baseline level during critical events.

Successful rates, including time invariant rates and baseline-rebate rates, prevent transient power scarcities from causing bill spikes. CPPIPR shares this property. Conventional CPP does not. IP rebates use correctly defined and priced property rights to manage bill volatility. Time invariant rates require everyone to pay for a use-it-or-lose-it right to as much under-priced power as they want during high cost periods, which encourages peak-period overconsumption. Typical baseline-rebate rates that add features to a time invariant rate exhibit the same flaws whenever customers are ineligible for rebates. In addition, baseline-rebate rates create incentives to over consume during baseline setting periods by providing but not charging for valuable rights bundled with electricity.

Baseline rebate rate mechanics: Baseline-rebate rates use a customer’s “normal” usage during periods that are comparable to critical periods to set a baseline and give rebates to customers whose critical period use is below their baseline.²⁴ The baseline amount, \hat{q}_e^b , is generally the average of the customer’s use during the N_b periods before event e at time t . Formally, considering use q_{t-i} where the baseline setting time offset, i , takes values $1 \cdots N_b$, the baseline \hat{q}_e^b is: .

$$\hat{q}_e^b = \frac{1}{N_b} \sum_{i=1}^{N_b} q_{t-i}$$

²⁴The baseline setting process is an asymmetric information game in which customers know their demand for electricity, but the utility only observes the quantity that the customer used. It is generally difficult to design efficient mechanisms to get customers to reveal characteristics like their demand in games of asymmetric information. In the absence of mechanisms that eliminate the incentive to distort consumption, customers have incentives to strategically misrepresent their demand by increasing consumption during baseline-setting periods. Basing each customer’s baseline on the consumption of other, comparable, customers would address incentives for misrepresentation, but make the baseline less accurate.

The customer’s monthly total bill under a baseline rebate plan is:

$$TC_m^{baseline} = P_L Q_L + P_H(Q_H + Q_c) - \sum_{e \in E} P_B \max\{0, \hat{q}_e^b - q_c\} \quad (3)$$

Baseline-rebate rates create perverse incentives during baseline-setting periods. Baseline-rebate rates bundle free baseline rights with power during baseline setting periods. This makes power artificially cheap and gives customers incentives to increase usage during baseline setting periods. To see how baseline rebate rates reduce the implicit price of power from the desired rate of P_H , substitute the formula for \hat{q}_e^b into the baseline-rebate bill formula, 3, and take the partial derivative with respect to the quantity of power used during a baseline-setting period assuming, for notational simplicity, that the customer gets a rebate:²⁵

$$\frac{\partial TC}{\partial q_{t-i}} = P_H - \frac{1}{N_b} P_B$$

This change in incentive can be so big that some baseline rebate rates can pay customers to use power during the baseline-setting period. For example, San Diego Gas and Electric’s baseline-rebate rate offers a 75 cent rebate for every kWh that a customer’s critical period use is below a baseline set by averaging the customer’s use on the three highest use days from the five non-event weekdays preceding the event day (San Diego Gas & Electric, b). San Diego customers get another $\frac{1}{3}$ kWh of baseline rights, worth 25 cents, bundled with every baseline-setting kWh, a kWh which cost them between 4 and 23 cents (San Diego Gas and Electric).²⁶ The bundled rights are worth even more when one day sets the baseline for more than one critical event. Anaheim offered a 35 cent rebate and used the average of the consumption during the three highest use non-event weekdays of the summer season as its

²⁵Incentives from baselines do not affect the choices of customers whose utility maximizing choices never earn them rebates. And there is an unenlightening, somewhat less distorted corner case for customers who will be eligible for rebates only if they increase their baseline period consumption.

²⁶Most California utilities – including San Diego Gas and Electric and Anaheim Public Utilities – use an increasing block rate structure that offers the first few kWh per month at a low price, then increases the marginal price as customers use more.

baseline for every event. Since a single additional kWh consumed on a baseline-setting day increases the baseline by $\frac{1}{3}$ kWh over 12 events, this unit that costs either 6.75 or 11.07 cents comes bundled with rights worth \$1.40 to a customer getting rebates during every event (Wolak, 2006, 14).²⁷

Baseline-rebate programs force uncomfortable trade offs and often create cross subsidies: Increasing rates to fund these programs' rebates often creates inequitable cross-subsidies from people who the rate design recovers the costs of rebates from to rebate recipients.²⁸ Baseline levels can be mistakes since setting a baseline too high transfers cash to consumers who get paid not to use power they never would have used and while setting it too low means some customers have no incentive to conserve.²⁹ Hence, the ideal baseline is the amount the customer would have used without the rebate opportunity. Normal variations in weather and customers' situations make deviations from baseline predictions common even in the absence of rebate opportunities. IP rebates avoid these flaws through customer level revenue neutrality.

7.1 Baseline-rebate rates: field experience

Baseline-rebate rates add salient rewards for conservation to existing rates, while recovering costs later. Baseline-rebate rates' offer of carrots without visible sticks allows utilities to automatically enroll broad classes of customers in them. Baseline-rebate programs that claim to provide only rebate opportunities often recover rebate costs by raising rates later. A PG&E proposal reads, “[T]he 10/20 Winter Gas Savings Program is forecasted to pay out \$200 million in rebates...PG&E proposes that these costs...be recovered in residential and small commercial customers' transportation rates during the summer gas season...” (Pacific

²⁷Longer baseline-setting periods distort incentives less, but are a less accurate counterfactual estimate of how much the consumer would have used in the absence of a rebate opportunity.

²⁸Some rates observe their rebate costs in one season and recover costs by raising rates the next season when a different set of customers may be heavy users. This has the potential to create large cross subsidies. (See e.g. Pacific Gas & Electric (b, 4).)

²⁹By contrast, the underlying CPP rate creates the incentives in CPPIPR; incentive preserving rebates present those incentives in a more palatable way.

Gas & Electric, b, 4). Thus, some customers could have saved if they were allowed to opt out of both rebate opportunities and the obligation to pay a share of the rebates' costs. California addressed its 2000-01 crisis with a "20/20" program that offered customers a 20% rebate on their electricity bill if they reduced their total summer electricity use 20% below their use the prior summer. California Utilities' "10/20" baseline rebate program during a winter 2005-06 natural gas price spike offered a 20% rebate for reducing gas consumption at least 10% below the previous winter's level. San Diego Gas and Electric offers a "Peak Time Rebate" rate to customers who have advanced meters. Experience with baseline-rebate rates have left many utility employees and regulators dissatisfied. Wolak (2006) analyzes a baseline-rebate dynamic pricing program in Anaheim, California and reports that consumers reduced use during critical periods but that many customers exploited opportunities to increase their rebate eligibility.³⁰

8 CPPIPR's feasibility

CPPIPR needs to be administratively and financially feasible to implement:

- **Economic feasibility.** CPPIPR works well if we can assign each customer a revenue neutral pair of a rights size, q_R , and a number of units bundled with rights, Q_B , that addresses the concerns described below.
- **Administrative and political feasibility.** CPPIPR will be easier to implement if it coexists with existing analytic categories, is an incremental change from existing rates, and lets regulators address equity concerns.

Data from a California CPP pilot study shows that most customers can satisfy CPPIPR's financial constraints.

³⁰The Anaheim and San Diego rate designs comply with the AB1X prohibition on raising certain rates in California.

8.1 Adding IP rebates to existing rates

IP rebates are a revenue neutral, incentive preserving feature that can be added to any CPP rate. Thus, rate designers who choose IP rebates are free to design an underlying CPP rate to meet revenue requirements, make incremental change, and balance objectives like price accuracy, simplicity, and equity.

While IP rebates can be added to any CPP rate, the number of customers for whom consistent offers exist may be sensitive to the difference between offpeak and time-invariant prices which is the maximum markup, $\mathcal{M} \leq P_u - P_L$. Larger markups allow more rights to be bundled with each kWh, which creates consistent offers to some customers whose demand in their lowest use months is too low to make consistent rights purchases when fewer rights were bundled with each kWh.

8.2 Economic constraints

IP rebates make each customer an **offer**, (q_R, Q_B) , which specifies the number of kWh of rights per event customers buy, q_R , and the number of kWh per month with which customers buy bundled rights, Q_B . All else equal, offers that meet the following constraints for more customers are better:

- i. **Consistent rebates:** The offer includes enough rights that the customer gets a (weakly positive) rebate during each month with an event, or $q_R \geq \bar{q}_c$ where \bar{q}_c is the greatest of the customer's monthly average event use levels $\bar{q}_c = \max_{m \in M} \{Q_{c,m}/N_m\}$.
- ii. **Consistent purchases of bundled rights:** Customers buy all the power with which their offer bundles rights or $Q_B \leq \underline{Q}_m$ where \underline{Q}_m is the amount of power the customer used in their lowest consumption month.³¹

³¹This discussion assumes q_R and Q_B stay the same year round. Making seasonal changes to the number of bundled rights offered each month, Q_B , may be an important way to provide consistent offers. Extra contributions early could cover under contribution later. It may be particularly natural to consider seasonal variations in Q_B or \mathcal{M} in electricity systems that seasonally adjust rates. Seasonal adjustments may, however, confuse customers.

iii. **Customer-level revenue neutrality:** Each customer’s payments for rights equals the value of the rights they receive. Revenue neutrality requires that $12\mathcal{M}Q_B = N_c q_R(P_c - P_h)$ in the well-behaved case where the customer purchases at least Q_B per month (i.e. satisfies constraint ii) .

IP rebates achieve universal customer-level revenue neutrality (constraint iii) while aspiring to make as many customers as possible “**consistent**” offers so the customer gets consistent rebates (constraint i) and makes consistent purchases of bundled rights (constraint ii).³²

Substituting constraints i and ii into constraint iii, reveals a criterion that determines whether a consistent offer exists, namely:

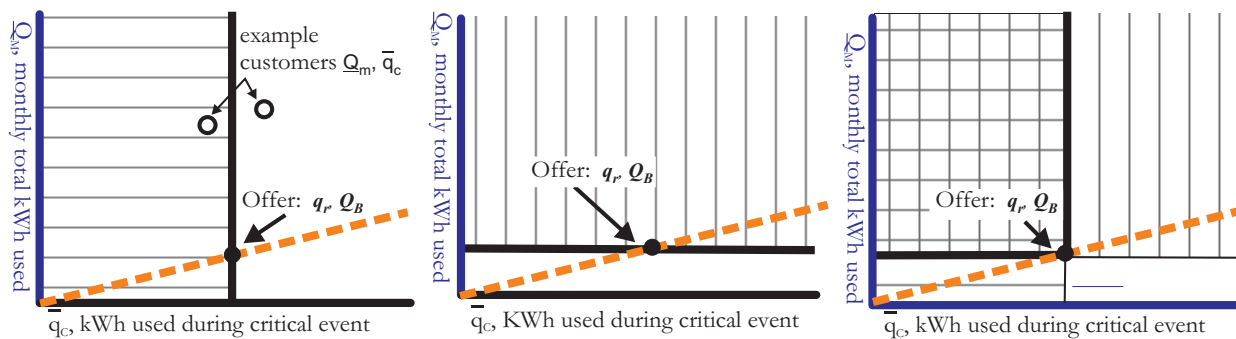
$$12\mathcal{M}\underline{Q}_m \geq 12\mathcal{M}Q_B = N_c q_R(P_c - P_h) \geq N_c \bar{q}_c(P_c - P_h) \quad (4)$$

Dropping the middle, revenue neutrality terms creates a feasibility criterion that depends only on customer characteristics and characteristics of the underlying CPP rate that we take as given. The criterion implies that a consistent offer exists only if the biggest bundled rights purchase the customer can consistently make is at least as big as the smallest rights level that offer that customer consistent rebates, formally:

$$12\mathcal{M}\underline{Q}_m \geq N_c \bar{q}_c(P_c - P_h) \quad (5)$$

Figure 2 illustrates the three constraints.

³²This project focuses on maximizing the probability of getting a consistent offer during each customer year. Calculating the minimum monthly use, \underline{Q}_m , and maximum critical use, \bar{q}_c , from a larger number of days will generate more extreme results. Knowing that a family’s annual values of \underline{Q}_m and \bar{q}_c supported consistent offers in 19 of 20 years seems relevant. It is not clear that knowing how many people’s lowest use month in 20 years (\underline{Q}_m) could not have bought enough rights to cover their highest use critical event (\bar{q}_c) chosen from those 20 years. Outlying events during the decades like extended vacations or the one time that someone ran the dryer during a critical period will leave a lot of people without consistent offers. A more subtle measure that uses an offer that maximizes the percentage of months during which a customer gets a consistent offer and the percentage of months in which this offer succeeds would be more appropriate for analysis of long term data.



The consistent rebate constraint (i) requires that customers be in the region with horizontal lines to the left of the offer.

The revenue neutrality constraint (iii) requires offers to be on the dotted diagonal line.

The consistent purchase of bundled rights constraint (ii) is satisfied by the group of customers in the vertically striped region above the offer. They use at least Q_B kWh per month, so they consistently buy all the bundled rights the offer includes.

An offer is “consistent” in the region that is the union of scenarios that satisfy the consistent rebate constraint (i) and the consistent purchase constraint (ii): Customers consistently buy their rights and consistently get rebates if they are in the hashed rectangle above and to the left of the offer.

Implication (5) means that consistent offers exist only for customers with consumption $(\underline{q}_c, \underline{Q}_m)$ above the dotted diagonal line.

Figure 2: Visualizing constraints 1-3.

8.3 Implementing CPPIPR

8.3.1 Offer existence, predictability, and administrative feasibility

Data from California Statewide Pricing Pilot CPP customers suggests that CPPIPR implementations are feasible. These customers’ CPP rate was similar to the example in the CPP column of table 1 on page 13³³

Making consistent offers requires that a consistent offer exist for the customer’s demand pattern (i.e. it must satisfy 5) and that the consistent offer be feasible to predict. There is no field experience with CPPIPR, so customer behavior on economically-similar CPP rates is the best available evidence about CPPIPR feasibility. California’s Statewide Pricing Pilot (SPP) collected data on 500 CPP customers who experienced 27 CPP events from summer 2003 into fall 2004 (Charles River Associates, 20).

³³The example CPPIPR rate in table 1 is adapted from the CPP rate described in an SPP welcome kit (Pacific Gas & Electric, c).

Appendix F uses SPP data to estimate that 97% of customers statewide have demand patterns that satisfy feasibility criterion 5 for the example rate and that other rates are feasible as well.

8.3.2 Making offers at the individual and group levels

IP rebate implementations either customize an offer for each customer or make offers to categories of customers. Category level offers seem fair because they offer (superficially) similar customers identical rebate opportunities. Observers who understand that offers do not affect total annual bills are likely to find any offer fair, but offers to categories are more likely to seem fair to people who do not understand this. Making broad categories of customers identical offers reduces the likelihood that customers will get the (wrong) notion that they can profit by strategically distorting their consumption to get more rights. Thus, category level CPPIPR offers improve incentives even if customers only understand that CPPIPR makes it advantageous to reduce power use weekday afternoons and, especially, during critical events. Category-level offers reduce customer inquiries about how the utility set their rebate eligibility and simplify answering those questions.

Rate implementers need to use existing information to identify offers that are likely to be consistent for customers or groups of customers. The best available information may be total use per billing cycle under a time invariant rate which captures neither peak period use nor their reaction to dynamic pricing. Analysis in appendix F.1 shows that aggregate use, account type, and climate zone predict consistent offers well.

8.3.3 Testing category level offers' feasibility

This section tests the feasibility of using existing distinctions to categorize customers using the SPP's customer classification. It summarizes results from Letzler (2009) and Letzler (2007). The SPP divided the state into 4 climate zones and each climate zone into three groups: apartments, high use single family houses, and low use single family houses. It

classified customers' use levels as high or low using consumption from the summer before the experiment began. The low use category's ceiling varies from 16 to 28 kWh per day. Categorization schemes that, like this one, use existing regulatory categorizations and readily available data, are easier to implement.

The SPP's original low use and apartment categories in the hottest climate zones contained a set of customers too diverse for a single IP rebate offer to fit well. Discarding the distinction between apartments and single family homes collapses 12 groups into 8 groups. Subdividing each group at its median use level yields 16 groups, namely very low use, low use, high use, and very high use categories in each of the four climate zones. Making the optimal offer to each of these 16 groups provides consistent offers to the vast majority of customers.³⁴

It may be desirable to further simplify the 16 group approach. In particular, it is worth searching for groups that are similar enough that they could be combined into a broader category, while retaining the ability to make a single offer that is consistent for most of the customers in the combined category. The analysis calculated the optimal offer to each of the 16 groups and then repeated that analysis to find the optimal offer for each possible assignment of 16 groups to 1, 2, 3, 4 and 5 categories as described in Letzler (2007). The analysis below concludes that 3 offers can perform almost as well as 16 offers if we collapse the 16 groups into 3 optimal categories.

8.3.4 Optimization algorithm

The optimal offer calculation algorithm proceeded as follows. For each customer, i , it calculated the per-event rights levels, $[q_{R,i}^{min}, q_{R,i}^{max}]$, that satisfy feasibility criterion 5. This range, $[q_{R,i}^{min}, q_{R,i}^{max}]$, runs from the smallest offer that provides customer i consistent rebates, $q_{R,i}^{min} = \bar{q}_c$, to the largest offer that customer i can consistently buy, $q_{R,i}^{max} = \frac{12M Q_m}{N_c(P_c - P_h)}$. We

³⁴Most apartments were low use. Retaining and subdividing the apartment category yielded 24 cells, some of which were quite small in the 500 customer SPP treatment group. All else equal, subdividing a category before computing optimal offers for each of the expanded set of categories will improve the offers' fit.

calculate the proportion of customers who would get a consistent offer for each potential rights level q_R by testing whether q_R falls into the customer’s optimal range $[q_{R,i}^{min}, q_{R,i}^{max}]$.³⁵ This yields the kind of objective step function in figure 4. The plateau on top of that function is the set of optimal offers which maximize the number of customers getting consistent offers.

8.3.5 Performance of optimal group rates and optimal categorical rates

The analysis below uses the optimized 16-offer CPPIPR rate in Appendix F.2 as a benchmark. That rate makes consistent offers to 90.3% of customers.³⁶ We can get from 16 to 9 categories without making any compromises by combining groups with overlapping optimal regions.

Group-level performance Calculating the offer that is consistent for the greatest weighted³⁷ number of people in each group yields a set of 16 offers listed in table 6 and visualized in figure 10 both in appendix F.2. These are consistent for 86% of all customers statewide regardless of whether a feasible offer exists for that customer.³⁸ Appendix F.3 reports that most inconsistent offers that are only a few dollars from being consistent, while the average annual bill is roughly \$900.

³⁵The category-level offer analysis rounded feasible ranges to .25 kWh increments to reduce the number of substantively similar options to search.

³⁶These results and the results below modify the example rate in table 1 to replace the 15 annual events the SPP promised with the 18 events it called during the 12 months from October '03 through September '04. The analysis reallocates the fixed credits by offering 15/18 of R the value per event – reducing the critical price from 60 cents to 54 cents. This reduces the utilities’ total revenue slightly.

³⁷Determining the optimal assignment of groups to broader, category level offers requires (potentially implicit) weights capturing the relative benefits of making consistent offers to the average customer in each group. The optimization reported here chose weights so that the optimal category-level offer delivers the greatest reduction in deadweight loss. It proceeds under assumptions, documented in Letzler (2007), implying that any increase in the probability that a customer gets a consistent offer increases the probability that they sign up. Letzler (2007) converts estimates of the peak-period, energy use impact of exposing each of the 16 groups of customers to peak and critical prices from Letzler (2009) into a scalar estimate of each category’s summer season, average deadweight loss reduction value.

³⁸This number reflects a 92% consistent offer rate in the more temperate climates zones 1 and 2 and a 77% rate in the hottest climate zones 3 and 4. Five percent of zone 3 and 4 customers’ demand patterns violate criterion 5, so no budget balanced consistent offers exist for them.

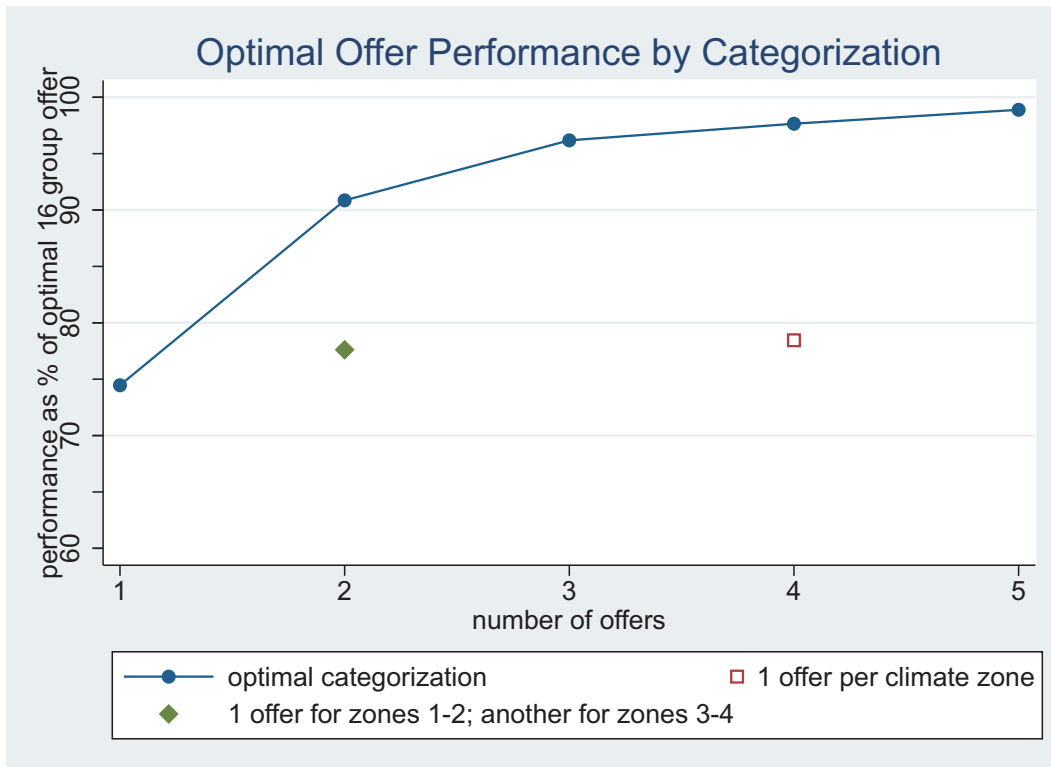


Figure 3: The line illustrates the performance of the optimal category-level offers as a function of the number of categories allowed. The two points below the line show the performance of the optimal offers based only on climate zone, which use no consumption data. The left dot uses hot (zone 3-4) and cold (zone 1-2) climate zone offers. The right climate zone based offer makes four offers, one to each of the zones.

Category-level performance: The category-level optimization ran the algorithm above on every possible combination of the 16 groups into c categories for each value of c between 1 and 5. Doing so reveals that making offers after optimally collapsing these groups into large, medium, and small categories performs 96% as well as making the optimal 16 group-level offers. These three offers far outperform the best one- and two-category offers.³⁹ Four and five category offers perform only modestly better than the optimal three category offer. Categorizing based on both aggregate, historical use and climate zones far outperforms categorizing based on climate alone.^{40, 41}

The optimal three-category offer makes “consistent” offers to between 75% and 90% of the customers in most groups⁴² which reflects both limits on the predictability of electricity consumption and California’s climate, building stock and human diversity. A three category system is easier to understand, implement, discuss and explain than a 16 offer system or a one-offer-per-customer approach.

9 Conclusion

Giving small customers incentives to make their power consumption patterns more responsive to changes in generation costs has enormous potential value. Consumers’ low willingness to sign up for dynamic pricing programs reflects – in part – a presentation that focuses customer attention on their risks and downsides. Presenting good incentives in a way that is compatible with the way people think makes such programs more likely to thrive. Many innovative

³⁹This paper identifies and reports the characteristics of the optimal one-size-fits-all offer. The approach’s other results are only optimal assuming that we categorize people by subdividing each of 4 climate zones into 4 use levels. We cannot rule out the possibility that there is a two category offer that uses a better way to assign customers to categories that performs as well as the best three category offer that collapses the 16 groups.

⁴⁰The 500-customer SPP data set lacks size to evaluate the effectiveness of making narrow geographic offers that are specific to ZIP codes, Census blocks, or subdivisions.

⁴¹When energy consumption data are not available, estimates based on the building’s size, age, and neighborhood, or a previous tenant’s use might be valuable.

⁴²No consistent offer exists for about 3% of all customers. Even an omniscient system would be unable to make these customers a consistent offer, so they are not in the denominator here.

Table 3: The optimal assignment of 16 groups to three categories and the level of rights that provide consistent offers to the greatest number of customers. The groups with white backgrounds are in the category that gets 25.75 kWh per event, which is the largest offer. The darkest background color designates groups that get the smallest offer, 6.5 kWh per event. This reports the percentage of customers who would get consistent offers under the optimal 16 group offer who still get them under the optimal 3 category offer.

Optimal 3 category offer					
size class	zone 1	zone 2	zone 3	zone 4	offer
very low	84.0% Cat. 3	88.0% Cat. 3	99.5% Cat. 3	100.0% Cat. 3	Category 3 6.5 kWh/event
low	92.6% Cat. 3	88.6% Cat. 3	100.0% Cat. 2	100.0% Cat. 2	Category 2 14.25 kWh/event
high	100.0% Cat. 2	92.5% Cat. 2	97.1% Cat. 1	89.2% Cat. 1	Category 1 25.75 kWh/event
very high	91.3% Cat. 1	100.0% Cat. 1	94.6% Cat. 1	100.0% Cat. 1	

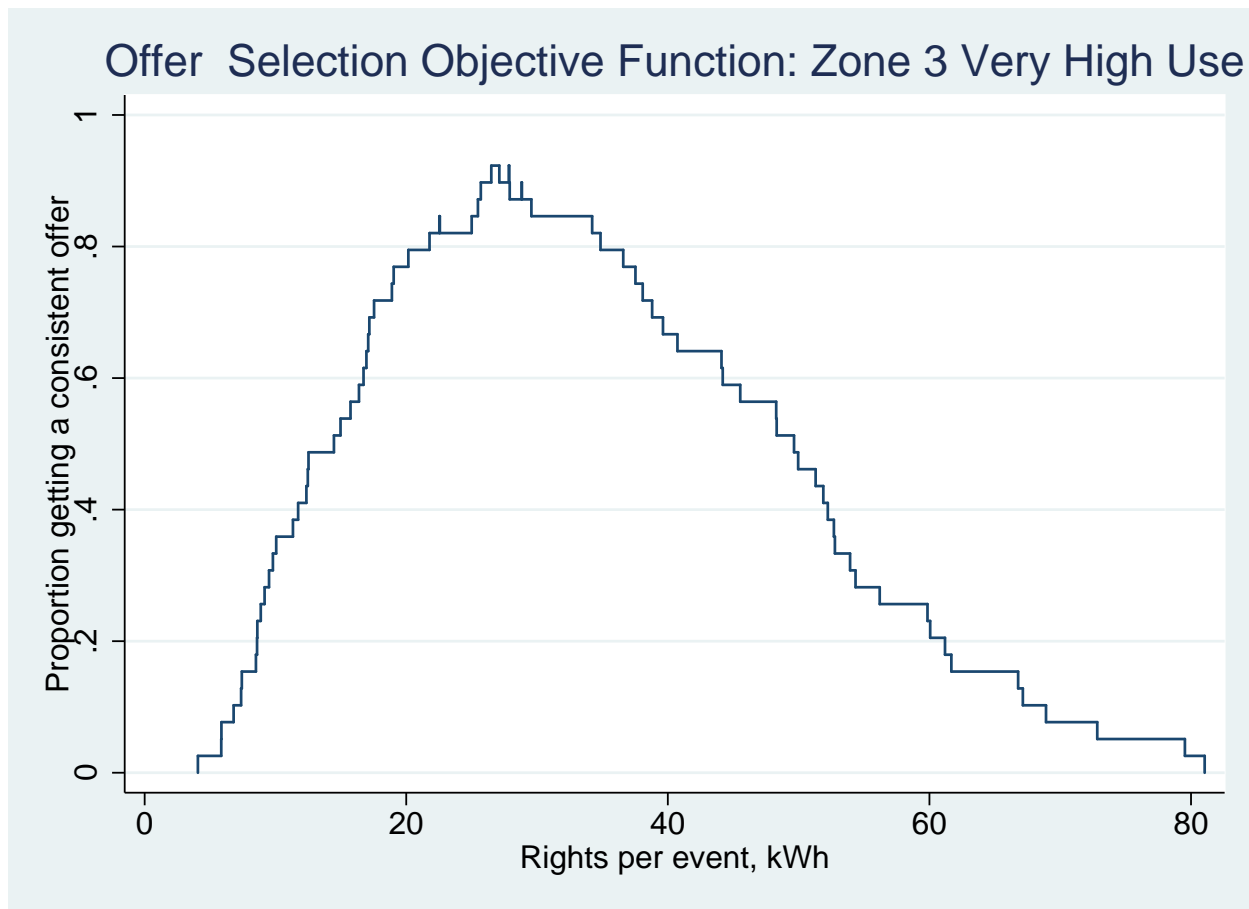


Figure 4: The proportion of very high use customers in climate zone 3 for whom each possible offer is consistent.

programs are likely to have to establish a track record on an opt-in basis before they can become opt out or universal. Baseline rebate rates present incentives well, but have flaws that lead to unintended consequences and unpredictable bill impacts. A “buy your own carrots” approach to rebates allows an attractive presentation of good incentives. Incentive Preserving Rebates preserve CPP’s revenues and marginal incentives while changing the presentation to sidestep flawed decision making patterns and avoid counterproductive resistance.

California data suggests that IP rebates are administratively feasible and that coarse, categorical offers can meet the needs of most customers. Most customers can fully fund rights that deliver them consistent rebates. When IP rebate rates fail to meet their consistency goals, the deviations’ bill impacts are typically less than 1% of the customer’s total annual bill.

This project is a first step in a long, important project of designing and implementing energy programs for small consumers that create good incentives and present them in ways that make effective participation attractive.

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A IP rebates and seasonal bill variations

Many consumers and policy makers prefer consistent bill levels from month to month. Many utilities offer balanced payment or “flat bill” plans.⁴³

IP rebates reduce CPP bills during critical periods and increase CPP bills during the first Q_B hours each month. This shifts bills among months since the monthly contributions are spread evenly around the year, while most critical periods take place during the summer. Thus, IP rebates reduce seasonal variations in bills relative to CPP for customers whose total use peaks during the season with the largest number of critical events. IP rebates can amplify seasonal differences in regions where electricity use peaks in a different season from the majority of the electricity use in their system.

Figure 5 shows how this plays out in California’s most temperate and hottest climate zones. The top three lines on the graph show that CPPIPR smooths the air-conditioning-driven, summer bill peak in the desert (zone 4) relative to the bill pattern from time invariant and conventional CPP. Similarly, CPPIPR smooths the more modest summer peaks in the two intermediate zones (not shown) – the Foothills (zone 2) and Central Valley (zone 3). CPPIPR slightly amplifies the modest winter bill peak in zone 1’s temperate climate. The patterns in zones 2 and 3 lie between the zone 1 and zone 4 extremes.⁴⁴

⁴³Indeed, large numbers of customers are willing to pay a roughly 10% premium to participate in a flat bill program which charges them one twelfth of their expected total annual bill plus the risk premium each month, regardless of their actual usage.

⁴⁴Looking at customer-level bill volatility – as Borenstein (2007b) did – yields qualitatively similar results: IP rebates reduce each customer’s month-to-month bill volatility relative to CPP in climates that hit their peak consumption season when the system does and increase each customer’s month-to-month bill volatility in regions where residential use peaks in a different season than the system does.

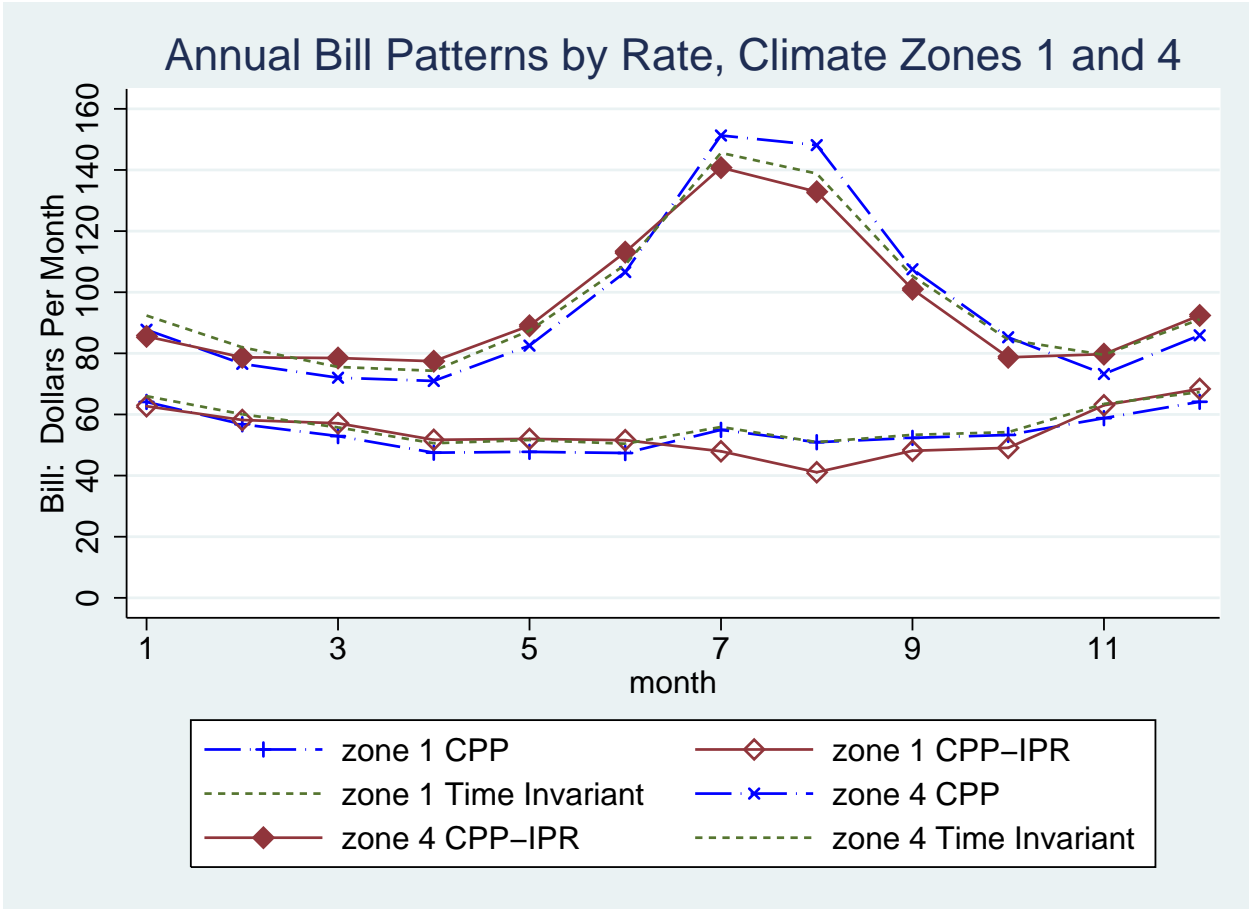


Figure 5: IP rebate rates (diamond) smooth a high summer peak in the climate zone 4 (desert) at the top of this graph but exacerbate modestly winter peaking bills in climate zone 1 (the temperate fog belt; largely the San Francisco Bay Area) at the bottom of the graph. We calculate all three billing patterns for the same consumption pattern, namely the average usage by customers on the SPP’s CPP rate with telephone notification.

A.1 Managing Volatility

The dynamic rates customers reject (CPP and RTP) generally make risk management optional.⁴⁵ Borenstein (2007b) reports that RTP increases bill volatility, but that simple hedges can control that volatility. Offering risk management through well defined property rights by default makes sense.^{46, 47}

Time invariant rates and baseline-rebate rates create flawed incentives because their volatility management features do not use well defined property rights. For example, time invariant rates require customers to buy a use-it-or-lose-it right to as much under-priced peak and critical period power as they want. Customers use too much power during periods when wholesale power is expensive and they would prefer to sell their rights for their true cost. Time invariant rates and CPPIPR ask customers to contribute toward insurance against critical events year round, while plain CPP does not – so, in this sense CPPIPR is a more incremental change from the time-invariant status quo than CPP would be. Baseline-rebate rates bundle a “free” hedge with electricity purchases during baseline setting periods, creating an incentive to increase consumption during those periods.

⁴⁵The rights that IP rebate customers buy have bill-volatility reduction effects that are akin hedging by buying ahead on the futures market, but differ from conventional hedging in that there is no unknown state of the world that affects the realization of the price of the commodity when the customer uses their forward rights, although there is uncertainty about the number of critical events in each billing period and about the customer’s demand during events.

⁴⁶Zero-expected-cost risk management or month-to-month volatility reduction make customers happier for both psychological and neoclassical reasons. IP rebates are in this category since they provide features that reduce month to month bill volatility at zero cost to the consumer while their dynamic pricing lets customers reduce their overall bill. More generally, rational customers should be willing to pay only a small risk premium to reduce the risk of modest bill spikes (Rabin, 2000).

⁴⁷It is attractive to provide customers with a revenue-neutral volatility dampening mechanism or actuarially fair hedge unless they opt out. Including the hedge by default reduces the transaction costs of protection against fairly small bill shocks. People often refuse to choose when they face too many choices (Iyengar and Lepper, 2000; Dhar, 1997); and are strongly influenced by default offers (Choi et al., 2003). Economically rational customers will generally be nearly indifferent between competing revenue neutral bill volatility reduction strategies.

B Choosing details to ensure revenue neutrality

B.1 Calendar design for revenue neutrality

Flawed policies to handle under-contribution or mid-year customer exit could break the account-level revenue neutrality. Concentrating events at the end of the rebate program's fiscal year can ensure that customers pay for property rights before they use them. A requirement that customers buy rights before using them prevents customers from profiting by strategically entering for just the peak season, claiming rebates, and then exiting the program. Clustering events at the end of the fiscal year also ensures the feasibility of reducing credit sizes if customers use too little power during a month and prevents customers from using rights during the summer and then underpaying for them in the fall. A calendar that makes customers who leave eligible to cash in their unused rights is often administratively preferable to imposing fees on exiting customers or adding the value of rights that were used, but never purchased to utility's revenue requirement.⁴⁸

A standard fiscal year also facilitates making equitable, revenue neutral program revisions since everyone would experience new charges or benefits at the same time.

B.2 Ensuring that customers get the rights they paid for

CPPIPR can handle year to year fluctuations in the number of times that weather and equipment problems justify critical events by returning the fixed credits for any unused event days. In other words, the customer would get the rebate they would have received if the critical periods had been called and the customers used zero power during the period. CPPIPR with that rebate provision creates identical incentives for utilities to call critical events as does a CPP rate that caps the number of events. By contrast, allowing utilities to pocket credits from unused event days would create an incentive to not call events.

⁴⁸Standardizing the fiscal year requires a provision for customers who joined after current fiscal year started, like calling fewer critical events for them.

C Generalized proofs: dealing with customers who do not buy all of the offered rights

This section generalizes the discussion in section 5 to allow customers to buy less than Q_B kWh of power in some months, which means that they did not purchase a full $\mathcal{M}Q_B$ worth of rights. It maintains revenue neutrality by only selling customers the rights they have paid for, \hat{R} .⁴⁹ Selling customers only the number of rights that they pay for is consistent with treating this bill volatility control strategy as a well-defined property right – which section 7 discussed further. The customer buys rights bundled with the lesser of Q_B and their actual consumption, Q_m each month, acquiring rights worth $\mathcal{M} \min\{Q_B, Q_m\}$

Customers thus own rights worth \hat{R}_e during critical event e . Formally, budget balance entails:

$$\sum_{e \in E} \hat{R}_e = \mathcal{M} \sum_{m=1}^{12} \min\{Q_B, Q_m\}$$

Strategies to restore account-level revenue neutrality reduce bills relative to the full contribution scenario during the months when the customer contributes too little and increases bills during months in which the customers get a reduced credit of $\hat{R}_e < R$. Reference dependent people may perceive these adjustments as a gain and a loss of the same size, which they would take as a net loss since they weigh losses more heavily than gains.⁵⁰

We can calculate the reduced rights level, \hat{R}_e , using the cumulative deficit, δ_m , in month m , in rights purchases relative to the value of rights that the rate slated for the customer. The deficit grows when monthly consumption is too low, $Q_m < Q_B$, and shrinks when the customer gets fewer rights during an event.⁵¹ Formally, the definition is:

⁴⁹Equivalently, we could return to the original plan by marking up more than Q_B units of power and buying the missing units in a later month.

⁵⁰Customers may also be frustrated that issues in the fine print of their offer letter are costing them money.

⁵¹This algebra, for simplicity, closes as much of the deficit as possible at the first available event. Equivalent, perhaps more palatable, approaches would attempt to spread the reduction over several events. If deficits are modest, the substantive differences between these approaches is small.

$$\delta_m = \min \{0, N_m R - \delta_{m-1} - \mathcal{M}(Q_B - \min\{Q_B, Q_m\})\} \quad (6)$$

Formula 6 defines the cumulative deficit recursively as the sum of that month's deficit and the previous deficit, less any amount of the deficit that can be applied to reduce the value of the rights offered during events in that month.

We can ensure budget balance by offering rights each month worth

$$N_m \hat{R} = \max \{0, N_m R - \delta_{m-1} - \mathcal{M}(Q_B - \min\{Q_B, Q_m\})\} = \max \{0, N_m R - \delta_m\}$$

This reduces to the full contribution case above if the customer buys at least Q_B kWh each month. In the full contribution case the following three equations hold:

$$\begin{aligned} \delta_m &= \delta_{m-1} = 0 \\ \min\{Q_B, Q_m\} &= Q_B \\ \hat{R} &= R \end{aligned}$$

C.1 Bundling rights with the first units of power never creates a deadweight loss

Bundling rights with the first units of power a customer buys each month never creates a deadweight loss because every extra dollar that a customer pays through this rate's markup, \mathcal{M} , returns to the customer as an extra dollar of rights.⁵²

Typical rates that mark up the first few units can create deadweight losses by increasing the price of a customer's marginal unit.

Formally, consider the marginal incentives for a customer to buy one more unit of power

⁵²Customers may not notice this subtle connection, but the markup is still unlikely to cause significant distortions because many customers are unaware of whether the quantity they have consumed so far during a month means they are paying a markup on the margin and because demand at the offpeak and peak prices is quite inelastic.

during period $i \in \{c, H, L\}$ for a month m when $Q_m < Q_B$. Taking the derivative with respect to the total annual bill:

$$\frac{\partial TC_a}{\partial Q_m} = P_i + \mathcal{M} - \frac{\partial \delta_m}{\partial Q_m} = P_i + \mathcal{M} - \mathcal{M} = P_i$$

D Generalizing IP Rebates to other markets

IP rebates can be used to implement dynamic pricing and improve incentives over uniform pricing for products which have underlying costs that fluctuate over time. Generalized IP rebates offer customers:

- rights to buy a block of the product at the usual nominal price during high priced periods,
- rebates for unused rights, and
- product purchase opportunity costs closer to the cost of production during high and low cost periods.

Further, an IP rebate implementation will often cause a smaller change to the customer's uniform pricing annual bill patterns than a conventional implementation of dynamic pricing would.⁵³

The uniform pricing that we seek to improve can generally only survive in the context of exclusive, long term relationships with a single supplier for perishable products. Customers who choose suppliers frequently would purchase from firms with dynamic pricing during low

⁵³This IP rebate approach will not change a customer's uniform pricing bill patterns at all if the customer has zero demand elasticity and consumes the average ratio of peak to off peak product. In other words, the customer who sees no bill impact is neither gaining nor losing from the price insurance inherent in uniform pricing. By contrast, consider a customer who buys during the lowest cost season, meaning she buys anytime under uniform pricing. She would see a larger change under IP rebates than they would under conventional dynamic pricing. Under both pricing schemes, this customer will shift all of their spending to the low cost season. Under an IP rebate scheme that marks up the product and then returns those markups during the high cost season, her bill increase (decrease) would be larger during the low (high) cost seasons than under the conventional dynamic pricing approach.

cost seasons. Inexpensive storage smoothes cost differences over time. It is common for companies to provide difficult-to-store products through long term, exclusive relationships in utilities, in telecommunications, and in services like shipping, answering phone calls, or technical support.

I simplify this discussion by assuming that the firm prices at average marginal cost plus a uniform markup. The uniform markup makes the firm indifferent between selling high cost and low cost units of the product.^{54, 55} This assumption makes the terms “high cost period” and “high price period” interchangeable below.

Intuition: Uniform pricing marks up products during low cost periods to cover other times’ higher costs. We can set opportunity costs that better reflect production cost during each period. Divert the markups the customer pays to buy credits that he can either use to buy the product during high cost periods or keep as a rebate. These markups can preserve the nominal prices during low cost seasons and they sell customers rights to a quantity of the product at the usual nominal price during high cost seasons.

Proof: We can decompose the uniform price paid during low priced periods into the low cost and the markup, then apply the total markup paid to buy an equal value of refundable rights to buy a fixed quantity of product at the uniform price during the high priced period. Specifically:

Consider a market with low and high cost sets of time periods with prices \bar{P}_L and \bar{P}_H respectively. The high price can be decomposed into the low price plus a price increase $\bar{P}_H = \bar{P}_L + \Delta P$.

Let f_H be the fraction of all consumption at uniform prices P_u that takes place during high cost hours. Then, setting a uniform price of $P_u = \bar{P}_L + f_H \Delta P$ will raise the same amount of revenue as would selling the same amount of product during each time period,

⁵⁴Adams and Yellen (1976) show that pricing that makes the firm indifferent between selling two different products can be part of an optimal bundling strategy.

⁵⁵Changing to either kind of dynamic pricing will generally change the total quantity that the firm sells and often change the seller’s profits. I ignore the profit issue here because utility regulators can adjust rates to ensure that the utility earns its rate of return despite the change in quantity and because any welfare improving change in pricing creates a potential Pareto improvement that can increase firm profits.

but charging \bar{P}_L and \bar{P}_H for it. Let $\mathcal{M}_u = f_H \Delta P$ be the markup that customers pay during low priced periods to offset the cost of the expensive product. Then customers who buy the population average proportion of the product, f_H , during high cost periods pay in exactly as much in markups as they get back in reductions of the price of the high cost product.

We can move prices closer to costs by setting each customer's peak period opportunity costs to \bar{P}_H and converting each customer's payment of $Q_L \mathcal{M}_u$ into a bill credit of R that the customer gets regardless of his critical period use. An IP rebate style description would present this as rights to buy $q_R = \frac{Q_L \mathcal{M}_u}{\bar{P}_H - P_u}$ units at the uniform price of P_u where Q_L is the customer's consumption during low priced-periods. Offering a rebate $\bar{P}_H - P_u$ for each unused unit makes the opportunity cost of a high cost unit \bar{P}_H . This approach also implicitly lowers the opportunity cost of consuming off peak to \bar{P}_L because the customer gets back every cent they pay through the markup of \mathcal{M}_u . This moves opportunity costs closer to true costs while maintaining nominal prices.

The high and low cost periods can be subdivided into any number of subsets so long as the customer pays markups during low priced periods, $\mathbf{L} \in L$, that equal the value of the rights the customer gets during high priced periods, $h \in H$, or:

$$\sum_{\mathbf{L} \in L} \mathcal{M}_{\mathbf{L}} Q_{\mathbf{L}} = \sum_{h \in H} R_h$$

It generalizes to a single high and single low price period (e.g. CPP with just low and critical price periods), cases with a few periods per subset (e.g. CPP with low, high, and critical periods), and to cases with a very large number of price periods per subset (e.g. real time pricing that charges the market price every hour).

D.1 Comparing the performance of this two-period generalization to three-period CPPIPR

This two period generalization will not offer consistent rebates and is harder to explain to customers than the three-period CPPIPR approach.

- Each customer gets rights as a function of their usage, causing fluctuations in rights levels that may confuse customers.
- This approach leaves the nominal price during low-cost periods at P_u . It may be difficult to explain that customers pay $P_u = \bar{P}_L + \mathcal{M}_u$, but that the opportunity cost is \bar{P}_L since the customer gets \mathcal{M}_u back. Customers who do not understand that the opportunity cost has dropped to \bar{P}_L may consume as if the opportunity cost were $\bar{P}_L + \mathcal{M}_u$.
- The two period implementation does not offer most customers consistent rebates. Customer-base wide revenue neutrality implies that, in the absence of demand elasticity, the average customer in the population would get rights to exactly as much power as they use during high priced periods. Customers who use a greater than average proportion of their energy during high priced periods will not get a rebate and will pay the high price on the margin. However, demand elasticity will increase the number of customers getting rebates by increasing purchases bundled with rights and decreasing purchases that use rights.

D.2 Benefits of offering credits selectively

CPPIPR works well because it splits high cost periods into “high” priced periods without rights and “critical” periods with rights. Offering rights selectively is a generally applicable strategy that frees up cash to offer more customers consistent rebates, to reduce nominal

offpeak prices, or to bundle rights with a fixed initial number of units per month.⁵⁶

E Graphical comparison of rates' incentives

Figures 6 and 7 graphically compare the incentives of the rate designs discussed here.

F Percentage of customers for whom consistent offers exist

Section 8.2 discusses three constraints on desirable IP rebate offers. IP rebates achieve universal customer-level revenue neutrality (section 8.2's constraint iii) while aspiring to make as many customers as possible consistent offers so the customer gets consistent rebates (section 8.2's constraint i) and makes consistent purchases of bundled rights (section 8.2's constraint ii).

Figure 8 plots the distribution of customer data relative to those constraints. It adds data to a diagram similar to figure 2 on page 27. SPP data suggest that 97% of customers statewide have demand patterns that satisfy feasibility criterion 5 for the example rate.

The rectangular region above the diagonal line is the single offer that provides consistent rebates to the largest number of customers. The rectangle encloses the largest set of customers who get consistent rebates under a single-optimal offer. One size does not fit all. It is not surprising that a coastal apartment's monthly usage bundled with \mathcal{M} in rights per kWh is insufficient to provide consistent rebates to a big desert house.

We can generalize this analysis to a family of CPPIPR rates by rearranging feasibility constraint 5 as a relationship between characteristics of customers and characteristics of rates, namely:

⁵⁶I have made no assumptions about the proportion of unhedged hours in the unhedged high price bin – so it is not clear how much cash is available to fund consistent rebates for more customers or to move to a declining block implementation.

Marginal (Opportunity) Costs of Each Rate Model

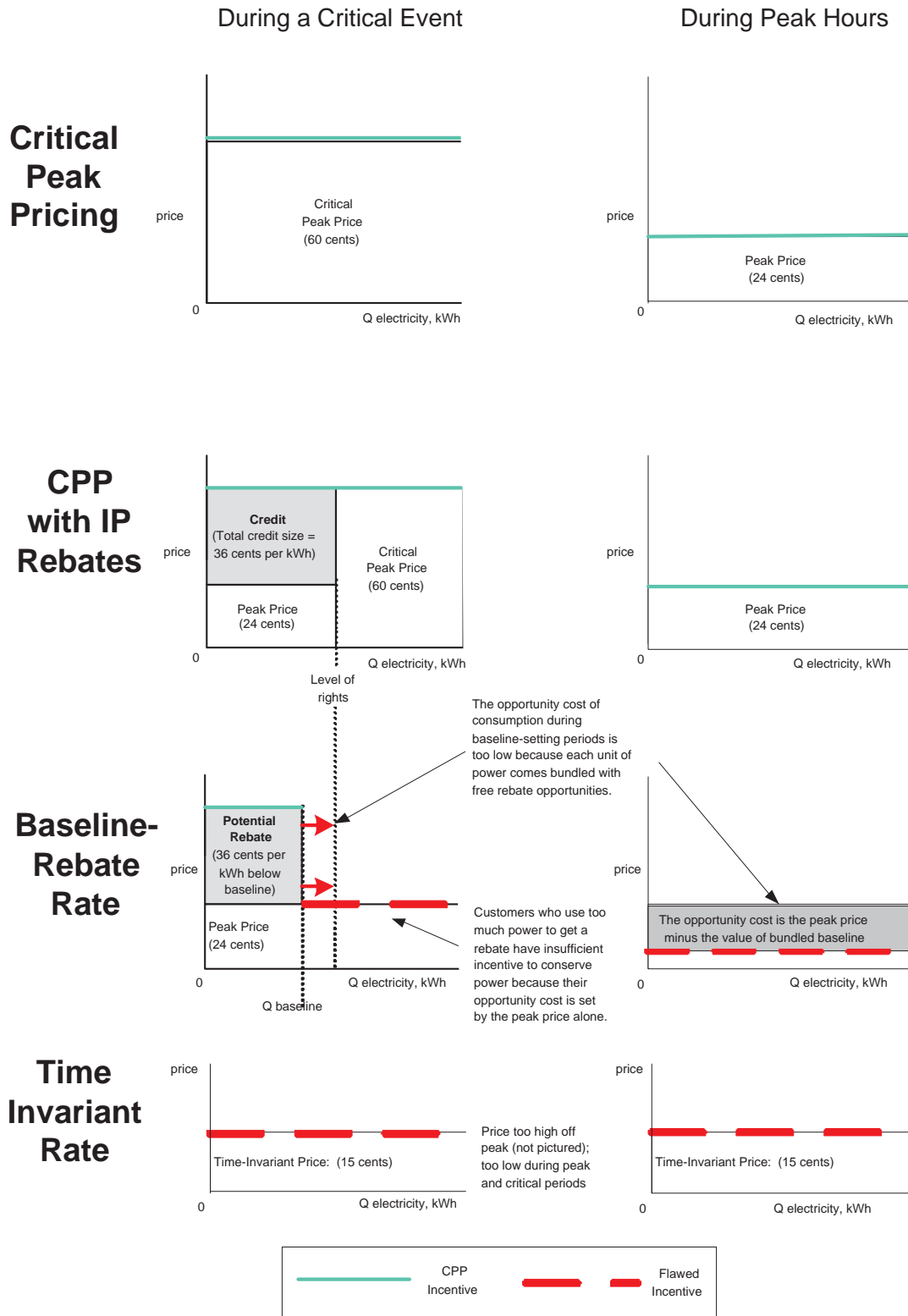


Figure 6: These diagrams compare the plans' marginal incentives during critical events and peak periods, including the peak periods that may set baselines for the critical events.

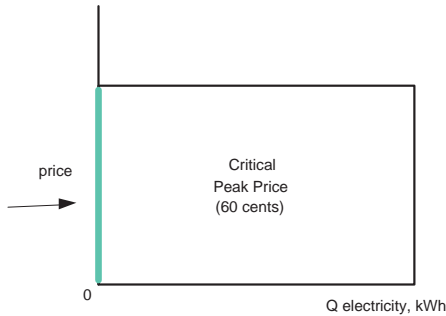
Pricing Rights to Buy Power at a Set Price

Economics suggests that mechanisms to protect consumers' total bills from volatility should:

- 1) Recognize that the right (or "option") to buy at a set price is often valuable and price it at its expected value.
- 2) Have people who consume a quantity other than the quantity to which they had rights buy or sell at the current market price.

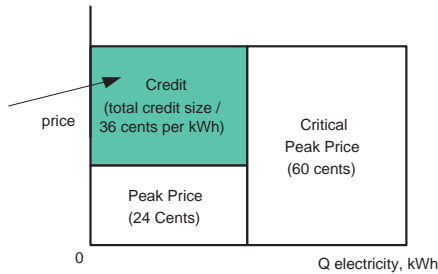
Critical Peak Pricing

The rights are priced correctly. The customer has no right to buy discounted power during events and pays nothing for such rights. (All the plans discussed on this page is imperfect because it offers full, free insurance against prices going above the critical price.)



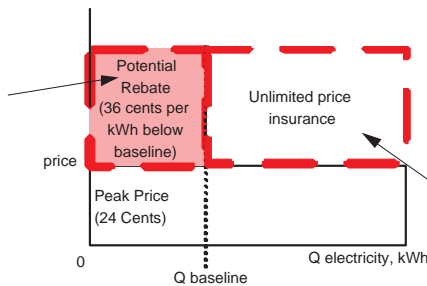
CPP with IP Rebates

This customer pays to get rights during each critical event.



Baseline-Rebate Rate

Customers get rights during critical peak events and unlimited price insurance. The cost of these rights are added to the rate base. This typically creates cross subsidies since all ratepayers share the costs of rebates and selling expensive power at low prices, but customers differ in their ratio of critical period to other period power consumption.



Unlimited price insurance is an incomplete property right that customers can use but not sell. This creates an incentive for customers to use their right to buy power when they would have sold it if the power company would pay them the difference between the wholesale and retail prices.

Time Invariant Rate

Customers get unlimited price insurance. This typically creates cross subsidies since ratepayers create costs in proportion to their critical period consumption and repay them in proportion to their consumption offpeak.

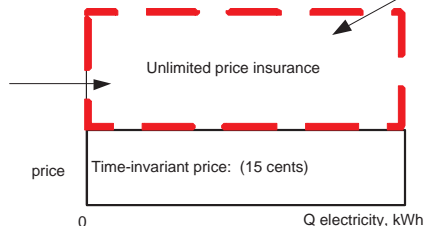


Figure 7: These diagrams compare the plans' pricing of rights to access low cost power during events.

$$\frac{12\mathcal{M}}{N_C(P_C - P_h)} \geq \frac{\bar{q}_c}{Q_m} \quad (7)$$

The left side of this equation describes rate characteristics, while the right side describes customer characteristics. The left side is the ratio of the rate’s ability to raise money to the cost of providing each kWh of rights during each event. The right hand side is the ratio of the the number of rights required to offer the customer consistent rebates to the greatest number of bundled rights they could consistently purchase.

Figure 9 shows the cumulative distribution of the right hand side of criterion 7, $\frac{\bar{q}_c}{Q_m}$, to see the percentage of customers who could get consistent offers under the IP rebates that could be added to a variety of CPP offers. Figure 9 suggests that IP rebates work well with three-period rates. IP rebates struggle with a two-period rate proposed by Pepco for Washington DC customers for the reasons outlined in section D.1. The figure also shows that mindlessly implementing this IP rebate approach struggles with Ameren’s four period rate and is less than ideal for Gulf Power’s four period rate, because they both split the low priced period into a low priced rate and an intermediate, shoulder rate that is quite close (.9 cents in Gulf Power; 0.14 cents for Ameren) to the time invariant rate. Markups that keep the shoulder rate less expensive than the time invariant rate often generate no consistent offers. Either imposing a larger markup (a four cent markup would keep prices lower 64% of the time under Ameren’s rate) or sacrificing some economic efficiency by reducing the price during the shoulder period⁵⁷ – to allow a greater markup – could address these problems.

F.1 Predicting consistent offers using readily available information

Rate implementers need to be able to identify consistent offers but often lack customer-level hot weekday afternoons power use data, which bound the level of rights customers need to

⁵⁷One option would be to add more low priced hours to the shoulder period.

Most customers can fund consistent rebates
but rights level offers are not one-size-fits all.

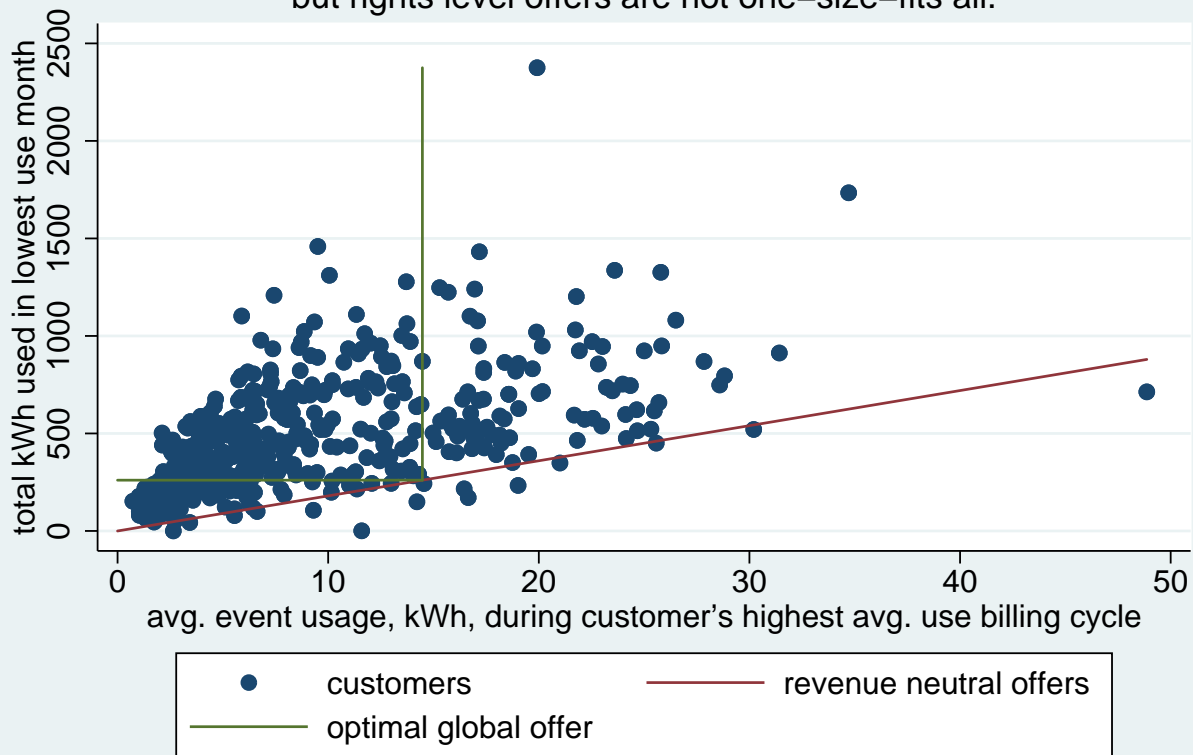


Figure 8: Most California's SPP customers' demand patterns are above the diagonal line defined by feasibility criterion 5, so consistent offers exist for them. But the single offer that provides consistent rebates and rights purchases for the greatest number of customers does not perform particularly well, so there is reason to consider approaches that make different offers to different categories of customers.

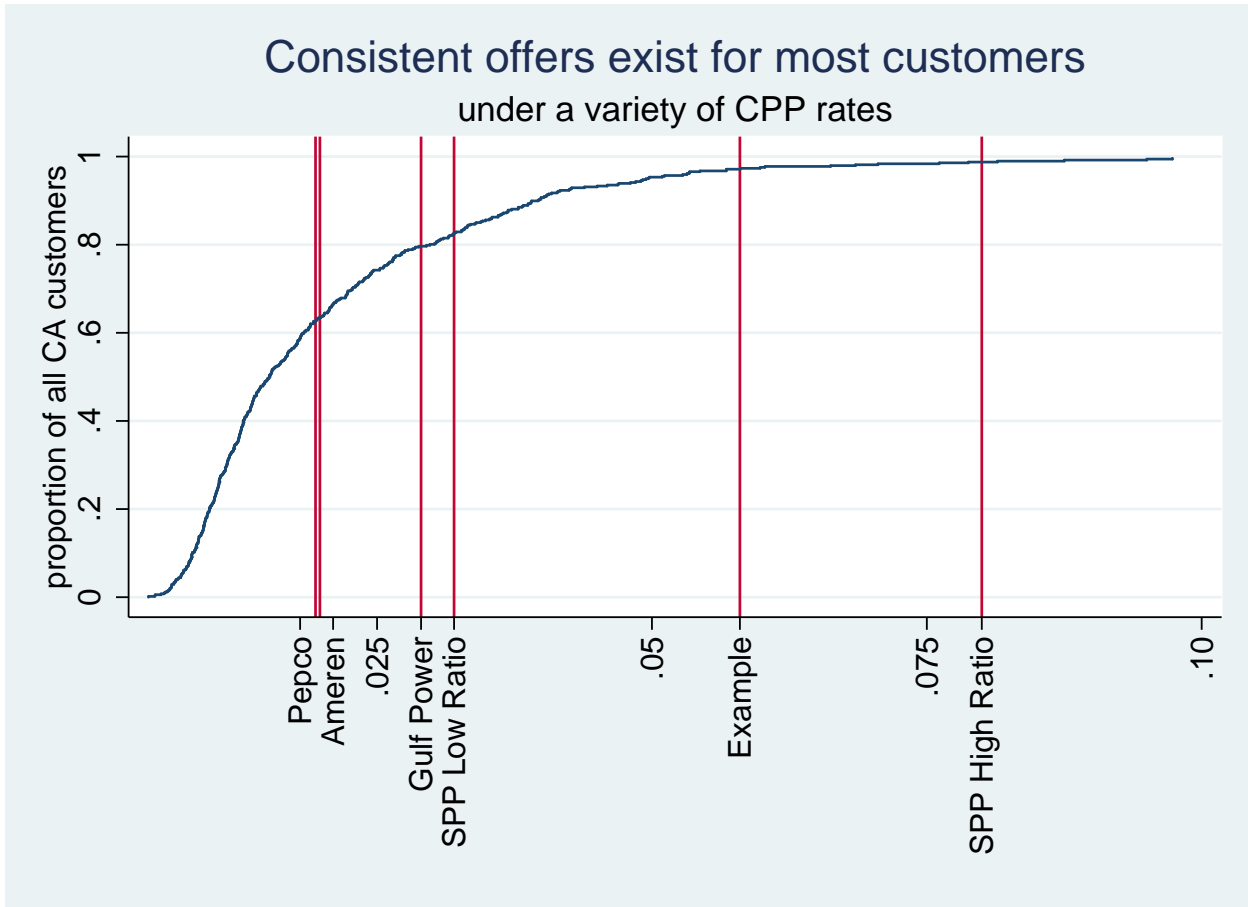


Figure 9: Offer feasibility under a variety of rates: Rearranging criterion 5 to $\frac{12\mathcal{M}}{N_C(P_C - P_h)} \geq \frac{\bar{q}_c}{Q_m}$ lets us compute the percentage of California CPP customers for whom consistent offers exist for real CPP-rates. This approximation assumes negligible demand elasticity. Table 4 describes the rates pictured here.

Source of Rate (State)	# rate pds.	crit. hrs $5N_C$	uniform price P_u	peak price P_L	off peak price P_H	critical price P_C	$\frac{12(P_u - P_L)}{N_C(P_C - P_h)}$
Pepco (DC)	2	60	7.92	6.81	6.81	63.98	.019
Ameren (MO)	4	32	7.64	7.5, 4.8	16.75	30.0	.020
Gulf Power (FL)	4	87.6	8	7.1, 5.9	11.7	32.6	.029
SPP Low Ratio (CA)	3	75	P_U	$P_U - 1.2$	$P_U + 9.8$	$P_U + 41.8$.030
Example, Table 1	3	75	14.6	12	24	60	.058
SPP High Ratio (CA)	3	75	P_U	$P_U - 5.09$	$P_U + 11.64$	$P_U + 60.91$.083

Table 4: The table describes the CPP rates plotted in figure 9. These CPP rates have 2-4 periods. Two-period rates have just normal and critical periods. The two period rate presented here is designed to generate identical average bills to the time-invariant rate and its IP rebate modification looks like the one proposed in section D and suffers the shortcomings described in section D.1. Three period rates have offpeak, peak, and critical rates. Four period rates add a “shoulder” period that contains hours during the transition between the peak and offpeak periods. The four-period rates struggle to fund rights because the shoulder rate is quite close to the uniform price. Adjusting the rate to expand the shoulder period and reduce its average price or changing the IP rebate markup structure would improve their performance. For example, basing a markup on Ameren’s lowest price of 4.8 cents per kWh would yield prices that are lower during 64% rather than 90% of all hours, but would yield a $\frac{12(P_u - P_L)}{N_C(P_C - P_h)}$ of .39 – which performs so well as to be off this chart. The SPP called 5 hour events, so N_C counts events assuming that they lasts 5 hours. I calculate the number of “5-hour events” that other rates call by dividing number of hours of events that they call by 5. This table reports the summer prices of seasonally varying rates. (Sources: Wilson (2006); Pepco; Voytas (2006); Ameren; Gulf Power; Pacific Gas & Electric (a); San Diego Gas & Electric (a))

get consistent rebates. Some utilities install “interval” meters that capture disaggregated usage data only for dynamic pricing customers. Firms may want to use existing data to make initial CPPIPR offers. The analysis below shows that aggregate use, account type, and geographic data predict consistent offers well enough to support implementation.

In order to use a regression to estimate desirable offers using billing-cycle-level consumption data, we identify an optimal offer from the set of consistent offers. Most customers’ use patterns mean that criterion 4 defines a range of consistent offers ranging from the smallest q_R that provides consistent rebates to the largest Q_B that the customer can buy each month. For the purposes of this analysis, I selected the consistent offer, (q_R^*, Q_B^*) , that satisfies criterion 4 in a way that is robust to the largest number of dollar deviations in total ability to buy rights, $12\mathcal{M}\underline{Q}_m$, and the needs for rights, $N_C\bar{q}_c(P_C - P_H)$.⁵⁸

This analysis proceeded in three steps:

- i. I constructed an optimal offer $q_{R,2004}^{i*}$ for each customer. It specified the set of offers that would be consistent for that customer-year, typically the year October 2003-September 2004.⁵⁹
- ii. I ran the following OLS regression: $q_{R,2004}^{i*} = \alpha + \beta_1 * useSummer02 + \beta_2 * ClimateZone + \beta_3 * apartment + \epsilon$ where *useSummer02* is the customer’s average kWh per day during three summer months the year before the experiment began, *apartment* is 1 if the account is in a multifamily building and zero if the account is a single family home, and *ClimateZone* is a set of dummies indicating whether the account is located in each of four mutually exclusive climate zones. The omitted category, fog-belt zone 1, is the coolest. The zones get progressively hotter and culminate in desert zone 4. Table 5

⁵⁸The optimal offer should minimize the likelihood that random variation would prevent the offer from providing consistent rebates or purchases. This requires knowing the within-customer standard deviations of rights needs, \bar{q}_c , and of the ability to purchase rights, \underline{Q}_m . The SPP data only tracks 27 events over 15 months, so there are too few years and too little variation in exogenous factors like weather, economic conditions, appliance upgrades, and family configuration changes to calculate meaningful standard deviations.

⁵⁹I focus on the last 12 months of the 15 month sample where possible because the experiment enrolled customers gradually, but ended abruptly, so looking at the initial 12 months would yield different date ranges for different subjects. Using each customer’s first 12 months would make the results harder to understand, especially because usage is heavily weather driven.

shows that regressing the optimal offer $q_{R,2004}^{i*}$ on total summer usage in 2002 explains 76% percent of the variation. Adding readily available variables about the climate and whether the account is in a single or multifamily building improves the fit to explain 78% percent of the variation.⁶⁰

- iii. I used the results of that regression to predict a consistent offer, $\hat{q}_{R,2004}^{i*}$, for each customer and determined whether it was consistent in the sense of satisfying criterion 4 for that customer's values of $(\underline{Q}_m, \bar{q}_c)$ for that year. The full regression predicts consistent offers that satisfy criterion 4 for 80% of all customers for whom a consistent offer exists. Many $\hat{q}_{R,2004}^{i*}$ that were not consistent offers were close. Half were less than 2.4 kWh of rights away from the nearest consistent offer. That size of deviation customers would force customers with too few rights to buy high-priced power costing no more than \$1.44 per event.
- iv. I tested a model from one summer's ability to predict appropriate offers for another summer. Most California scarcity events take place in the summer months of July through September, and the SPP called 21 of its 27 events during those months. Thus, the 15-month experiment contained the important, summer months from 2 years. This allows us to make some preliminary investigations of how well parameters developed from one year predict for a different year. I went out of sample to check whether $\hat{q}_{R,2004}^{i*}$ calculated from the year containing Summer 2004 (namely October 2003-September 2004) was a consistent offer that satisfied criterion 4 using the customers' consumption patterns $(\underline{Q}_{m,2003}, \bar{q}_{c,2003})$ for the year including Summer 2003, namely July 2003-June 2004. The out of sample universe contained 61% of customers. These customers had to be in the sample for two summers, and had to have $(\underline{Q}_{m,2003}, \bar{q}_{c,2003})$ that was different from $(\underline{Q}_{m,2004}, \bar{q}_{c,2004})$. This implies that either or both their their highest event use that set \bar{q}_c or their minimum consumption that set \underline{Q}_m had to occur between July and

⁶⁰This approach sometimes performs worse than the optimal offer range for each group calculations in part because the range optimization used data on each customer's whole range of consistent offers rather than representing the range with a single point.

Table 5: Using an OLS regression to predict the optimal IP rebate offer in kWh per event works well. Standard errors in parentheses.

	usage only model	usage, climate, account type model
avg. daily use Summer 2002, kWh	.78*** (.028)	.80*** (.031)
climate zone 2		.84 (.621)
climate zone 3		-.45 (.668)
climate zone 4		-2.95*** (.869)
apartment		-1.47** (.466)
intercept	2.62*** (.452)	2.91*** (.644)
N	482	482
R^2	0.764	0.781

September.⁶¹ That analysis found $\hat{q}_{R,2004}^{i*}$ was a consistent offer for 2003 using $(Q_{m,2003}, \bar{q}_{c,2003})$ for 82% of the out-of-sample universe.

F.2 Optimal offers to each of the 16 groups.

We can get from 16 to 9 categories without making any compromises by merging groups with similar rights needs. Most often, these involve combining usage categories from the same region or combining the same usage level in neighboring regions.⁶²

⁶¹The SPP CPP treatment started in July 2003 and ran through September 2004. California’s electricity demand (and scarcity) peaks during the summer, so we observe two separate summers but not two separate years. A significant proportion of Zone 1, fog-belt customers used more during the winter events than during any summer events. These customers set their their rights needs, \bar{q}_c , during the winter and thus get dropped from the out-of-sample analysis which used summer 2004 data to predict summer 2003 needs.

⁶²Specifically, we can make offers from the following offer ranges to each of the following sets of categories {3VH, 4VH: offer 31.42-31.46 kWh of rights per event}, {3H, 4H, 1VH, 2VH: 25.83-26.00 kWh of rights per event}, {1L, 2L, 1H: 10.15 - 12.79 kWh of rights per event}, and {3VL, 4VL: 6.13-6.36 kWh of rights per event}. The four other groups would get their own offers, as listed in table 6.

Table 6: Optimal group offers: the range of rights values that provides consistent offers to the greatest number of customers. This reports the number of number of customers getting consistent offers as a proportion of the number of consumers whose demand patterns satisfy consistent-offer-existence criterion 5.

climate zone, use type	proportion getting consistent offers	optimal range:	
		optimal range: lower end	upper end
1 very low use	.93	3.19	3.28
2 very low use	.87	4.97	5.17
3 very low use	.84	6.00	6.36
4 very low use	.87	6.13	7.55
1 low use	1.00	7.61	14.21
2 low use	1.00	10.15	12.79
4 low use	.81	14.30	15.13
3 low use	.84	17.98	19.42
1 high use	1.00	9.65	18.04
2 high use	1.00	18.38	18.98
3 high use	.85	24.15	26.00
4 high use	.96	23.49	27.18
1 very high use	1.00	17.13	27.43
2 very high use	1.00	25.83	28.30
3 very high use	.97	28.82	31.46
4 very high use	.88	31.42	31.82

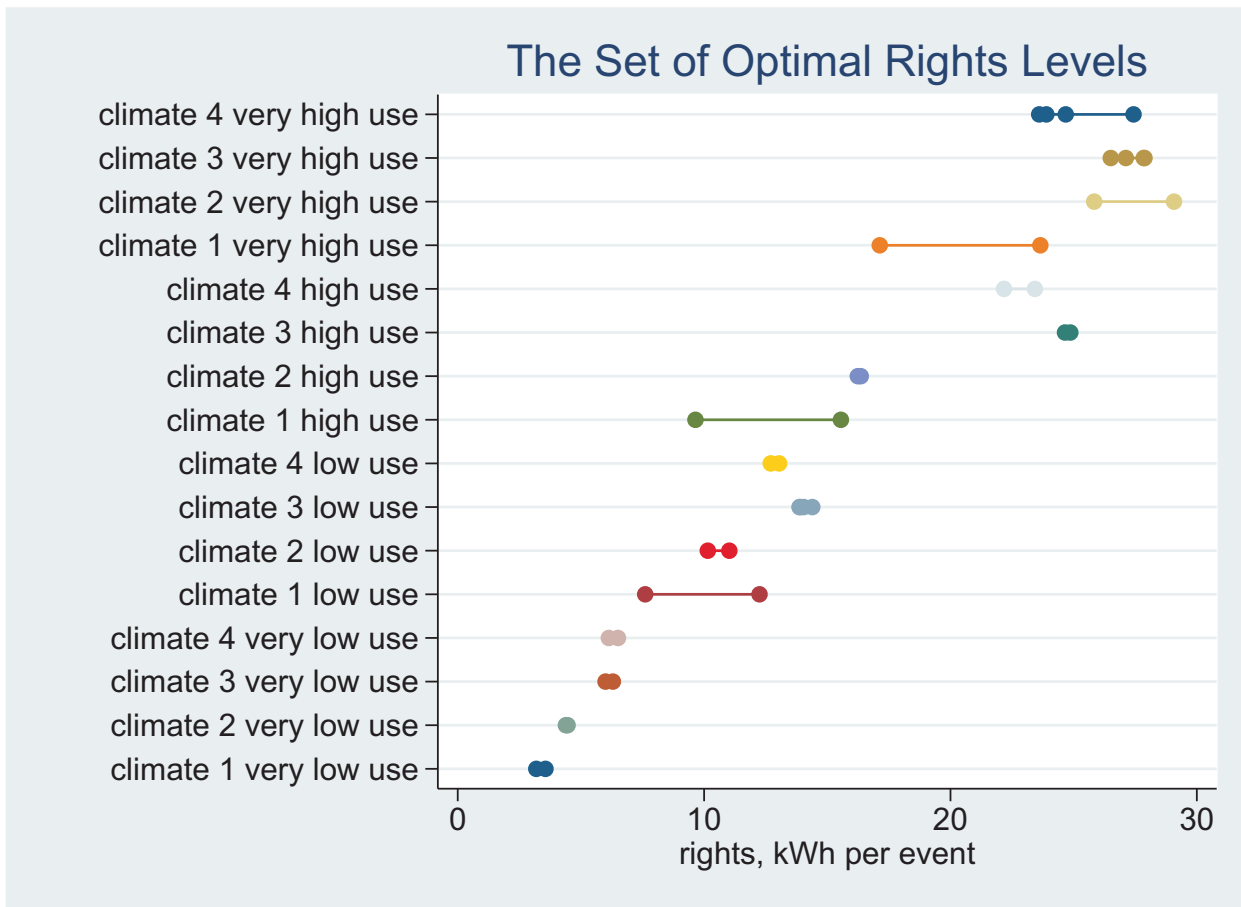


Figure 10: Optimal offers by group: Consistent offers for higher use customers and customers in hotter climates provide more rights.

F.3 Offers that are not consistent are typically fairly close to being consistent

Offers that are not consistent are generally close to being consistent and expose customers to only a few dollars per year of either exposure to critical pricing or of reduced rebates. Specifically:

- The majority of the 9.3% of customers who did not get consistent rebates paid the high marginal price in just one month. After weighting the data set to be representative of the state's population, the median (mean) customer who did not get consistent rebates paid for 4.67 (8.23) kWh at the full critical price, which cost \$2.80 (\$4.94).
- The rate marked up more power in at least one month than customers bought for 3.9% of all customers. The mean amount of rights that these customers were supposed to buy, but did not was a total of \$3.65 per year.
- To put these deviations of under \$5 in perspective, this sample of customers spent a weighted average of \$898.71 on power over the course of the year under the example CPP or CPPIPR rates.
- Customers in hot climates 3 and 4 were roughly twice as likely to have too few rights or to contribute too little as customers in more temperate climates 1 and 2.

F.4 Robustness of these offers to changes in weather, economic conditions, and customer characteristics

Good rights offers need to work not only for the kind of summer and customer-base for which they were designed, but also for summers that have unexpected weather and economic conditions and for customers who shift their consumption patterns. A thorough exploration of these issues merits a paper in its own right, but the results from some simple tests suggest that the offers are reasonably robust. One promising way to understand the robustness of the

offers is to look for evidence about the engineering and social limits on power consumption. If a customer would get consistent rebates despite running their air conditioner flat out and using other major appliances such as their oven and dryer, their offer is quite robust. And if the customer is never home to activate another major appliance during a critical event, then an offer that is consistent under their maximum weekday air conditioning load appears robust to weather changes.

- 72% of all customers would get consistent rebates even if every event matched their highest use event over the 15 month study. The other customers who got consistent rebates did so because they had their extreme event in the same month as at least one lower-use event.
- 47% of all customers would get consistent rebates even if their critical period use equaled their consumption on their maximum use weekday afternoon over the 15 month study. These customers appear to have engineering or social limits that are likely to prevent them from using more power than they have rights to.
- The median customer uses only 49.1% of their rights to get consistent rebates and gets rights bundled with only 57.1% of the power that they use in their lowest use month. Similarly the 75th percentile customer has only 71.3% of their power marked up in their lowest use month and needs only 71.4% of their rights to get consistent rebates. Most customers get significant cushions that make their IP rebate offers fairly robust to variations in conditions. Once we reach the 90th percentile, however, the cushions largely disappear and customers have 93.7% of the power they use marked up in their lowest use month and need 99.0% of their rights to get consistent rebates. It is likely that some of the marginal customers in the SPP experiment who needed the greatest rights levels joined the experiment to contribute to knowledge and earn \$175 but were not responding to price signals and would not opt in CPPIPR.

G Notation

Object	Source	Notation
Basic objects		
price	rate design	P
quantity per month	varies	Q
quantity per critical or baseline-setting peak pe- riod	varies	q
Time periods – subscripts and sets		
month	exogenous	$m \in M$
critical peak events	CPP design and operation	$e \in E$
Rate period subscripts		
low (offpeak)	rate design	L
high (peak)	rate design	H
critical (event)	rate design	C
uniform (time-invariant)	rate design	u
IPR features		
dollar value of rights	IPR design	R
kWh of rights per event	IPR design	q_R
price of 1 kWh of rights	IPR design	P_R
markup to cover cost of bundled rights	IPR design	\mathcal{M}
number of kWh bundled with rights	IPR design	Q_B

Object	Source	Notation
Counts		
number of critical events, per year	CPP rate design	N_c
number of critical events in month m	CPP rate design and operation	N_m
Baseline-rebate features		
baseline setting period	baseline rate design and operation	$b \in B$
number of days in baseline setting period	baseline rate design	N_b
baseline-rebate rebate per kWh	baseline rate design	P_B
Total customer cost	Note that B abbreviates baseline not bill.	
CPP Bill	implication	TC^{CPP}
CPPIPR Bill	implication	TC^{CPPIPR}
Customer characteristics		
minimum monthly consumption (ability to buy rights)	customer consumption	\underline{Q}_m
maximum consumption during an event (need for rights)	customer consumption	\bar{q}_c
deficit / cumulative under contribution	customer consumption	δ_m