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Contents

Abstract

This project extends the idea that policy makers should address problems by improving economic incentives. This project adds that presenting incentives in a way that reflects how people make decisions can sometimes improve consumers' responses to the incentives and policy outcomes. This paper uses behavioral economics to propose ways to increase electricity policy effectiveness.

The cost of generating power fluctuates enormously from hour to hour but most customers pay time-invariant prices for power. The mismatch between the fluctuating cost and the fixed price wastes billions of dollars. Critical Peak Pricing (CPP) reduces this waste by setting offpeak, peak, and "critical" prices that better reflect the cost of power during time periods. Customers in CPP pilot programs used less power during high-priced periods than did customers on traditional, time-invariant rates. CPP customers reported high satisfaction levels and often saved 10% or more. Yet, roughly 99% of customers reject opportunities to switch to CPP. The psychology literature documents a set of decision making heuristics that people use to choose among options with uncertain payoffs. This paper describes the evidence that one or more of these heuristics explains customer reluctance to opt-in to CPP. It then suggests Incentive Preserving Rebates that 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 the presentation, but change neither marginal incentives nor each customer's total annual payments. The paper then explores the implications of Incentive Preserving Rebates for customers who participated in a California pilot program.

1 Introduction: The economics and psychology of dynamic electricity pricing

This project extends the idea that policies should address problems by improving economic incentives. Insights about how people make decisions suggest that careful presentation can help consumers understand incentives and make the individually rational responses that economists expect them to. This project applies insights about economics and psychology to understand and address costly consumer resistance to improved residential electricity pricing. This project proposes Incentive Preserving (IP) Rebates to sidestep heuristics that can cause mistaken resistance to critical peak pricing (CPP) of electricity.

Most customers are on time-invariant pricing that charges the same price per unit of power during high and low cost hours. "Real time" electricity pricing sets hourly prices that reflect the marginal cost for that hour. Signing up every residential customer for real time pricing could deliver an estimated \$6-12 billion in annual social benefits.[1]

CPP is a simplification of real time pricing that announces a schedule containing a handful of peak and offpeak periods and sets a price for each period. CPP makes prices reflect some

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[1] American residences spent \$116 billion on electricity in 2004. (http://www.eia.doe.gov/cneaf/electricity/epm/table5_2.html) Borenstein (2005) reports that real time pricing could yield 5-10% annual savings on energy over the long term. There are – to the best of my knowledge – no academic papers that estimate the potential benefits of CPP and compare those to real time pricing.

of the enormous variations in marginal social costs between periods when power is scarce and when it is plentiful. CPP allows the utility to address scarcity by designating roughly 1% of all hours as critical periods which invoke a significantly more expensive critical rate. Policy makers consider CPP an attractive rate for residential and small commercial customers. This project takes CPP rates' prices and schedules as given.

CPP works. Residential customers who switch to CPP reduce their usage during higher-priced, peak periods and the highest-priced, critical periods. CPP customers 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 get a 1.3% opt-in rate (White, 2006). Customers are more receptive to baseline-rebate programs that create similar incentives by offering rebates to customers who use less than a baseline amount of power during critical periods, but calculating baselines from the customer's recent usage creates perverse incentives for customers to use more power during baseline-setting periods in order to increase their eligibility for rebates. Customers who resist CPP but are open to rebate programs with the same average bill appear to have preferences about elements of the presentation that affect neither incentives nor total bills.[2]

Residential CPP will generally be an opt-in program until it develops a track record that justifies making it the default. Current sign-up rates limit CPP's ability to generate a compelling track record. It is difficult to generalize from the unusual customers who opt in to existing CPP programs to the customer base as a whole. Pilot programs attempt to recruit more representative customer pools, but they provide limited evidence because they only have tens or hundreds of customers. Policy makers are likely to want field experience with broad-enrollment programs before they consider making dynamic pricing the default rate. Presenting the rate in a way that helps customers to make better enrollment choices will both improve the performance of opt-in programs and may be a stepping stone toward making dynamic pricing the default rate. 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.

CPP presents good incentives, but does so in a way that biases several heuristics toward choosing not to enroll. CPP delivers subtle savings by lowering prices most of the time. Its critical events inflict visible losses by notifying customers that it is raising prices so much that customers spend more on power or get less power during the critical period than they would had it been an ordinary period. California customers reduced usage 12% when the CPP pilot experiment events more than doubled prices.(Faruqui and George, 2005; Charles River Associates; Herter et al., 2006) Thus, during the 1% of all hours that were events, many customers paid more for power despite conserving. CPP reduced most participating customers' total annual bills because the savings from small price reductions nights, morn-

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[2] It is rational for consumers to prefer time-invariant pricing to CPP if CPP's transaction costs or higher prices during peak periods reduce the consumers' overall utility. By the same token, a significant number of consumers who use a smaller-than-average proportion of their electricity during weekday afternoons could save money under CPP without changing their consumption patterns. Yet, the majority of these consumers do not sign up to claim these savings.

ings, and weekends more than offset any bill increases during the rare, but visible critical events. People's heuristic decision making procedures are likely to notice and overweight the high priced periods and either not notice or underweight the gains. Concentrating losses in a few high cost months and diffusing gains over the calendar repels loss-averse customers if they "narrowly bracket", meaning that they consider bills one cycle – or even one day – at a time, rather than over the long term (Thaler, 1999; Read et al., 1999). CPP also repels customers who believe it is unfair to charge very high prices for air conditioning when they need it the most (Kahneman et al., 1986). Incentive Preserving Rebates change the presentation of CPP to avoid these biases.[3],[4]

IP rebates present critical events as opportunities to earn rebates through sacrifice. IP rebates change neither the total annual bill nor marginal incentives.[5] IP rebates add a fixed amount to each month's CPP bill. This monthly payment buys the customer rights to buy a fixed quantity of power at the usual price during critical events. If customers use less power than they had rights to during an event, they get a rebate for the value of the unused rights.

We can see how this works in practice by considering a rate that sets the opportunity cost of a kilowatt hour (kWh)[6] during a critical event at 60 cents and charges 24 cents per kWh during normal peak periods. A customer who has the right to buy one kWh during a critical event for the normal price of 24 cents can use the right for either 36 cents worth of power or for a 36 cent rebate. We can offer a customer the right to 8 kWh at the usual price during each of 15 events if we charge the customer $3.60 (which buys 10 kWh of rights) each month. A customer who exhausts their rights during an event has to pay the full price of 60 cents per kWh.

The IP rebate-rate design collects monthly fees to purchase rights. It does so through declining block pricing that adds a markup to the first, fixed number of kWh that a customer purchases each month. Section 4.2 describes this approach and literature reporting that customers make better choices under this presentation.

IP rebates maintain the right marginal incentives while using fixed transfers of cash or property rights to adjust the size of monthly bills and to use forgone credits rather than price increases to raise opportunity costs during events. Variations on this fixed transfer strategy underlie the Coase Theorem, hedging to manage risks in financial markets, and policies like cap-and-trade pollution permit systems.

Psychological and economic factors are important throughout the life cycle of a dynamic pricing program. This project suggests a way to present good economic incentives that is

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[3] IP rebates can work with 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. Section 6 describes the generalization.

[4] Adding IP rebates to CPP may slightly change the amount of power that customers buy 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.

[5] This project, like much of the policy-oriented behavioral economics literature, assumes that consumer errors and biases are a common but not universal problem and thus seeks interventions that improve biased consumers' choices without affecting rational consumers' choices. (c.f. Camerer et al. (2003) "Regulation for Conservatives: Behavioral Economics and the Case for 'Asymmetric Paternalism'" and Sunstein and Thaler (2003) "Libertarian Paternalism is Not an Oxymoron")

[6] A kWh is enough energy to run a 100 watt light bulb for 10 hours, or a central air conditioner for about 15 minutes.

compatible with participants' decision-making heuristics. This project focuses on psychology at the opt-in stage and on economics of creating the right incentives at the participation stage. This prioritization reflects several insights:

- Decision making heuristics appear to cause mistakes at the opt-in stage that hurt consumers and society. Customers who have experienced dynamic pricing appear to respond to its prices and consumption incentives in roughly economically rational ways. Customers who experience dynamic pricing reduce use during high-priced periods, save money, and report high satisfaction levels, which is consistent with them being economically rational.
- If there are bad incentives for participating customers, enough customers find and take advantage of them to cause problems. For example, some Anaheim customers reacted to incentives by using extra power on ordinary summer afternoons to become eligible for larger rebates (Wolak, 2006).
- Many customers suffer "projection bias" which causes them to overestimate how difficult a new situation will be to get used to (Loewenstein et al., 2003). This makes loss-averse heuristics more important when consumers decide whether to opt-in than after they have some experience with dynamic pricing.

Increasing the credit size has no effect on the utility's annual revenue or the consumers total annual payments, but ensuring that customers get rebates rather than pay high prices during events makes the offer more attractive to loss-averse customers. This project aspires to design a rate that offers most customers a rebate during any month with an event. This goal comes from considering psychological factors that are likely to affect the satisfaction of customers who have already signed up for the program.

1.1 Implementation

There is good reason to think that the IP rebates are feasible. IP rebates add revenue neutral charges and credits to an underlying rate that regulators can tailor to meet local needs.

This project proposes a rate that asks customers to pay for their rights through a small markup on a fixed number of units of power per month. This creates a trade off between the customer's likelihood of getting rebates and their ability to pay for their rights. For example, a rate might work well for a customer if they used fewer than 20 kilowatt hours during each five hour event and used at least 300 kilowatt hours per month.

An IP rebate policy has to decide whether to address the challenge of making an appropriate offer to each customer by offering each customer a customized offer or by splitting customers into categories and making one offer to each category. Making offers to broad categories of customers defined by use and geography can perform adequately and has compelling advantages over individualized offers. Specifically, assigning rebate eligibility by category seems fair since neighbors who live in superficially similar houses will generally get the same offer. Offers to categories of customers facilitate analysis and discussion among utilities, regulators, and advocates who may be able to use categories already in use for other regulatory purposes. Categorical offers reduce the likelihood that customers will demand extra power in a (misinformed and fruitless) attempt to profit by becoming eligible

Table 1: Price and demand are very high during one percent of all hours. California ISO Electricity Market: October 2005 through September 2006; Spot market prices are for the NP 15 Northern California Region

	Median	99%	Max
Usage, Megawatts	27,064	43,779	50,198
Wholesale Price, $/kWh	$0.045	$0.163	$0.396

for more rebates. An analysis of California data shows that we can make adequate offers to the vast majority of customers even if we crudely split up customers using readily observable characteristics like climate zones and monthly summer electricity usage.

This paper proceeds in two stages. The first stage describes the economic case for improved electricity pricing, the behavioral challenges to implementing it, and proposes Incentive Preserving (IP) Rebates. The second stage explores whether IP rebate deployment is feasible by simulating IP rebates' impacts on a set of California CPP customers.

2 Background: Improved electricity pricing can deliver significant savings

Providing better incentives for customers to shift power use away from periods of electricity scarcity has the potential to save billions of dollars, to deliver significant environmental benefits in some markets (Holland and Mansur, 2005, 2006), and to facilitate the integration of wind generation into electricity systems.

Electricity storage is generally not cost effective, but electricity supply has to meet demand minute by minute to prevent blackouts. This creates enormous variations from hour to hour in the cost of generating electricity.

Most consumers are on time invariant rates, which do not depend on when the customer uses the power. Time invariant rates offer customers no incentive to shift use away from high cost periods. The combination of time-invariant rates and the need to meet demand minute by minute creates extremely inelastic demand and can give suppliers a great deal of market power. These factors require electric system operators to maintain extra generating capacity that they only use when extreme weather or equipment problems tax the system a few hours a year. (Joskow (2000) and Borenstein (2005) discuss this background in detail.) Table 1 shows that the 1% of all hours with the highest demand are very costly. California's electricity demand was more than 6,400 megawatts higher in its maximum hour than it was in the 99th percentile hour. The Energy Information Administration estimates that building a megawatt of generating capacity costs roughly $400,000 and keeping that facility maintained and ready to operate costs $11,000 a year (Conti et al., 2006). The maximum spot market price was more than twice the 99th percentile price and roughly nine times the median price.[7]

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[7] The wholesale market price of energy during extremely high demand periods is a lower bound on the true marginal cost of producing the energy. Electricity spot markets include features – like price caps – that control prices during scarcity periods and cover the true costs of maintaining capacity to meet demand

Dynamic electricity rates are a family of rates that vary prices over time to better reflect hour-to-hour differences in the marginal cost of power. Dynamic residential electricity pricing has the potential to save up to 5-10% of the $116 billion that American residences spent on electricity in 2004 – or $6-12 billion a year. Dynamic pricing was generally not deployed in the past because it was not cost effective. It requires meters that record when customers use power as well as their cumulative total use, but new computer technology makes these meters much cheaper. There is compelling evidence that dynamic pricing can save billions of dollars (Borenstein, 2005). Residential customers consume 36% of the electricity used in the US[8] and respond well to the incentives in dynamic electricity prices (Faruqui and George, 2005; Charles River Associates; Herter et al., 2006).

Critical peak pricing (CPP) is the dynamic rate that gets the strongest consideration for residential and small commercial customers. CPP announces a schedule of peak and offpeak periods and prices, and allows the utility to address scarcity by designating roughly 1% of all hours as critical periods that invoke an expensive, critical rate. Table 2 on page 19 presents an example of CPP.

The technology and economics are largely ready to support widespread dynamic pricing. Two recent National Town Meetings on dynamic pricing brought together more than a hundred regulators, utility staff members, academics, and suppliers. Few utilities have successfully implemented dynamic pricing – largely because they have struggled to present dynamic pricing in ways that consumers find attractive (Barbose et al., 2004). Many have not done a good job of risk management, marketing, and implementation. Most implementations have struggled to get customers.

For example, field experience in Florida and Illinois shows that residential resistance is a serious problem.[9] Gulf Power offers GoodCents Select residential CPP in Florida. Gulf Power and its parent, the Southern Company, are considered leaders among utilities in marketing and customer service. The Community Energy Cooperative's Energy-Smart Pricing Plan offers Illinois residences "real time prices" based on the hourly market rate. Both notify customers of high priced periods. The two retailers report that most customers who sign up save significant amounts of money, are satisfied, and stay enrolled. But both programs get sign up rates of only about 1%.

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. Practitioners and scholars are working to address both issues (see e.g. Borenstein (2006a); Wright et al.). Gulf Power's Good Cents Select program creates winners by saving participants an average of $90 a year (White, 2006), and reduces transaction costs by providing a computerized "set it and forget it" thermostat

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during those hours through other payments. Borenstein (2005) discusses how current electricity prices can understate the cost of scarcity and simulates more accurate prices. Wholesale energy prices are lower than retail prices because wholesale prices omit costs of infrastructure like the electrical distribution network, customer service, and utility sunk costs from things like nuclear power plant construction and the California electricity crisis.

[8] source: Electric Power Monthly 2004 figures: http://www.eia.doe.gov/cneaf/electricity/epm/table5_1.html

[9] Large commercial and industrial customer resistance is also a problem. Commercial and industrial customer are beyond the scope of this project because large consumers should hire analysts and otherwise analyze economic decisions in different ways than small customers do. Large customers may also suffer principal agent problems.

that automatically shifts air conditioning away from critical periods (Gulf Power). However, conventional economic reasons cannot explain the high rejection rate among customers who 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.

Customer retention and customer recruiting are related, but fundamentally different challenges. Retention involves customers who have experienced CPP. They know the program's implications for their total bills, lifestyles, decision making heuristics, and preferences. Recruiting involves decisions by customers who know significantly less. Further, retaining customers requires 1) that responsive customers save money under the new program which is a function of the CPP rate; 2) that the program be explained clearly and that customers know when they are saving money; 3) that responding not be too onerous – which requires thinking carefully about whether to include evening hours in events and whether to call events on consecutive days; and 4) – potentially – that the program use something like IP rebates to present critical events in a way that meshes with the way people make decisions. Gulf Power, the Community Energy Cooperative, and California's Statewide Pricing Pilot have high customer retention rates. Field experience suggests, however, that recruiting is a harder, unsolved problem. This project concentrates on designing CPP rates that facilitate recruiting customers.

This project tries to address the recruiting challenge by designing policies that overcome psychological resistance to efficient policies among consumers who stand to gain from signing up for them. It parallels a literature that reports that economic efficiency does not sell itself in the political marketplace. That literature reports the success of clever designs and compromises that protect features that achieve efficiency while letting political concerns drive other design choices (Robyn, 1987; Hausker, 1992).

Residential CPP will generally be an opt-in program until it develops a track record that justifies making it the default.[10] The benefits of signing an additional customer up for dynamic pricing are greatest when there are few customers on the program and diminish as dynamic pricing's market share expands (Borenstein and Holland, 2005). Getting a significant fraction of customers signed up could deliver compelling benefits even if it is well under 100%. Hence, this project seeks to present CPP in a way that elicits good choices when shown side by side with the status-quo time invariant rate.

3 A variety of psychological theories suggest that CPP's presentation of incentives will repel customers.

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 is flawed and will repel consumers.

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[10] CPP's initial opt-in status is a political reality, but making it opt-out or mandatory might be better policy. 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 retirement savings. (See Choi et al. (2003) and the literature it cites.) Wood (2002a,b) argues that changing the default may be sufficient to get large scale participation in pure-pricing, time differentiated electricity rates.

- "Narrow bracketing" consumers base their decision on short term outcomes like a billing period or an afternoon rather than considering the appropriate long term outcomes (Thaler and et. al., 1997; Read et al., 1999). Narrow bracketing underlies most of these psychological theories because many customers will come out ahead on CPP in the long run. (The intervention proposed here specifically addresses narrow bracketing by delivering significant monetary benefits during the critical periods that ask people to make the most salient consumption sacrifices).

- A reference dependent loss averse customer codes outcomes as gains or losses relative to an anticipated (reference) outcome. These consumers consider that losses relative to the reference point loom larger than gains. A critical event that leads the average customer to pay more to buy less than they would on their reference, non-critical day would seem quite painful (Kahneman and Tversky, 1979).

- Studies of choice under risk suggest that consumers not only exhibit something akin to loss aversion, but also often consider just the worst case rather than the whole outcome distribution. (March and Shapira, 1987; Lopes, 1987)

Field evidence is consistent with these factors playing a role: "A number of program managers suggested that the modest participation rates in their RTP [real time pricing] program were a result of the fact that .... the vast majority of eligible customers view the risks of RTP as too great and/or the potential benefits as too small." (Barbose et al., 2004)

Customers sometimes appear to choose the option with the greater number of attributes that compare favorably (Redden and Hoch, 2005). A typical CPP rate defines three-periods: offpeak, peak, and critical periods. Two of these periods – peak and critical – are more expensive than the time invariant price but account for less than 20% of all hours. Hence, three period CPP compares unfavorably to time invariant prices to customers using this heuristic. Gulf Power's decision to use four CPP periods that sets two off-peak prices – "medium" and "low" – lower than the time invariant price – might reflect this customer decision-making heuristic.

Many consumers find it unfair to raise prices to deal with a shortage stemming from a shock that has increased their demand for a product. CPP often invokes critical periods that raises prices when heat waves maximize air conditioning demand. This is nearly the exact summer analog to Kahneman et al. (1986)'s finding that most consumers found it unfair to raise the price of snow shovels during a blizzard. Many customers consider conventional, efficient pricing an unfair way to deal with shortages (Kahneman et al., 1986).[11] Gulf Power (Gulf Power) assures customers that its Critical Peak Pricing price levels "[R]eflect the actual cost of producing electricity during those periods."

The marketing literature reports that customers prefer declining block pricing to fixed fees that generate identical revenues and incentives for most consumers (Ho and Zhang, 2004). This is not a challenge to CPP but constrains the ways we can we modify it.

A variety of decision making heuristics in the psychology literature can explain customers rejection of a CPP rate that would save them money in the long term, but creates the possibility of larger, more salient short term losses on critical days or during months when

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[11] Rabin (1993) and Charness and Rabin (2002) formally model preferences for fairness.

they already use the most power; that raises prices in two out of three kinds of pricing periods and that raises prices during periods when customers need air conditioning the most. Indeed, narrow bracketing and any one of the other heuristics could explain the resistance.

The evidence about these heuristics comes from studies in other, often simpler, contexts so it is not immediately clear how those studies play out in the CPP context. A paper in development explores how people think about dynamic pricing to clarify whether and how these heuristics applies to electricity pricing choices. The study seeks to understand the thought process that drives resistance to CPP and how IP rebates change customer thinking.

3.1 Behavioral interventions can significantly reduce irrational choices without affecting the decisions of rational players

Scholars have proposed interventions which, like IP rebates, change the timing of decisions, costs, and benefits; presentation; and information flows. Studies show that these interventions improve consumer choices in areas like retirement savings and investment choices. For example, the "Save More Tomorrow" program increased employee savings at companies by asking them to precommit to increase their retirement savings rate the next time they got a raise. This timing sidesteps loss aversion. (Thaler and Benartzi, 2004) A series of lab experiments (Gneezy et al., 2003; Thaler and et. al., 1997; Gneezy and Potters, 1997) show that customers invest more in riskier, but higher expected return instruments when experimenters send them aggregated information which forces them to broadly bracket. This reduces the likelihood that subjects will learn of temporary losses, which reduces resistance from reference dependent loss aversion. Most of the increase in risk taking happened as soon as the subjects learned that they will be getting aggregated feedback but before they experienced the aggregated reports (Gneezy and Potters, 1997) which offers hope that merely promising to reduce the experience of losses can recruit customers.

Marketers frame costs as gains by presenting sales below a "regular" reference price or by offering rebates. They use deferred payments to deliver benefits now and costs later. Public policy designers who consider decision making heuristics in designing policies should aspire to use interventions that correct, rather than cause self-destructive mistakes. The policy oriented behavioral economics literature is yet to consider whether changing the presentation of prices in economically neutral ways could help people make better decisions about whether to sign up for CPP, whether to invest in energy efficient products, or whether to own a car or rely on pay-per-use transportation. The policy oriented literature uses many of the same insights, but aspires to help people avoid mistakes rather than just changing decisions to maximize profits.

Behavioral economics studies and commentaries on their policy implications (Sunstein and Thaler, 2003; Camerer et al., 2003) seek interventions that improve biased consumers' choices without affecting rational consumers' choices because consumer errors and biases are a common but not universal problem. This project shares that outlook.

Interventions like changing the presentation of choices and information flows and the combination of CPP and IP rebates (CPP-IPR) proposed here reflect the emerging idea that we should address problems by not only using good incentives – like CPP – but also by presenting incentives in ways that reflect how consumers decide.

3.2 Similar interventions to improve decision making by addressing biases are possible for electricity pricing

Assigning customers property rights that allow them to earn rebates and come out ahead during critical peak events can sidestep resistance from all of these heuristics:

- Rebate opportunities can transform the presentation of critical events into opportunities to earn rebates through sacrifice rather than obvious losses when customers pay more to get less.
- Moving monetary gains into the same evaluation period as consumption losses largely sidesteps narrow bracketing.
- Customers who count the number of favorable attributes will see outcomes during critical events that look better than the status quo time invariant rate instead of looking worse. That means that the majority of CPP-IPR periods look better than the status quo rate.
- A rebate program seems fair because customers have the right to use power during shortages and the program pays willing customers to conserve, rather than making customers face the likelihood of paying more to get less during each event.
- The property rights that creates rebate opportunities will typically improve outcomes on both the costliest days and costliest months[12] which will make the offer more attractive to customers focused on the worst case. As 10 describes, CPP-IPR is particularly effective in reducing the worst monthly outcomes in climates with the hottest where customers use the most power and concentrate that use during the season of scarcity.

Rebate programs seem popular with consumers. Members of a PEPCO focus group of residential customers from Washington DC considered conventional real time pricing and a similar rate presented with rebates. When asked which of the rate features presented that night they liked, most customers mentioned rebates. (King and Harper-Slaboszewicz, 2006)

We need to worry that using IP rebates to reframe critical events as opportunities rather than threats will make customers more willing to sign up, but less responsive to critical events. A series of experiments have documented an "endowment effect" that makes customers demand far more to give up mugs that they have just been handed than they are willing to pay for mugs that they do not have, so there is reason to be concerned that telling customers that they own the right to low priced power will make them less likely to give it up. Anaheim customers shifted a significant amount of consumption away from critical periods to earn rebates in a pilot test of a a critical peak rebate program (Wolak, 2006). A CPP-IPR program that created an endowment effect might still deliver more benefits than a CPP program with no endowment effect, if the CPP-IPR program got a higher participation rate than the CPP program.

The remaining challenge is to develop an intervention along these lines that preserves CPP's incentives and is feasible to implement.

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[12] Critical events happen disproportionately when the average customer is using the most power and paying the most for it. CPP-IPR dampens seasonal variations for these customers. Some customers' usage does not follow these patterns.

4 Improving the presentation while preserving incentives

Psychology suggests a need to change the presentation of dynamic pricing to make critical events into opportunities to gain and to do so without imposing fixed fees. This section seeks ways to deliver that presentation in a way that preserves marginal incentives and charges each customer a total annual bill identical to what would have been charged under CPP.

CPP rates are attractive because they are a simple rate that creates a uniform and reasonably good marginal incentive during each time period. Their incentives are independent of the customer's power usage in this time period or a previous time period. Preserving marginal incentives is important because Wolak (2006) reports that many customers exploited the incentives in Anaheim's rebate program. A senior regulator characterized these customers as "mini-Enrons" when she discussed his findings at the University of California Energy Institute POWER Conference in March 2006.

4.1 Using fixed credits and fixed charges to offer rebates while preserving CPP's marginal incentives and annual total bills

Incentive preserving rebates transform the presentation of CPP while preserving CPP's revenue streams and generally preserving its 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 offering rebates for the value of any unused credits. The rebate value 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 \$4 worth of power during each of 15 events a year. So the customer pays a total of $12 * \$5 = \$60$ per year to get credits worth \$60.[13]

The essential insight here is that we can maintain the right marginal incentives while adjusting daily and monthly bills through fixed transfers of cash or property rights. Since CPP defines the number of events per year and the prices during the critical events the value of rights to use power during each event is clear and there is no reason to charge a risk premium. Hence, there is a well defined price of the property rights to power, so transfers of cash are identical to transfers of property rights. Versions of this insight underlie the Coase Theorem, hedging in financial markets, and policies like cap-and-trade pollution permit systems.

We can make these transfers of rights revenue neutral for each customer – every penny they put in they get back either as power or as a rebate.[14] This revenue neutrality means that it is impossible for a customer to profit by strategically manipulating the number of rights that the utility assigns to them. Hence, the only new economic incentive that the

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[13] The rate in Table 2 has customers contribute $2.5\ cents * 450kWh = \$11.25$ per month, which is \$135 per year, and offers them $\$9 * 15\ events = \$135\ per\ year$

[14] Achieving true revenue neutrality requires paying interest on contributions 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.

program creates is the desired incentive to shift use away from peak and critical periods. Revenue neutrality allows designers to offer quantities of rights that depart from a customers' likely usage. They can use this freedom to ensure that most customers get rebates and to make the same offer to a broad class of customers. Cross subsidies, where some types of electricity customers pay more than their share of total system costs, while other types of customers pay less than their share, are a ubiquitous flaw of electricity rates.[15] Revenue neutrality means that there are no cross subsidies in the rebate program, making CPP-IPR as transparent and as equitable as the underlying CPP rate. Further, it means that the rebate program should deliver revenue that is identical to CPP revenue – so none of the design parameters that the rebate program dictates lessens the utility's revenue stream or makes revenues harder to predict.[16]

We have a great deal of flexibility in how to describe the rights that the customers own, but one attractive way to do so is to describe it not as a fixed bill credit during each event, but as a property right to access a set number of units of power at the reference price during each critical event. Customers can cash in unused rights for the value of the discount that the rights provide. Customers on the rate in table 2 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 the unused part of these rights for a rebate of 36 cents per kWh. Figure 1 shows the equivalence of the fixed credit and regular-priced-units presentations while section 5.2 proves their equivalence.

Loss-averse customers may be more receptive to the "usual-price" explanation (used in table 2) than to the "fixed-credit" presentation. The usual price presentation casts critical event incentives as rights to buy up to a fixed number of kWh at the usual price, and to earn rebates by automatically cashing in any unused rights. The usual price is the strongest candidate for the customer's reference price. The usual price presentation means that the customers who use less power than they had rights to buy at the usual price during an event will buy at their reference price and experience no losses. Further, this presentation allows bills to indicate that a customer never paid for power at the critical price whenever they had rights to more critical period power in that billing cycle than they used during events, even if they used more power than they had rights to during some events. By contrast, the fixed-credit presentation sells power to customers at a higher price, creating a perceived loss and then returns "lost" dollars through a credit that customers will code as a gain.[17] Since loss-averse customers put more weight on losses than gains, customers may perceive

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[15] Going to real time pricing that sets a price of power each hour is a necessary, but not sufficient condition to eliminate cross subsidies. Critical peak pricing reduces cross subsidies.

[16] CPP and CPP-IPR raise identical revenue assuming that customers behave identically under them. Section 3.2 discusses endowment effects that might cause CPP-IPR customers to use more critical period power. This might cause the kind of shift in revenue that would reflect the relationship between the CPP price's critical price and the cost of providing power during those times. If utilities charged a critical price equal to the marginal cost of critical-period power, then this change would also be (net) revenue neutral. Rates are often marked up to recover fixed costs and regulators deal with shifts in demand on a regular basis.

[17] Prospect 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 of presented by the fixed-credit presentation and the smaller rebate emphasized by the usual-price presentation.

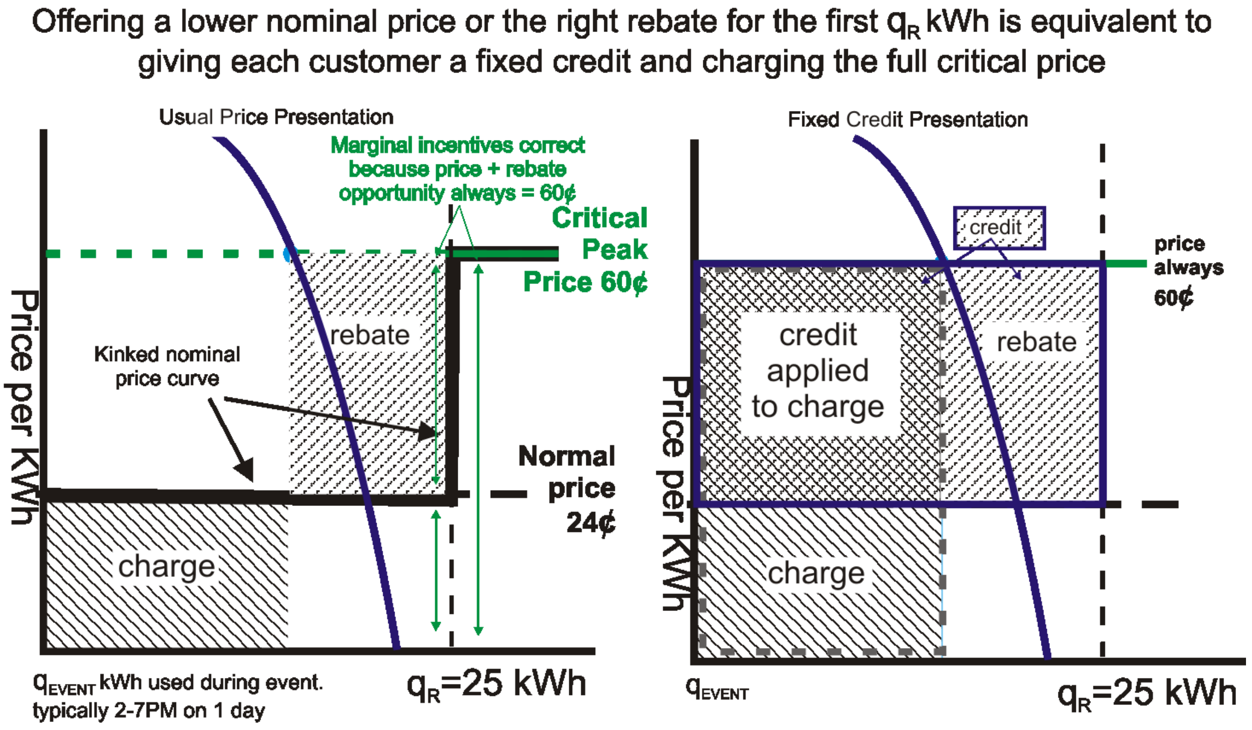

Figure 1: *Presenting IP rebates as the right to choose between power at the usual price or a rebate during each event is equivalent to presenting it as a fixed credit during each critical event. Both presentations keep the marginal incentives equal to the critical peak price.*

the offsetting gains and losses in the fixed-credit presentation as a net loss.[18]

This presentation of IP rebates preserves CPP's marginal incentive 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 the customer is eligible for a rebate. The critical rate presented in table 2 achieves this by having customers with no rights left pay 60 cents per kWh, while those with rights face a 60 cent opportunity cost because they pay 24 cents and forgo a 36 cent rebate for each kWh.

4.2 Implementing the monthly fixed fee through declining block pricing

The marketing literature reports that customers are averse to paying the kind of fixed monthly fees that would be the natural way to charge customers for power rights without changing their incentives, but that customers are more receptive to almost identical incentives and charges presented through declining block prices (Ho and Zhang, 2004). A declining block rate marks up the first few units that each customer uses each month. For example, instead of using the $5 a month markup in the example in section 4.1, we could mark up the first 200 kWh of power the customer used by 2.5 cents each.

This markup does not change the consumer's incentive to buy the efficient amount since IP rebates' revenue neutrality means they return every cent that customers pay through it. Section 5.5.1 proves this. We aspire to have each customer buy the entire marked-up quantity each month in order to ensure that each customer buys the rights that the offer promised them. If the rate fails to offer a customer the 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 marked-up offpeak power less expensive than the time invariant rate so 3-period CPP-IPR 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-IPR offers lower prices more than 80% of the time – as Gulf Power does.

IP rebates that use declining block pricing to collect money and return it during critical events reschedule a significant part of CPP's savings. CPP delivers savings in a subtle way year round during offpeak times. CPP-IPR delivers many of those benefits in a visible way during critical events. Table 3 compares the proportion of customer bills that come from peak, offpeak, and critical periods under time invariant, CPP, and CPP-IPR rates. This change in the timing of charges over the year may cause small income effects, but these effects are likely to be negligible.

Table 2 provides an example of how CPP-IPR works in practice and how offer letters might explain it to consumers.[19] In this example rate, customers on the time invariant rate

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[18] We could use a model like Koszegi and Rabin (forthcoming) to formalize this.

[19] The CPP rate in table 2 is based on Pacific Gas and Electric's "low ratio" experimental CPP rate (Pacific Gas & Electric, a). These CPP and CPP-IPR rates would raise the same amount of money as the

pay 14.6 cents per kWh regardless of when they use it. Customers on CPP pay more – a 24 cent per kWh "high rate"– during non-holiday weekday afternoons. Customers on CPP pay less – a 12 cent per kWh "low rate"– during off peak periods. More than 85% of all hours are offpeak. All hours except for weekday afternoons are offpeak inlcuding weekends, holidays, nights and mornings. The utility can notify customers by telephone that a period – typically a weekday afternoon – will be a critical period, invoking a 60 cent per kWh critical rate. Roughly 1% of all hours are critical. The CPP-IPR example rate is identical to CPP with three modifications:

1. The customer's first 450 kWh per month are marked up by 2.5 cents.
2. The customer has the right to access up to 25 kWh of power during an event at the usual price (typically the 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 rebate on $25kWh\ of\ rights - 20kWh\ used = 5kWh$, for a total of a \$1.80 rebates.
3. CPP puts a ceiling of 1% on the proportion of hours in which the utility can invoke critical prices, while CPP-IPR has a floor that requires the utilities to offer customers rebate opportunities equivalent to declaring 1% of all hours as critical periods. Section 4.3.2 discusses this in more detail.

4.3 Strict revenue neutrality: customers cannot profit by becoming eligible for extra rights if they pay a dollar for every dollar of rights that they get

It is important to design IP rebates to provide the appropriate level of rights to each person without creating perverse incentives. If an IP rebate program is strictly revenue neutral because it charges customers a dollar for every dollar of rights they get, the marginal change in bills with respect to a change in rights levels is zero. Thus, customers and utilities are economically indifferent about how many rights they get and face the same marginal incentives as CPP. This section considers how to use strict revenue neutrality to preserve incentives in the assignment of a rights level, in preventing customers from cashing in rights and then exiting the program before they paid for them, and in giving utilities the right incentives to call events.

Customers' electricity use is an important – but manipulable – signal about the quantity of rights a customer needs to avoid bill increases from critical peak events. If our IP rebate system uses customer consumption to adjust the number of rights we sell them, it is important to do so in a way that avoids creating perverse incentives. If a system lets a customer increase the value of the rights he gets in future periods by using more power now, it would implicitly change the price of present power consumption unless it increases the customer's future

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time invariant rate did from the customers on time-invariant rates in California's Statewide Pricing Pilot. California has some of the highest electricity prices in the country.

Table 2: Examples of rates. The IP rebate offer here is appropriate for a high use customer with air conditioning in a hot climate.

		Price per kWh			
Price Period	Times in effect	**Time Invariant Rates**	**CPP**	**CPP-IPR**	
				initial price	beyond 450 kWh/mo.
Low	weekdays before 2PM; after 7PM; all day weekends & holidays	14.6 cents	12 Cents	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: usual price for the period, as listed in the two rows above; 36 cent rebate for every kWh you save additional kWh after the first 25: 60 cents	

Table 3: Bills by time of electricity use. CPP and CPP-IPR generated lower bills than time-invariant rates would have for these California CPP customers. IP rebates rescheduled savings into critical periods. Data: California State Wide Pricing Pilot CPP customers, described in section 8.2, CPP-IPR benchmark offers described in section 9.3.

	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
CPP-IPR	77.6%	24.9%	-2.4%	\$909

payments by an amount equal to the increase in rights. Consider a provision that gives the customer an extra \$1 worth of rights if they increase consumption by q^*. If the provision increases their contributions by \$1 for every \$1 of rights that they get, it does not affect their incentive to increase consumption by q^*. If it changes their contributions by less (more) than \$1, it creates a perverse incentive to (not to) increase consumption by q^*. Section 7 takes up this issue in more detail.

4.3.1 A clever calendar can help ensure person-level revenue neutrality

Sloppy handling of customer exit in mid-year or of under-contribution could break the person-level revenue neutrality. A clever calendar that concentrates events at the end of the fiscal year can, however, ensure that customers buy and pay for property rights before they have a chance to use them. This means that customers cannot profit from the program by strategically entering for just the peak season, claiming rebates, and then exiting the program. A calendar that clusters events at the end of the fiscal year also means it is always possible to reduce 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. This calendar would make customers who leave CPP-IPR before the end of a fiscal year eligible to cash in their unused rights. This is preferable to leaving customers who exit owing the utility money or leaving their neighbors to pay for their rights.[20],[21] A standard fiscal year facilitates making equitable, revenue neutral program revisions since everyone would experience new charges or benefits at the same time.

4.3.2 Ensuring that customers get the rights they paid for

A good CPP-IPR implementation needs to handle year to year fluctuations in the number of times that weather and equipment problems justify critical events, while a CPP-IPR rate is designed to return the funds it raised to customers during a preset number of rebate opportunities per year. An attractive way to deal with this is to return 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.[22]

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[20] If customers are reluctant to contribute through declining blocks now to pay for future benefits, we could phase in the program with an abbreviated first fiscal cycle that began in late spring and called proportionally fewer critical events.

[21] The fiscal year approach would require a special rule, like calling new customers for a reduced number of critical events during their first year.

[22] Refunding the unused rights rather than calling an event will slightly reduce the utility's revenue since the utility forgoes the possibility of charging customers the critical price – in a way that is identical to the loss that a utility would take if it failed to call a critical day that it could call under a conventional CPP rate. Thinking about how to get incentives to call critical days right is an important issue, but is beyond the scope of this paper. By contrast, if utilities could simply pocket the fixed credits from unused event days, they would have a fairly strong incentive to not call events.

4.4 Psychological criteria suggest offering customers consistent rebates.

If customers dislike paying critical prices or experiencing bill spikes, then we can sell customers enough rights to ensure that most customers receive rebates during each billing cycle containing an event.[23] The IP rebate design means selling customers more credits will not reduce utility revenue or distort incentives. Thus, we aspire to provide most customers with "consistent rebates".

Offering rebates so broadly may have some minor downsides. IP rebates might create incentives for customers to actively manage their air conditioning use at the cost of reducing their awareness of the total cost of their air conditioning. Customers might misinterpret consistent rebates as a sign that they were already managing their peak use well – especially if they were less motivated to find gains than to avoid losses. Ranking each customer's rebate size might avoid this misinterpretation by sending messages like "7 out of 10 of your neighbors earned significantly bigger rebates than you did last month."

We need to the amount of rights that the rate offers each customer carefully to deliver consistent rebates that the customer can fully fund through a declining block that is consistently inframarginal and keeps marked up offpeak power cheaper than the time invariant price. Section 8.4 shows that it is not hard to make offers meeting these criteria for most California customers.

5 A formal introduction to CPP and CPP-IPR

This section analyzes CPP and CPP-IPR and formally establishes that IP rebates are revenue neutral and preserve marginal incentives.

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"). During month m, denote the set of critical hours C_m, higher-priced, peak hours H_m and low-priced, offpeak hours L_m. The quantity of power that the customer uses during period i is $\mathsf{Q_i}$.[24] The rate sets prices for each period, denoted P_H, P_L, and P_c.[25] The total monthly bill, TC_m^{CPP}, under this rate is:

$$TC_m^{CPP} = P_c \sum_{c \in C_m} \mathsf{Q_c} + P_L \sum_{L \in L_m} \mathsf{Q_L} + P_H \sum_{H \in H_m} \mathsf{Q_H}$$

5.1 A formal overview of CPP-IPR

IP rebates change the presentation of CPP by adding charges and credits that sum to zero and that retain CPP's marginal incentives.

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[23] Analogously, the US income tax system is tuned so that many citizens withhold too much and get refunds when they file rather than writing large checks.

[24] Characteristics that vary by customer – like quantity consumed, $\mathsf{Q_i}$ – appear in sans serif.

[25] Rate characteristics like P_L and miscellaneous entries appear in the *math* typeface. Rate characteristics reflect local system costs and this document generally takes them as given in designing an IP rebate system. Section 12 lists the notation used in this document.

Consider a rate that calls N_c critical events per year and a month m in which the utility called $N_m \leq N_c$ events. The rate includes a declining block that imposes a markup of $\mathcal{M}$ on the first $\mathbf{Q_D}$[26] kWh.

5.2 Offering the right to units at the regular price and rebates is equivalent to offering an incentive-preserving fixed credit

There are a variety of ways to describe the rights that CPP-IPR customers get during critical events. Explanations for customers like table 2 report that CPP-IPR customers get access to up to $\mathbf{q_R}$ of power at the normal price, typically P_H, during a critical event. Section 4.1 discusses the rationale for that presentation. Further, if they use $\mathsf{q_e} < \mathbf{q_R}$ they get a rebate of $P_c - P_H$ per unit for any unused rights, $\mathbf{q_R} - \mathsf{q_e}$. Writing this out and multiplying through shows that this is mathematically equivalent to offering each customer a fixed credit that reduces bills by $\mathbf{R} = (P_c - P_H)(\mathbf{q_R})$ during each event.

$$
\begin{aligned}
TC_e^{CPP-IPR} &= P_H\mathsf{q_e} - (P_c - P_H)(\mathbf{q_R} - \mathsf{q_e}) \\
&= P_H\mathsf{q_e} - P_H\mathsf{q_e} + P_c\mathsf{q_e} - (P_c - P_H)(\mathbf{q_R}) \qquad (1) \\
&= P_c\mathsf{q_e} - (P_c - P_H)(qr) \\
&= P_c\mathsf{q_e} - \mathbf{R} \qquad (2)
\end{aligned}
$$

Equation 2 makes it clear that CPP-IPR 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 $\mathbf{R}$. 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.

Customers who use $\mathsf{q_e} > \mathbf{q_R}$ pay P_c for their marginal power use. The calculations to show the equivalence between the two descriptions are analogous and are omitted here for brevity.

The balance of this analysis describes IP rebates as providing a fixed credit of $\mathbf{R}$ to both simplify its notation and draw attention to the fact that the credit of $\mathbf{R}$ does not affect the marginal incentive.

5.3 CPP-IPR Total bills and revenue equivalence for customers who buy all the rights the rate offers

This section defines the CPP-IPR monthly bill in the well-behaved case where customers buy $Q_m \geq \mathbf{Q_D}$ kWh in each month m.[27] Thus, they purchase all the rights the rate offers them, namely $\mathcal{M}\mathbf{Q_D}$ worth of rights per month. This sets up the proof that CPP and CPP-IPR generate the same total bill over the course of a year. These contributions provide customers

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[26] IP rebate designers choose values for the variables listed in **bold**, including $\mathbf{Q_D}$, $\mathbf{R}$, and $\mathbf{q_R}$.

[27] IP rebates change seasonal bill patterns by raising CPP bills by up to $\mathcal{M}Q_D$ each month and returning that money during (typically summer) months with events. A section below discusses how impacts on seasonal bill patterns vary by region. Most areas' highest use season coincides with the California summer peak, but usage in other regions peaks during the winter.

with power rights worth $\mathbf{R}$ during each of N_c events. 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 $12\mathcal{M}Q_D = N_c\mathbf{R}$.[28]

Section 5.5 considers the analogous general case that maintains revenue neutrality even if customers buy less than the planned $\mathcal{M}\mathbf{Q_D}$ worth of rights in some months.

This customer's total monthly bill, $TC_m^{CPP-IPR}$, will be:

$$TC_m^{CPP-IPR} = \mathcal{M}Q_D - N_m\mathbf{R} + TC_m^{CPP} = \mathcal{M}Q_D - N_m\mathbf{R} + P_c \sum_{c \in C_m} \mathsf{Q}_{\mathsf{c}} + P_L \sum_{L \in L_m} \mathsf{Q}_{\mathsf{L}} + P_H \sum_{H \in H_m} \mathsf{Q}_{\mathsf{H}}$$

5.4 CPP-IPR generates the same total annual bill as CPP for each customer

Each customer pays the same amount over the course of a year on a CPP-IPR rate that they would pay on the underlying CPP rate. The total annual CPP-IPR bill, $TC_a^{CPP-IPR}$, 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 CPP-IPR bill, rearranging terms, and recalling that $12\mathcal{M}Q_D = N_c\mathbf{R}$, as follows:

$$\begin{aligned} TC_a^{CPP-IPR} &= \sum_{m=1}^{12} [\mathcal{M}Q_D - N_m\mathbf{R} + P_c \sum_{c \in C_m} \mathsf{Q}_{\mathsf{c}} + P_L \sum_{L \in L_m} \mathsf{Q}_{\mathsf{L}} + P_H \sum_{H \in H_m} \mathsf{Q}_{\mathsf{H}}] \\ &= 12\mathcal{M}Q_D - N_c\mathbf{R} + \sum_{m=1}^{12} [TC_m^{CPP}] \\ &= 0 + \sum_{m=1}^{12} [TC_m^{CPP}] \end{aligned}$$

5.5 The general case: dealing with customers who do not buy all of the offered rights

This section generalizes the discussion above to allow customers to buy less than $\mathbf{Q_D}$ kWh of power in some months, which means that they did not purchase a full $\mathcal{M}\mathbf{Q_D}$ worth of rights. It maintains revenue neutrality by only selling customers the rights they have paid for, $\hat{\mathbf{R}}$.[29] Selling customers only the number of rights that they pay for is consistent with treating this

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[28] I present these examples without calculating interest on the contributions to keep the algebra simple. It is technically correct to equate the two values in net present value, formally: $\sum_{m=1}^{12}(1+r)^{\frac{m}{12}}\mathcal{M}Q_D = \sum_{m=1}^{12}(1+r)^{\frac{m}{12}}N_m\mathbf{R}$ where r is the annual interest rate. The interest-free approximation differs from the net present value by less than the interest rate r, a few percent. Ensuring that the net present value of the rights and charges match exactly would require making minute adjustments to the value of the rights, $\mathbf{R}$, depending on the distribution of event dates, since designers have to set rates before the fact using estimates of when heat waves and equipment problems will cause critical days. Failure to adjust $\mathbf{R}$ or utility revenues to compensate for the timing of events creates tiny incentives for the utility to earn extra interest by calling events later in the year.

[29] Equivalently, we could return to the original plan by marking up more than $\mathbf{Q_D}$units of power and buying the missing units in a later month.

bill volatility control strategy as a well-defined property right – which section 7 discusses further. The customer buys rights worth the markup times the lesser of $\mathbf{Q_D}$ and their actual consumption, $\mathsf{Q_m}$ each month. Formally, they buy rights worth $\mathcal{M}\min\{\mathbf{Q_D}, \mathsf{Q_m}\} \leq \mathcal{M}\mathbf{Q_D}$.

This implies that customers own rights worth $\hat{\mathbf{R}}_c$ during event c. Customer level revenue neutrality requires that the sum of adjusted right values equal the sum of customer contributions, formally:

$$\sum_{c=1}^{N_c} \hat{\mathbf{R}}_c = \mathcal{M} \sum_{m=1}^{12} \min\{\mathbf{Q_D}, \mathsf{Q_m}\}$$

Strategies to restore person-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 $\hat{\mathbf{R}}_c < \mathbf{R}$. 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.[30]

The cumulative deficit, δ_m in month m, is a deficit in a customer's purchases of rights for future events relative to the value of rights that the rate slated for the customer. The deficit grows when monthly consumption is too low, $\mathsf{Q_m} < \mathbf{Q_D}$, and shrinks when the customer gets fewer rights during an event.[31] Formally, the definition is:

$$\delta_\mathsf{m} = \min\{0, N_m\mathbf{R} - \delta_{\mathsf{m-1}} - \mathcal{M}(\mathbf{Q_D} - \min\{\mathbf{Q_D}, \mathsf{Q_m}\}\} \tag{3}$$

Formula 3 defines the cumulative deficit 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. There can never be a positive deficit so the deficit returns to zero after enough rights are applied to it.

We can ensure budget balance by offering rights each month worth

$$N_m\hat{\mathbf{R}} = \max\{0, N_m\mathbf{R} - \delta_{\mathsf{m-1}} - \mathcal{M}(\mathbf{Q_D} - \min\{\mathbf{Q_D}, \mathsf{Q_m}\}\}$$

Notice that this reduces back to the full contribution case considered above if the customer buys at least $\mathbf{Q_D}$ kWh each month, so $\delta_{\mathsf{m-1}} = 0$, $min\{\mathbf{Q_D}, \mathsf{Q_m}\} = \mathbf{Q_D}$, and $\hat{\mathbf{R}} = \mathbf{R}$.

5.5.1 Using a declining block rate to fund rebates never creates a deadweight loss

This rate, unlike most declining block rates, does not create a deadweight loss because every extra dollar that a customer pays for through this rate's markup, $\mathcal{M}$, comes directly back to the customer as an extra dollar of rights.[32]

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[30] Customers may be equally frustrated that issues in the fine print of their offer letter are costing them money.

[31] This algebra, for simplicity, closes the entire deficit at the first available event. There are equivalent, perhaps more palatable, approaches that would spread the reduction over multiple events where possible.

[32] Customers 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. All we really need customers to know for CPP-IPR to work well is that there is some economic reason for them to shift power use away from weekday afternoons, and stronger reason to shift power use when the utility notifies them of a critical period.

Customers who buy less than $\mathbf{Q_D}$ units on a typical declining block rate end up paying $\mathcal{M}$ more for their marginal unit. This price increase reduces purchases and creates a deadweight loss.

Formally, consider the marginal incentives for a customer to buy one more unit of power during period $i \in \{c, H, L\}$ for a month m when $\mathsf{Q_m} < \mathbf{Q_D}$. Taking the derivative with respect to the total annual bill shows that the cost of the marginal unit includes an increase in price of $\mathcal{M}$, but the increases in future rebates of $\mathcal{M}$ exactly offsets the price increase:

$$\frac{\partial TC_a}{\partial \mathsf{Q_m}} = P_i + \mathcal{M} - \frac{\partial \delta_\mathsf{m}}{\partial \mathsf{Q_m}} = P_i + \mathcal{M} - \mathcal{M}$$

6 IP Rebates generalize to many pricing challenges

IP rebates generalize to work with a wide variety of dynamic pricing plans that improve incentives over uniform pricing for products which have underlying costs that fluctuate over time. The generalized IP rebate approach will offer each customer:

- rights to buy a block of the product at the usual nominal price during the high priced periods,
- rebates for any unused rights, and
- opportunity costs to purchase the product that are closer to the cost of production during both the 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.[33]

The uniform pricing that we seek to improve can generally only survive in the context of exclusive, long term relationships with a single supplier. Customers who choose frequently among competing suppliers will purchase from firms with dynamic pricing during low cost seasons. Further, cheap storage opportunities will smooth differences in cost over time, so this approach will have the greatest benefits for products that are not cost effective to store. 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 phones at call centers, 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

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[33] This 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 power. 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 simply buys the product during the lowest cost season and uniformly spread her demand among seasons 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 during and then returns those markups during the low cost season, her bill increase (decrease) would be larger during the low (high) cost seasons than it would be under the conventional dynamic pricing approach.

and low cost units of the product.[34],[35] This assumption makes the terms "high cost periods" and "high price periods" interchangeable in the discussion below.

Intuition: Uniform pricing makes customers pay a markup during low cost periods that covers extra production costs during high cost periods. We can set opportunity costs that better reflect production cost during each period. Then we can divert each customer's markup to buy him a credit that he can either 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 the credits can preserve the nominal prices during high cost seasons for every unit that the customer buys rights to.

Proof: We can decompose the uniform price paid during low priced periods into the low cost and the markup, then applies the total markup paid to buy an equal value of refundable rights to buy a fixed quantity of power 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, formally $\bar{P}_H = \bar{P}_L + \Delta P$.

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

That strategy generalizes to pricing schemes that further subdivide the high and low cost periods into any number of subsets. The generalization requires that the customer pay markups during low priced periods that equal the value of the rights the customer gets back during the high priced periods, or:

$$\sum_{i \in L} \mathcal{M}^i_u Q^i_L = \sum_{h \in H} \mathbf{R}^h$$

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

[35] Changing 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.

if $L(H)$ represents the set of low (high) cost periods. 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).

6.1 This two period generalization does not perform as well as the three-period CPP-IPR approach

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

- Each customer get rights as a function of their usage. The fluctuations in rights levels may be hard to explain to customers.
- This approach leaves the nominal price during low-cost periods at P_u. It may be difficult to explain that customers pay $P_u = P_L + \mathcal{M}_u$, but that the opportunity cost is really P_L since the customer gets the $\mathcal{M}_u$ component of the price back. Customers who do not understand that the opportunity cost has dropped to P_L may inappropriately continue to consume as if the opportunity cost were the higher P_u .
- The two period implementation does not offer consistent rebates to most customers. 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. Elasticity increases purchases during low priced periods that come bundled with rights and decrease the use of rights to buy expensive power.

Further, this approach creates winners and losers relative to uniform pricing. Customers who used a smaller (larger) than the population average proportion of their power during high-priced periods will see their total annual bills decrease (increase) under the new pricing. For example, if P_u reflects the fact that the average customer buys 75% of his purchases of the product during low cost periods, a customer who buys 80% of her total consumption during low cost periods will see her bill for the same bundle drop because her average unit will now cost $.8P_L + .2P_H$ rather than the uniform cost of $P_u = .75P_L + .25P_H$. The new pricing eliminates the cross subsidy that offering unlimited access to high cost product at $\bar{P}_u$ provides. This flaw is typical of dynamic pricing approaches unless they are designed from the ground with complex, hard to explain and implement, features to preserve existing cross subsidies and deliver a Pareto improvement.

6.2 Concentrating credits on selected parts of the high-priced period can address these shortcomings

CPP-IPR works so well because it splits high cost periods into a set of “high” priced periods without rights to buy at the usual price and “critical” periods that get such rights. This is a generally applicable strategy that frees up cash to address some flaws in a two-period IP rebate implementation. Marking up the same number of low priced units while offering credits for fewer purchases creates a surplus of potential credits. This surplus can be used to offer more customers consistent rebates, to reduce nominal offpeak prices, or to implement a declining block and a fixed credit size.[36]

7 Comparing CPP-IPR to other rates

CPP-IPR offers better economic incentives than existing, time invariant and baseline-rebate rate designs, while being more compatible with customer decision-making heuristics than CPP. The major existing rate designs are:

- Most customers are on time invariant pricing and seem satisfied. Time invariant pricing gets prices wrong during almost all hours which leads to enormous waste and to significant cross subsidies. Specifically, it charges a uniform price, P_u, during every period. P_u is too high off peak hours and too low during peak and critical periods.
- Dynamic rates including CPP create significantly better incentives than time invariant rates but consumers resist signing up for them.
- Baseline rebate rates, discussed at length below, create dynamic incentives while using behaviorally astute rebate opportunities – but also create perverse incentives for customers to distort their consumption patterns to become eligible for larger rebates.

Figures 2 and 3 graphically compare their incentives to CPP and CPP-IPR.

The rates that consumers accept include hedges or other features that dampen bill volatility and reduce exposure to high prices by default, while the dynamic rates customers reject generally make risk management optional if it is available at all.[37] There may be both good customer perception and conventional economic risk management reasons to manage bill risks given the volatility of electricity prices. Borenstein (2006b) reports that RTP leads to significant increases in bill volatility, but that simple hedges can control that volatility.

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[36] I 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.

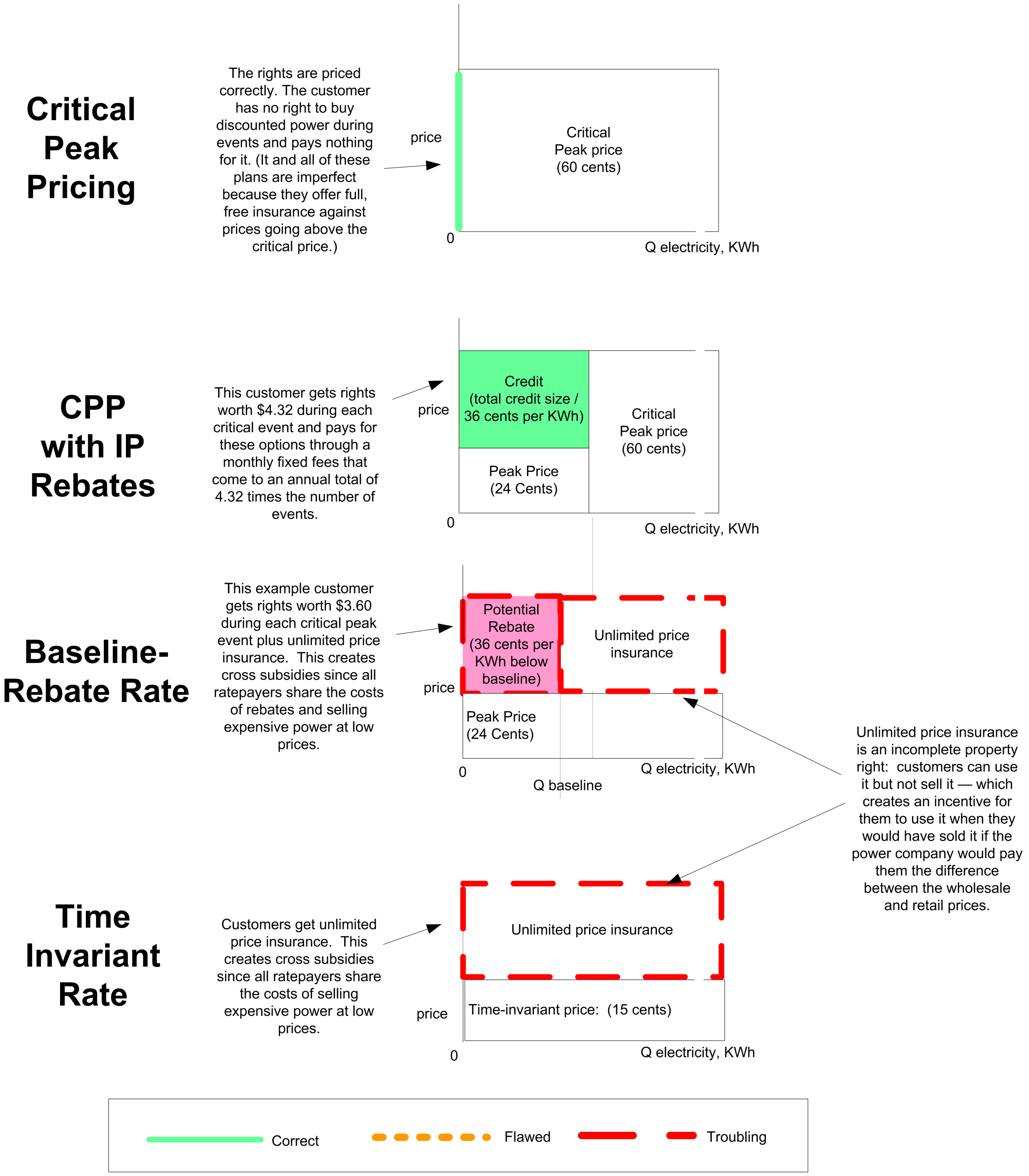
[37] The rights that IP rebate customers buy ahead of time have bill-volatility reduction effects that are akin hedging by buying ahead on the futures market, but differ from conventional hedging in that there is no unknown state of the world that affects the realization of the price of the commodity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

Figure 2: *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.*

The Pricing of Rights to Buy Low Price Power

Economics suggests two principles for the design of products that protect consumers' total bills from volatility, namely:

1) The rights to buy a product at a set price is an expensive, valuable product that delivers benefits to the people who own the right. Beneficiaries should pay the cost of their own rights.
2) People who use less (more) power than they had rights to should be able to sell (buy) 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 it. (It and all of these plans are imperfect because they offer full, free insurance against prices going above the critical price.)

CPP with IP Rebates

This customer gets rights worth $4.32 during each critical event and pays for these options through a monthly fixed fees that come to an annual total of 4.32 times the number of events.

Baseline-Rebate Rate

This example customer gets rights worth $3.60 during each critical peak event plus unlimited price insurance. This creates cross subsidies since all ratepayers share the costs of rebates and selling expensive power at low prices.

Unlimited price insurance is an incomplete property right: customers can use it but not sell it — which creates an incentive for them to use it 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 creates cross subsidies since all ratepayers share the costs of selling expensive power at low prices.

Figure 3: *These diagrams compare the plans' pricing of rights to access low cost power during events.*

It makes sense to make risk management that uses well defined property rights part of the default rate.[38]

The existing rates that manage volatility generally fail to manage volatility through well defined property rights and thus create flawed incentives. For example, time invariant rates include a built in mandatory hedge that gives customers a use-it-or-lose-it right to as much cheap power as they want. Customers use too much power during periods when wholesale power is expensive and they would prefer to sell their rights if they could sell them for their true cost. Time invariant rates and CPP-IPR ask customers to contribute toward insurance against critical events year round, while plain CPP does not – so IP rebates are 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 – which are typically weekday afternoons during the hottest months – which creates a perverse incentive, discussed at length below, for customers to consume more during the baseline setting periods to get more rebates during events. Baseline rebate rates introduce perverse incentives because they succumb to the temptation to develop ad hoc solutions to provide rebates and create incentives to shift away from critical periods rather than doing so with well defined property rights.

Dynamic rates generally offer the foundations for fairly well defined property rights, but generally include no volatility management by default and – at best – leave it to customers to acquire this kind of hedge separately. Bundling default rights that are priced at marginal cost addresses this omission. Doing so is a major step forward, but the remaining challenges include choosing the level of protection and paying for it in ways that are economically efficient and psychologically attractive.

There are compelling psychological and economic reasons to make a revenue-neutral volatility dampening mechanism or actuarially fair hedge the default.

- Making it a default minimizes transaction costs. The bill shocks that are involved are fairly small, and do not justify customers' spending hours to understand plans and choose a hedge.
- 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).
- Incentive preserving rebate type interventions are designed not to affect marginal incentives or annual per-customer revenues. A revenue neutral bill volatility reduction strategy – like those proposed in IP rebates – has no effect on total annual bills, so economically rational customers who really understand the program should be nearly indifferent between the default IP rebate eligibility-size offers and a menu of alternatives. Similarly, an actuarially fair offer has zero impact on total bills in expectation.

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[38] It is clear that zero expected cost risk management or month-to-month volatility reduction would make many customers happier for both behavioral 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. Rational customers, however, should be willing to pay only a very small risk premium to reduce the risk of a bill spike of a few tens of dollars (Rabin, 2000).

7.1 IP rebates avoid the economic flaws in baseline-rebate rates

Some utilities have used baseline-rebate rates that are superficially similar to IP rebates. 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. Baseline rebate programs, unlike IP rebates, create troubling cross subsidies and create flawed incentives both during ordinary periods that are used to set the baseline and sometimes during critical events.

Utilities have fielded baseline rebate rates in a variety of contexts. Utilities generally make every customer eligible to earn rebates because baseline-rebate plans are described as containing only rewards for conservation.[39] Thus, baseline rebate programs tend to expose far more customers to improved incentives than opt-in dynamic pricing programs do. Wolak (2006) analyzes an experiment with a baseline-rebate dynamic pricing program in Anaheim, California and reports that consumers reduced use during critical periods but many customers exploited the poor incentives. San Diego Gas and Electric has proposed offering all of its customers a "Peak Time Rebate" rate based on the Anaheim design.[40]

California utilities offered a "20/20" baseline rebate plan during its electricity crisis that offered customers a 20% rebate on their electricity bill if they reduced their total summer electricity use 20% below their use the previous summer. California Utilities offered a "10/20" natural gas baseline rebate program during a price spike in Winter 2005-06 that offered a 20% rebate for reducing gas consumption at least 10% relative to the previous winter. Utility staff and regulators report that they dislike baseline-rebate rates. The section below describes how baseline rebate rates work and then lays out three significant flaws of baseline-rebate rates: perverse incentives during baseline-setting periods; inconsistent incentives during critical periods; and significant revenue impacts.

Baseline rebate mechanics: A baseline-rebate rate customer gets rebates for getting consumption below their baseline usage level, which is a function of their "normal" behavior during similar, but non-critical periods.[41] The baseline amount for a baseline-rebate program applied to critical electricity periods, $\bar{\mathsf{Q}}_{\mathsf{bt}}$, is generally the customer's average use, $\mathsf{q}_{\mathsf{t-i,H}}$, during the set of N_b weekdays afternoons or peak periods (hence the subscript H), $t - N_b \cdots t-1$, before the event at time t.

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[39] Baseline-rebate programs tend to include every customer by default on the claim that they provide only rebate opportunities – carrots without visible sticks. They often quietly recover rebate costs by raising every customers' rate later. This means that some customers would have done better had they been able to opt out of the rebate program and the responsibility to pay for it. PG&E's proposal for its 10/20 baseline-rebate program reads in part "[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 Gas & Electric, b, 4).

[40] Both the Anaheim and San Diego rate designs comply with a California law, AB1X, that limits aspects of utility rates and makes it difficult to implement CPP. AB1X will sunset once a set of obligations from the California electricity crisis are paid off and may get amended or repealed even before that date.

[41] Situations where the customer knows his true demand for electricity, but the utility can only knows his usage level are asymmetric information games. It is generally difficult to design efficient mechanisms to get customers to reveal their types. In the absence of mechanisms designed to minimize distortions, customers have large incentives to strategically misrepresent their usual consumption during the baseline setting periods.

$$\bar{\mathsf{Q}}_{\mathsf{bt}} = \frac{1}{N}\sum_{i=1}^{n} \mathsf{q}_{\mathsf{t-i,H}}$$

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

$$TC^{baseline} = P_L \sum_{L \in L_m} \mathsf{Q}_{\mathsf{L}} + P_H(\sum_{H \in H_m} \mathsf{Q}_{\mathsf{H}} + \sum_{c \in C_m} \mathsf{Q}_{\mathsf{c}}) - \mathcal{P}_B \sum_{c \in C_m} \max\{0, \bar{\mathsf{Q}}_{\mathsf{bt}} - \mathsf{Q}_{\mathsf{c}}\} \tag{4}$$

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. Sometimes the rates offer a negative cost of power during baseline setting periods that pays customers to use power. To see this, substitute the formula for $\bar{\mathsf{Q}}_{\mathsf{bt}}$ into the baseline-rebate bill formula, 4, and take the partial derivative with respect to the quantity of power used during the baseline-setting period. The result is as follows, assuming for notational simplicity that the customer is getting a rebate:[42]

$$\frac{\partial TC}{\partial Q_i} = P_H - \mathcal{P}_B \sum_{i \in Bt} \frac{1}{N}$$

This formula also reveals that this distortion becomes small (large) as the baseline setting period gets large (small). Making the baseline-setting period large, however, is likely to include cooler weather in the baseline and thus to make it a less accurate estimate of what people would have been doing on the critical day in the absence of an incentive to conserve.

These bundled baseline rights create significant changes in incentives. For example, San Diego Gas and Electric's proposed baseline-rebate rate offers a 65 cent rebate for every kWh that a customer's period use is below a baseline set by the customer'average use on the five non-event weekdays preceding the event day (Gaines, 2006). This means that San Diego customers get another roughly[43] $\frac{1}{5}$ kWh of baseline rights, worth 13 cents, bundled with every baseline-setting kWh. Residential customers in San Diego pay between 4 and 18 cents per kWh of power (San Diego Gas and Electric).[44] The bundled rights can be worth even more if one day sets the baseline for more than one critical event if there were fewer than five non-event weekdays between events. 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 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

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[42] There is no distortion for customers who will never get rebates. And there is a tedious, unenlightening corner case for customers who switch from no rebates to rebates as they use more during the baseline period.

[43] San Diego's proposes to set its baseline by multiplying the average consumption during the baseline-setting period by a scaling factor, namely the ratio between the system wide demand on baseline-setting days and the critical day. This lets them correct for differences in demand – especially in weather-driven air conditioning demand – between the baseline-setting and critical days.

[44] Most 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.

cents comes bundled with rights worth \$1.40 to a customer getting rebates (Wolak, 2006, 14).

This distortion is more disturbing because it increases demand for expensive power. Baseline-setting periods are typically moderately hot weekday afternoons when wholesale power is moderately scarce and expensive.

Baseline-rebate rates offer customers who have used too much power to get rebates an unlimited amount of power at the usual price and does nothing to give these customers an extra incentive to reduce usage on the margin during events. The class of customers who generally consume more than their baseline quantity during critical events will quickly learn that they cannot earn rebates and have no incentive to conserve. Baseline-rebate rates, like time invariant rates, implicitly include the cost of mandatory, unlimited critical period price insurance in the price of basic electric service.

These are expensive programs that create cross subsidies and uncomfortable trade offs: Baseline-rebate rates are not revenue neutral for individual customers which means that baseline-rebate programs create unpredictable rebate costs that utilities will need to recover later. Utilities recover the costs of the rebate program by marking up power during all the non event periods, which can create inequitable cross-subsidies. Thus baseline levels can be mistakes since they both transfer cash among customers and create incentives, while IP rebates' choice of $\mathbf{q_R}$ neither creates incentives[45] nor transfers cash among consumers. Hence, baseline-rebate designers aspire to calculate baselines that reflect precise predictions of how much each customer would have used in the absence of the rebate opportunity. The limited data available to regulators and significant, normal day-to-day variation in power use mean that many customers' event usage would deviate significantly from their baselines even in the absence of rebate opportunities. Customers who get baselines above what they would have used on the day under the normal incentives get socially expensive "structural" rebates , while customers who would use far more than their baseline levels get no incentives to save.[46] By contrast, IP rebate designers can choose levels of rights that offer almost everyone rebates and are using a rate design that provides a constant opportunity cost of P_c.

In sum, IP rebates avoid flaws in baseline rebate designs. The flaws in baseline-rebate rates reduce efficiency and focus attention on dealing with perverse incentives, baseline estimation challenges, and the redistributive effects of the baselines rather than the real challenge of reducing consumption during critical and peak periods. Baseline-rebate rates offer customers opportunities to reduce their total annual bills through strategic baseline-manipulation without lowering the social cost of electricity provision.

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[45] The underlying CPP rate creates the incentives in CPP-IPR; IPR's simply presents those incentives in a more palatable way.

[46] San Diego Gas and Electric also reports that more than a quarter of their customers had usage in absence of the critical event that would have either given them a rebate or have given them a baseline that would require them to reduce usage 15% before they got a rebate.

8 The political, organizational, and financial feasibility of CPP-IPR: Evidence from California Customers

CPP-IPR implementations need to meet administrative and financial constraints. Data from a California CPP pilot study shows that most customers meet the financial constraints on CPP-IPR. The central, interlocking feasibility issues are:

- **Administrative and political feasibility.** CPP-IPR has to coexist with existing analytic categories and be an incremental change from existing rates. It has to give regulators the flexibility to address local equity concerns and distributional concerns.
- **Economic feasibility.** CPP-IPR works well if we can assign each customers a revenue neutral pair of a rights size, $\mathbf{q_R}$, and a declining block size, $\mathbf{Q_D}$, that is likely to work well for the customer. An offer that works well has enough rights that it never leaves the customer paying a high nominal price for power during a month that contains an event. And the customer needs to use at least $\mathbf{Q_D}$kWh during each month in order to buy all of the rights that the rate offered the customer. Rebates are only feasible if a customer's demand pattern means that this kind of offer exists. Utilities need to be able to make these offers using only limited information about customers' demand patterns and, probably, a limited amount of flexibility to customize offers.

8.1 The central economic feasibility constraints: consistent rebates, inframarginal declining blocks, and revenue neutrality

IP rebates make each customer an **offer**, which is a pair ($\mathbf{q_R}$, $\mathbf{Q_D}$) specifying the quantity of rights that the customer gets during each event rights and the number of kWh the declining block marks up each month. It is desirable for offers to meet the following constraints:

i. **Consistent rebates:** The utility needs to offer the customer enough kWh at the usual price so that the customer gets a (weakly positive) rebate during each month with an event, or $\mathbf{q_R} \geq \bar{\mathsf{q}}_{\mathsf{c}}$.[47] In other words, the number of protected kWh, $\mathbf{q_R}$, has to be at least as much as the customer consumed during the average event in the customer's highest average event use, month $\bar{\mathsf{q}}_{\mathsf{c}} = \max_{m \in M}\{\mathsf{Q}_{\mathsf{c}}/N_m\}$.

ii. **Consistent purchases through inframarginal declining blocks:** Only if the declining block marks up less power than the customer uses each month, or $\mathbf{Q_D} \leq \underline{\mathsf{Q}_{\mathsf{m}}}$, do customers buy all of the rights that the offer promised (which may be required for them to get consistent rebates).

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[47] I assume that $\mathbf{q_R}$ and $\mathbf{Q_D}$ stay the same year round. There may be some seasonal consumption patterns where changing the values of the rights and declining block parameters over the course of the year would be an important way to devise offers that provide customers with consistent rebates that they consistently purchase. Requiring extra contributions early in the year could provide a reserve fund to cover under contributions later. It may be particularly natural to consider seasonal variations in $\mathbf{Q_D}$ or $\mathcal{M}$in electricity systems that already adjust rates seasonally. Seasonal adjustments may, however, make rates considerably harder for customers to understand, especially if they were applied to rates that did not already vary by season.

iii. **Revenue neutrality:** The amount of money that the customer pays to buy rights is exactly the value of the rights they get back. If the customer consistently purchases $\mathbf{Q_D}$ per month (constraint ii) then, this becomes $12\mathcal{M}\mathbf{Q_D} = N_c\mathbf{q_R}(P_c - P_h)$.

IP rebate offers must satisfy revenue neutrality constraint[48] iii and aspire to do so while meeting consistent rebate and inframarginal declining block constraints for as many customers as possible. Throughout the discussion below, an offer is **consistent** if it satisfies the consistent rebates constraint i and the consistent rights purchase constraint ii over the course of a year.[49]

Substituting the first constraints i and ii into constraint iii, we discover a criterion that determines whether an offer exists that marks up $\mathbf{Q_D} \leq \underline{\mathsf{Q_m}}$ each month and provides consistent rebates, namely:

$$12\mathcal{M}\underline{\mathsf{Q_m}} \geq 12\mathcal{M}\mathbf{Q_D} = N_c\mathbf{q_R}(P_c - P_h) \geq N_c\bar{\mathsf{q}}_\mathsf{c}(P_c - P_h) \tag{5}$$

Dropping out the middle terms that specify a revenue neutral offer creates a feasibility criterion that depends only on customer characteristics and characteristics of the rate that we take as given. The criterion implies that an offer exists only if:

$$12\mathcal{M}\underline{\mathsf{Q_m}} \geq N_c\bar{\mathsf{q}}_\mathsf{c}(P_c - P_h) \tag{6}$$

Figure 4 visualizes the three constraints and their implications by plotting the use during events on the x-axis and monthly use on the y-axis. The y-axis plots the offer's requirement that the customer use at least $\mathbf{Q_D}$ kWh per month. We can plot the customers' use patterns that make $\underline{\mathsf{Q_m}}$ available on the same axis. The customer's right to buy $\mathbf{q_R}$ kWh per critical event at the usual nominal price can be plotted on the x-axis. The customer's need to get $\bar{\mathsf{q}}_\mathsf{c}$ kWh of rights to get consistent rebates can also be plotted on the x-axis.

IP rebate offers are consistent if they assign each customer a value of $\mathbf{q_R}$ that satisfies feasibility condition 5. Specifically, an offer is consistent if it provides **consistent rebates** paid for through a declining block that the customer **consistently purchases**. Providing consistent offers to most customers requires that the distribution of customers have two characteristics:

i. Customer-specific rights levels, ${\mathbf{q_R}}^i$ exist that satisfy feasibility condition 5 for most customers.

ii. The organizations making offers have enough data to predict a $\hat{\mathbf{q}}^i_\mathbf{R}$ that satisfies feasibility condition 5 for customer i.

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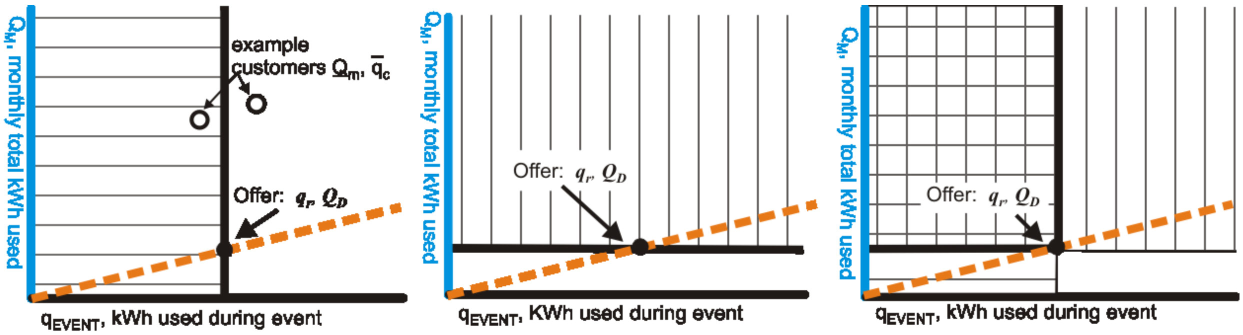
[48] Any deviation from the revenue neutrality constraint means that the rebate program will sometimes pay a customer more or less in rebates than they contributed to buy their rights, which creates flawed incentives that customers can exploit.

[49] This project focuses on maximizing the probability of getting a consistent offer during each customer year. Since $\underline{\mathsf{Q_m}}$and $\bar{\mathsf{q}}_\mathsf{c}$are a minimum and a maximum, respectively, so the more observations they consider, the more extreme results they will report. From a policy perspective, it is interesting to know that the Park family's annual values of $\underline{\mathsf{Q_m}}$and $\bar{\mathsf{q}}_\mathsf{c}$supported consistent offers in 19 of 20 years. It is less interesting to know that calculating $\underline{\mathsf{Q_m}}$' and $\bar{\mathsf{q}}_\mathsf{c}$' over 20 years picks up outlying values – like an extended vacation and running the dryer during a critical period – and makes it impossible to find a consistent offer.



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 requires that offers be on the dotted diagonal line.

Consistent rights purchase constraint (ii) is satisfied by the group of customers in the vertically striped region above the offer. They use at least Q_D kWh per month, so they consistently buy all the credits the offer allows them to buy through the declining block.

The Union of the Consistent Rebate Constraint (i) and Consistent Purchase Constraint (ii): Customers consistently fund their credit and get consistent rebates if they are in the hashed region above and to the left of the offer.

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

Figure 4: *Visualizing constraints 1-3.*

Answering these questions requires data about the behavior of real customers on CPP-IPR or comparable dynamic pricing. CPP-IPR is yet to be tested on real consumers, but there are data on customers on economically-similar CPP rates.

8.2 The California Statewide Pricing Pilot offers important evidence

California's Statewide Pricing Pilot (SPP) exposed about 500 customers to 27 CPP events (Charles River Associates, 20) from summer 2003 into fall 2004 while collecting survey data and recording hourly electricity use.[50] This created a 15 month panel of data. The SPP data are a powerful source of evidence about electricity use patterns. SPP data are particularly relevant to the example CPP-IPR rate in table 2 since that rate is adapted from an SPP Welcome kit (Pacific Gas & Electric, a).

8.3 Good IP rebate offers exist for most SPP customers

Figure 5 plots the constraints in the style of figure 4 with real data. Evidence from the SPP suggests that 97% of customers statewide have demand patterns that satisfy feasibility criterion 6 for the example rate.

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[50] The SPP was a vast field experiment. The data considered here are from its largest cell, customers on a CPP-Fixed Period ("CPP-F") rate who experienced events that ran from 2-7PM, who were notified of events by telephone the day before, and who did not get thermostats that could respond to price signals automatically.

The rectangular region above the diagonal line is the single offer that provides consistent rebates to the largest number of customers. The graph shows that one size does not fit all. The single-optimal offer is not consistent for customers outside of the rectangle. It is not very surprising that the monthly usage of a small apartment in a temperate climate is insufficient to pay for the level of rights required to provide consistent rebates for a big house in the desert.

We can generalize this analysis to a family of CPP-IPR rates by rearranging feasibility constraint 6 as a relationship between characteristics of customers and characteristics of rates. This rearrangement yields:

$$\frac{12\mathcal{M}}{N_c(P_c - P_h)} \geq \frac{\bar{\mathsf{q}}_\mathsf{c}}{\underline{\mathsf{Q}_\mathsf{m}}} \tag{7}$$

The left side of this equation describes characteristics of the rate, while the right side describes characteristics of the customers. 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 biggest declining block size that they consistently purchase. Figure 6 shows the cumulative distribution of the right hand side of the rearranged criterion, 7, $\frac{\bar{\mathsf{q}}_\mathsf{c}}{\underline{\mathsf{Q}_\mathsf{m}}}$ and uses it to see the percentage of customers who could get consistent offers under the IP rebates that could be added to a variety of real CPP offers. It 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 6.1. 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 consistentoffers. 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 period (perhaps by adding more low priced hours to it) could address these problems.

8.4 It is easy to predict consistent offers given readily available information

The rate implementers need to be able to identify consistent offers for each customer but will often not have data about how much power the customer used during hot weekday afternoons. This usage level determines the level of rights the customer needs to get consistent rebates. Many utilities – including Gulf Power – will lack this information because they only install "interval" electricity meters that provide disaggregated usage data when customers sign up for dynamic pricing. California's three major utilities plan to install interval meters for everyone, but may want to offer dynamic pricing as soon as they install the meters. Either of these scenarios would require the firm to make an initial offer to CPP-IPR customers based on the data they already have, like monthly usage data from old meters that provide only

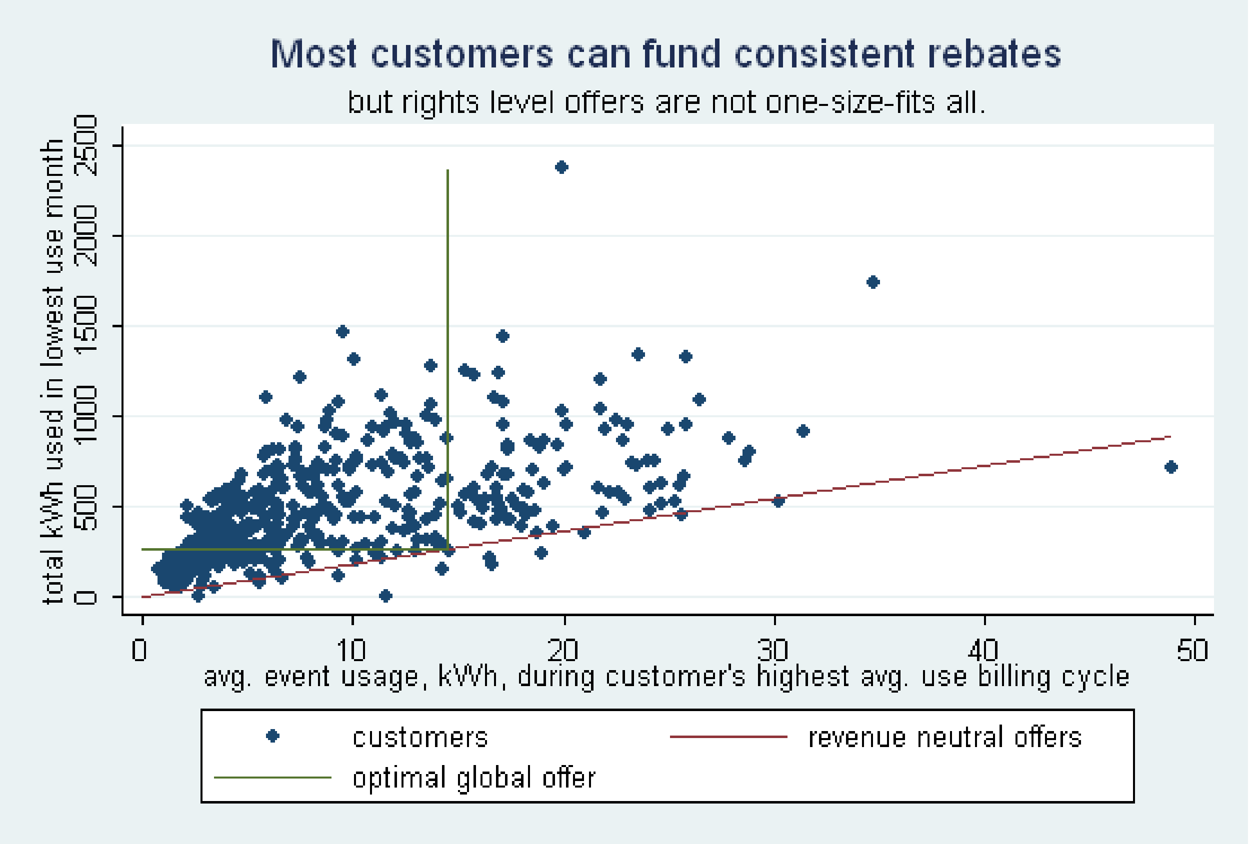

Figure 5: *Most California's SPP customers' demand patterns are above the diagonal line defined by feasibility criterion 6, so consistent offers exist for them. But the single offer that provides consistent rebates and rights purchases for the greatest number of customers does not perform particularly well, so we should consider more customized offers.*

Figure 6: *Offer feasibility under a variety of rates: Rearranging criterion 6 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.	critical hrs $5N_c$	uniform price P_u	offpeak price P_L	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 2	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 6. They have 2-4 rate 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 6 and suffers the shortcomings of taking approach to a two period rate that are described in section 6.1. Three period rates have offpeak, peak, and critical rates. Four period rates further subdivide the offpeak period into a low rate and a "shoulder" rate 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 (c); San Diego Gas & Electric)

aggregate data, account type, and geographic data. The analysis below shows that the data utilities have predict consistent offers quite well, so it appears to be feasible to implement CPP-IPR.

In order to estimate the desirable offers using a conventional approach, we need to identify an optimal offer from the set of consistent offers. Most customers' use patterns mean that criterion 5 defines a range of consistent offers between the smallest $\mathbf{q_R}$ that provides consistent rebates and the largest $\mathbf{Q_D}$ that the customer can buy each month. For the purposes of this analysis, I selected the consistent offer, $(\mathbf{q_R}^*, \mathbf{Q_D}^*)$, that satisfies criterion 5 in a way that is robust to the largest number of dollar deviations in total ability to buy rights, $12\underline{\mathsf{Q}_{\mathsf{m}}}$, and the needs for rights, $N_c\bar{\mathsf{q}}_{\mathsf{c}}(P_c - P_h)$.[51]

This analysis proceeded in three steps:

i. I constructed an optimal offer $\mathbf{q_{R,'04}}^{i*}$ for each customer. It specified the set of offers that would be consistent for that customer-year, typically the year October '03-September '04.[52]

ii. I ran the following OLS regression: $\mathbf{q_{R,'04}}^{i*} = \alpha + \beta_1 * useSummer02 + \beta_2 * ClimateZone + \beta_3 * apartment + \epsilon$ 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. Fog-belt zone 1 largely near San Francisco (the omitted category) is the coolest. The zones get progressively hotter and culminate in desert zone 4. Table 5 shows that regressing the optimal offer calculated from a 12 month period in 2003-04 $(\mathbf{q_R}^*, \mathbf{Q_D}^*)$ on total summer usage in 2002 explains 76% percent of the variation and that adding readily available variables about the climate and whether the account is at a single or multifamily building improves the fit to explain 78% percent of the variation.

iii. I used the results of that regression to predict a consistent offer, $\hat{\mathbf{q}}^{i*}_{\mathbf{R},'\mathbf{04}}$, for each customer and determined whether it was consistent in the sense of satisfying criterion 5 for the values of $(\underline{\mathsf{Q}_{\mathsf{m}}}, \bar{\mathsf{q}}_{\mathsf{c}})$ for that year. The full regression predicts consistent offers that satisfy criterion 5 for 80% of all customers for whom a consistent offer exists. When $\hat{\mathbf{q}}^{i*}_{\mathbf{R},'\mathbf{04}}$ was not a consistent offer, it was typically substantively fairly close to being a consistent offer. 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.

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[51] The 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,$\bar{\mathsf{q}}_{\mathsf{c}}$, and of the ability to purchase rights, $\underline{\mathsf{Q}_{\mathsf{m}}}$. 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.

[52] I 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. This would make the results harder to understand, especially because usage is heavily weather driven.

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

iv. I tested a model from one summer's ability to predict appropriate offers for another summers which real rate designers need to be able to do. 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. The 15-month experiment contained the important part of 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 $\hat{\mathbf{q}}^{i*}_{\mathbf{R},'04}$ calculated from the year containing Summer 2004 (namely October 2003-September 2004) was a consistent offer that satisfied criterion 5 using the customers' consumption patterns ($\underline{\mathsf{Q}_{\mathsf{m},03}}$, $\bar{\mathsf{q}}_{\mathsf{c},03}$) 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 ($\underline{\mathsf{Q}_{\mathsf{m},03}}$, $\bar{\mathsf{q}}_{\mathsf{c},03}$) that was different from ($\underline{\mathsf{Q}_{\mathsf{m},04}}$, $\bar{\mathsf{q}}_{\mathsf{c},04}$). This implies that either or both their their highest event use that set $\bar{\mathsf{q}}_{\mathsf{c}}$or their minimum consumption that set $\underline{\mathsf{Q}_{\mathsf{m}}}$had to occur between July and September.[53] The out of sample prediction of $\hat{\mathbf{q}}^{i*}_{\mathbf{R},'04}$ was a consistent offer that satisfied criterion 5 using ($\underline{\mathsf{Q}_{\mathsf{m},03}}$, $\bar{\mathsf{q}}_{\mathsf{c},03}$) for 82% of the out of sample universe.

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[53] The 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, $\bar{\mathsf{q}}_{\mathsf{c}}$, during the winter and thus get dropped from the out-of-sample analysis which used summer 2004 data to predict summer 2003 needs.

9 Implementation concerns

9.1 IP rebates are a rate feature, not a whole rate, and leave significant flexibility to rate designers

IP rebates are a revenue neutral feature that can be added to any CPP rate without affecting its marginal incentives. Implementing IP rebates as a flexible feature that coexists with a wide variety of rates preserves CPP rate designers' freedom to meet local needs and their ability to choose rates given limited information. Real CPP rates reflect compromises between pricing near marginal cost, meeting revenue requirements, maintaining simplicity, making incremental changes to the status quo, and treating rate payers equitably. CPP rate designers choose a small number of rate periods and prices for each. These parameters have reasonably transparent implications – unlike, for example, the choice of baseline-rebate parameters. Further, CPP rate designers generally set prices without knowing short term customer demand elasticities that Ramsey pricing would require. Ramsey pricing is most economically efficient approach to meeting a utility's revenue requirement by marking up the products it sells (in the case of CPP they would be offpeak, peak, and critical period power and perhaps connection the electricity system) in a way that minimizes deadweight loss (Hausker, 1986). The designers have to choose without knowing the marginal cost of power in each period. Market power and policies that control market power and prevent shortages make spot market electricity prices diverge from the marginal cost of power.

While IP rebates can be added to any underlying CPP rate, the number of customers who get consistent offers is sensitive to the size of the difference between offpeak and time-invariant prices because that difference is the upper bound on the markup, $\mathcal{M} \leq P_u - P_L$. Often the markup is a tenth of a cent less than the difference, $\mathcal{M} = P_u - P_L - .001$. Larger markups mean that each kWh that the declining block marks up provides more rights, $\mathbf{q_R}$. Thus, increasing the markup $\mathcal{M}$ expands the set of consistent offers by relaxing criterion 7 (a form of criterion 6) which should allow improvements in the percentage of customers' getting consistent offers.

9.2 There are good policy reasons to divide customers into coarse subsets

An IP rebate implementation can either make each customer a customized offer or categorize customers and make an offer to each category. The quantitative analysis below shows that making offers to broad categories of customers defined by use and geography can make consistent offers to a large percentage of customers. Making offers to categories of customers has compelling practical advantages over customizing offers because category-level offers are easy to understand, seem fair, and discourage distortion.

9.2.1 A small number of offers and clear rules are an advantage for analysts, regulators, utilities, and customers.

It is advantageous for a system to be easy for customers, utility staff, advocates, and regulators to understand.

- **Policy makers:** It is easier for regulators and advocates to understand, discuss, and tune a small menu of offers. It is easy to understand and adjust IP rebates' seasonal bill impacts if a large group of customers makes identical monthly contributions and then get identical credits during each event. Categorical offers allow conversations about the precise, category-wide impact rather than about average impacts. A rate will be easiest for regulators to work with if it makes offers to existing categories that the regulators are already familiar with and used to treating as a unit.

- **Customers:** If customers understand why they got their offer and that their neighbors got the same offer, they may be less likely to call their utilities with questions.

- **Customer service:** A simple system will make it easier to train call center staff, reduce the number of questions about offers that the call center receives, and make those questions quicker to answer. Broad categories may simplify the challenge of assigning hedges to new tenants or to new buildings and of explaining this initial decision to the customers.

9.2.2 Customers need to perceive the offers as fair

Every IP rebate offer gives a customer charges and credits that sum to zero over the course of the year, and it is difficult to consider differences in offers unfair while focusing on the zero annual effect bottom line. However, some customers will not know this and may see differences in rebate eligibility as unfair. CPP-IPR should be designed to work well even if some customers understand only that it is advantageous to reduce use of pricey weekday afternoon power and more advantageous to reduce power use during critical events to earn rebates. One step toward this goal is to maximize the number of customers who perceive the program as fair based on superficial knowledge of their own hedges and those of their neighbors and friends. Consumers' lack of knowledge about the program and whether their neighbors use electricity in a similar way makes it harder to maintain the perception of fairness.

There are at least three components of perceived fairness in rate offers: offer equity, process, and justice.

- **Offer equity** requires that (superficially) similar customers get similar rebate opportunities. Customers' electricity consumption patterns determine their need for rights. These patterns – and the equipment efficiency and habits that drive them – are often invisible to neighbors. Thus, assigning rights by consumption patterns may be objectively equitable, but appear inequitable to customers comparing bills over the back fence.[54] By contrast, assigning the same rights level to customers who live in similar buildings in the same geographic area may appear significantly fairer.

- **Process fairness** requires the use of transparent, objective category assignment rules. The policy should articulate simple criteria that explain why two customers received different levels of rights.

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[54] Multiple, mutually exclusive notions of fairness come into play on most policy issues. Stone (1997)[39-41] performs a thought experiment about how to equitably decide who can eat a cake and comes up with eight mutually exclusive notions of fairness.

- **Justice** requires the rebate program minimize real and perceived opportunities to profit through strategic efforts to exploit the program's rules.

9.2.3 Avoiding consumption distortions by confused customers

One of the central design features of incentive-preserving rebates is that they do not create incentives for rational, well-informed customers to distort their buying patterns to profit by getting more rebates. It takes considerable analysis to convert a rate schedule like table 2 and the fine print that would accompany it to uncover this incentive compatibility. A significant literature reports that lab subjects do not respond as intended to incentive compatible mechanisms in part because the incentive compatibility is often not obvious (See Chen (Forthcoming) for a review).

It is important to avoid using mechanisms that set offers in ways that systematically induce customers to believe wrongly that they can benefit by manipulating their demand to get more rights, $\mathbf{q_R}$, or reducing the number of marked up units, $\mathbf{Q_D}$. Using relatively immutable characteristics to set hedge levels can help achieve this goal. Utilities know which climate zone each account is in and whether it is an apartment. Customers can change these characteristics by moving, but even confused customers are unlikely to think that the misunderstood incentives justify the cost of moving unless they were already on the cusp of relocating. Using coarse total annual consumption bins to define categories may be compelling because they predict well and are readily accessible to utilities and because most customers have to engage in a prolonged, costly change in consumption to switch consumption bins.

There are strong practical reasons to assign each customer to one of a small number of categories and to make one offer per category. There is tension between using simple rules based on immutable characteristics to categorize customers in a way that seems fair and that minimizes distortion and the need to match customers with the right hedge-level. The balance of this section explores whether we can reach an adequate compromise between the goals of categorizing customers and of ensuring an adequate fit.

9.3 Making offers using existing categories worked well

Employing categories that rate designers already use would facilitate the implementation of CPP-IPR. This section tests the feasibility of that approach by calculating the optimal offers for each of the SPP's categories of customers. 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 ceiling on the low use category is 16 kWh per day in the coolest climate zones and rises with progressively hotter climate zones to 28 kWh per day in the hottest climates.

The analysis shows that the SPP's raw categories were not optimal because the customers in the low use and apartment categories in the hottest climate zones were too diverse for a single IP rebate offer to fit well. While the raw categories from the SPP performed poorly, a set of categories that preserved most of the SPP's distinctions and further subdivided customers at each category's median use level allowed us to make consistent offers to the vast majority of customers.

The modified set of 16 categories took the SPP's raw categories, discarded the distinction between apartments and single family homes, and categorized all customers using the SPP's high and low use categories.[55] The modified categories subdivided the SPP's high and low use categories at each category's median usage level. This yielded very low use, low use, high use, and very high use categories in each of the four climate zones for a total of 16 groups. It discarded the apartment category because the sample only contains about 500 customers. Retaining and subdividing the apartment category yielded unacceptably small cells. Further, apartment status explains far less variation than does total use.

Calculating the offer that is consistent for the greatest number of people in each group yields a set of offers listed in table 6 and visualized in figure 8. These are consistent for 86% of all customers statewide regardless of whether a feasible offer exists for that customer. This approach sometimes outperformed the regression approach in part because it used data on each customer's whole range of consistent offers rather than a single point representation of that range. This 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 the customers in zones 3 and 4 have no feasible consistent offers.

The algorithm to determine the optimal set of offers for each category proceeded as follows:

- It calculated the range of offers, $[\mathbf{q}_{\mathbf{R},\mathbf{i}}{}^{m}in, \mathbf{q}_{\mathbf{R},\mathbf{i}}{}^{m}ax]$, that satisfies feasibility criterion 5 for each customer, i. It ranges from the smallest offer that provides consistent rebates, $\mathbf{q}_{\mathbf{R},\mathbf{i}}{}^{m}in = \bar{\mathsf{q}}_{\mathsf{c}}$, to the largest offer that the customer can consistently buy, $\mathbf{q}_{\mathbf{R},\mathbf{i}}{}^{m}in = \frac{12\mathcal{M}\mathsf{Q}_{\mathsf{m}}}{N_c(P_c-P_h)}$.
- It used each customer's optimal range $[\mathbf{q}_{\mathbf{R},\mathbf{i}}{}^{m}in, \mathbf{q}_{\mathbf{R},\mathbf{i}}{}^{m}ax]$ to calculate the proportion of all customers in each group who would get a consistent offer for each value of $\mathbf{q}_{\mathbf{R}}$.[56]

  This yields an objective step function like that pictured in figure 7. Table 6 summarizes the 16 optimal offers and their performance in providing consistent offers, while figure 8 displays identical information about the optimal offers but not about their performance. The balance of this paper will use this 16-offer CPP-IPR rate as a benchmark in calculating the impacts of CPP-IPR.[57] The 16 analysis cells contain both apartment and single family customers. The analysis used weights to make each cell representative of the portion of the statewide population of accounts with its usage and climate zone characteristics.

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[55] The vast majority of apartments were low use.

[56] A future revision will use bootstrap resampling of the population to put confidence intervals on the optimal offer estimates and the estimates of the offer's performance.

[57] These results and the results below modify the example rate in table 2 by moving from the 15 events per year that the CPP promised to the 18 events that it in fact called during the 12 months from October '03 through September '04. It reallocates the fixed credits by offering 15/18 of the **R**value per event – reducing the critical price from 60 cents to 54 cents. This is a very small implicit CPP rate reduction

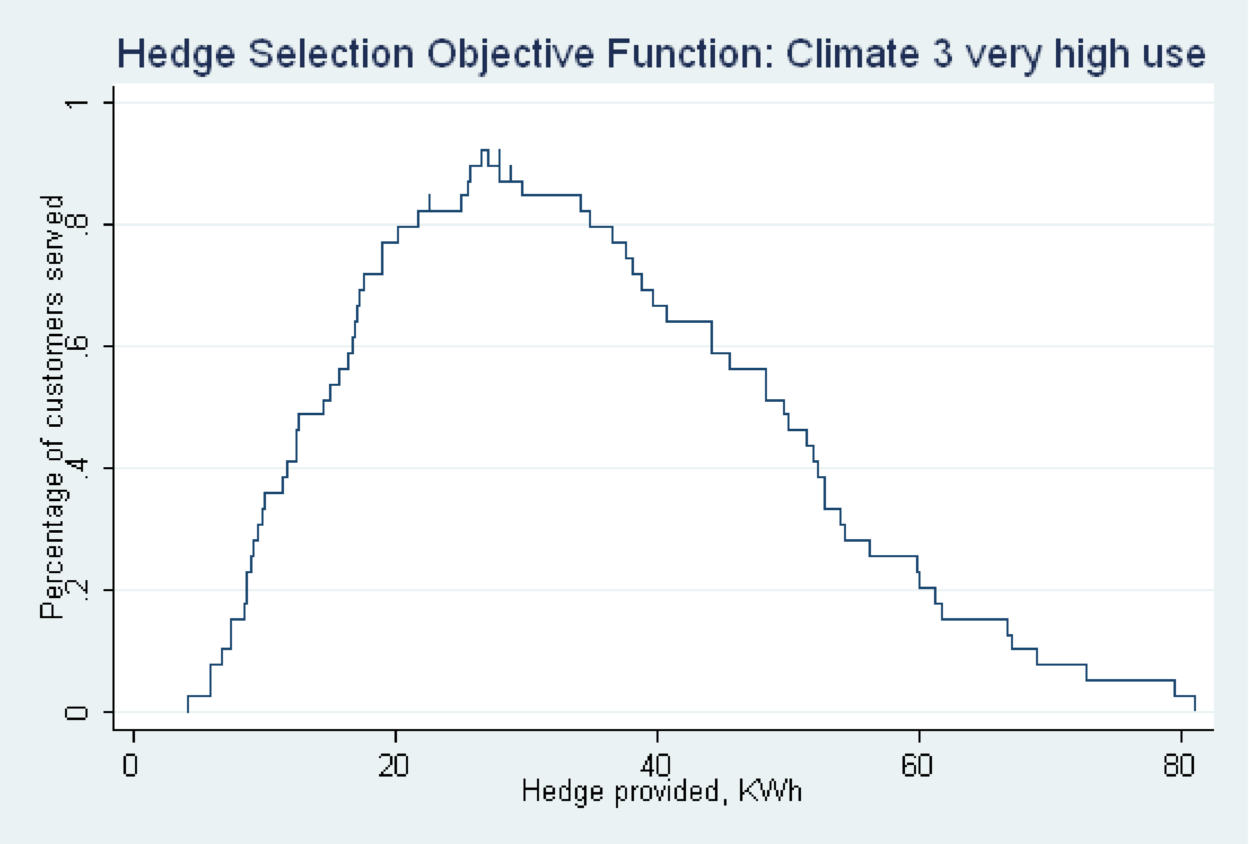

Figure 7: *The proportion of very high use customers in climate zone 3 for whom each possible offer is consistent.*

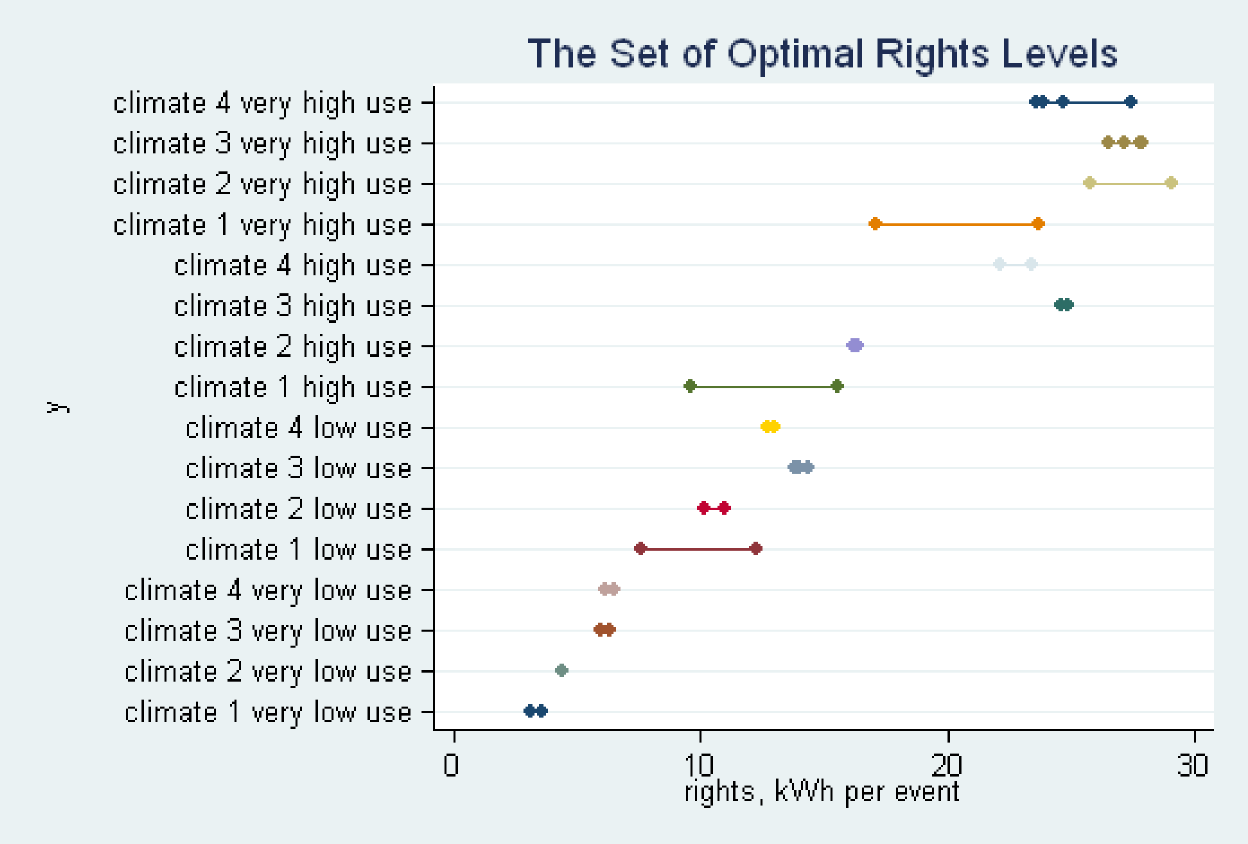

Figure 8: *Optimal Offers by Group: consistent offers for higher use customers and customers in hotter climates provide more rights.*

Table 6: Optimal group offers: the range of rights values that provides consistent offers to the greatest number of customers. This reports the percentage of customers for whom consistent offers exist who get them.

	proportion getting	optimal range:	
climate zone, use type	consistent offers	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

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.[58]

9.4 Offers that are not consistent are typically fairly close to being consistent

Offers that are not consistent are generally pretty 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. The weighted 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.

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[58] Specifically, 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}, {1L, 2L, 1H: 10.15 - 12.79 }, and {3VL, 4VL: 6.13-6.36}. The four other groups would get their own offers, as listed in 6.

- To put this 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 CPP-IPR 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.

9.5 Robustness of these offers to changes in weather, economic conditions, and customer characteristics

Good rights offers need to work not only for the summer and customer-base that they were designed for, but also for summers that have differing weather and economic conditions and for an unexpected subset of the customers. 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 turning on another major appliance like an oven or dryer, their offer is quite robust. And if the customer is either never home to activate the other major appliance or is paying enough attention to not do so during a critical event, then their offer also seems to be robust.

- 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 by averaging an extreme event with lower-use events over the course of a month.

- 47% of all customers would get consistent rebates even if they equaled 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 a declining block that marks up 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 hedge 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 their use marked up in their lowest use month and need 99.0% of their hedges to get consistent rebates. It's likely that some of the marginal customers in the SPP experiment who needed the greatest rights levels joined the experiment to contribute to knopwledge and earn $175 but were not responding to price signals and would not opt in CPP-IPR.

10 IP rebates smooth seasonal bill variations in regions where peak demand coincides with the system's peak demand

Consumers and policy makers both express a preference for bill levels that are consistent from month to month. Many utilities offer balanced payment plans that send customers bills of a constant size 11 months a year and then adjust for differences between the preset payments and the actual charges in the last billing period of the year. Further, some utilities have sold "flat bill" plans to a significant number of customers. These charge the customer a flat fee that reflects their expected bill plus a risk premium on the order of 10% regardless of the customer's usage.

IP rebates reduce CPP bills during critical periods and increase CPP bills during the first $\mathbf{Q_D}$ hours each month. This shift of bills among hours also drives a bill shift among months since the monthly contributions are spread evenly around the year, while most critical periods take place during the summer months. Thus, IP rebates reduce seasonal variations in bills 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 9 shows how these possibilities play out in California's most temperate and hottest climate zones. The top three lines on the graph show that CPP-IPR smooths the air-conditioning driven, summer bill peak in the desert (zone 4). CPP-IPR amplifies the modest bill peak in the zone 1's temperate climate, where electricity demand peaks during the winter in a summer peaking system.

The two intermediate zones have seasonal patterns between these two extremes. Bills in Central Valley, climate zone 3, peak during the summer. CPP-IPR dampens this peak, much as it does in climate zone 4. Climate zone 2 has the largest population of any of the four zones and includes much of the Los Angeles and San Diego areas, and some inland parts of the San Francisco area. It has modest summer and winter bill peaks that increase average bills from about $70 in the fall and spring to about $80 in the winter and summer under both CPP and under time invariant rates. The example CPP-IPR rate eliminates the summer peak, leaving the average customer with a modest winter peak.

Looking at customer-level bill volatility – as Borenstein (2006b) 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 statewide system does.

11 Conclusion

Efficient incentives can be an important part of improving public policies. But the obvious, natural implementations of efficient policies often repel customers who use flawed behavioral decision making heuristics.

The evidence from this project and from a line of behavioral field experiments suggests

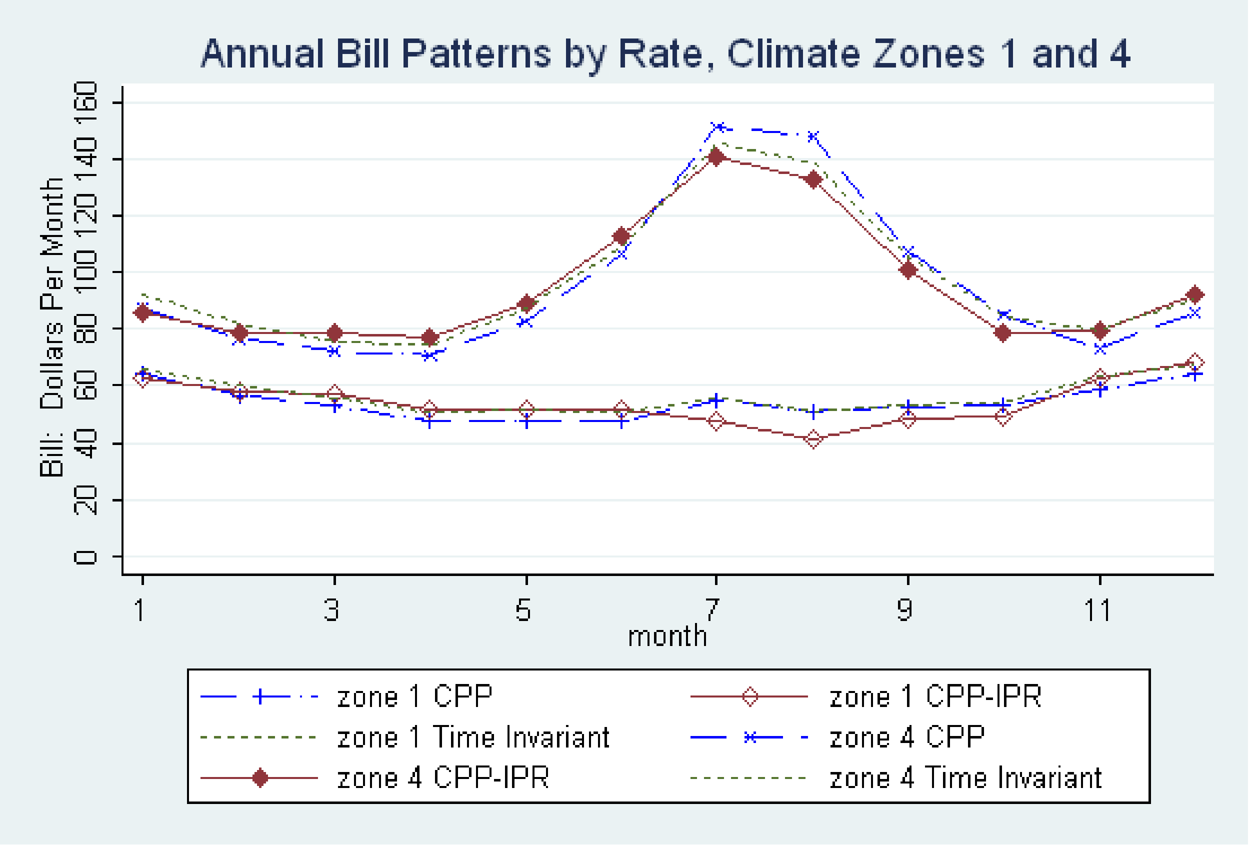

Figure 9: *IP rebate rates (diamond) smooth a high summer peak in the climate zone 4 (desert) at the top of this graph but exacerbate modestly winter peaking bills in climate zone 1 (the temperate fog belt; largely the San Francisco Bay Area) at the bottom of the graph.*

that behavioral insights can provide insights about the source of behavior that serves neither individuals nor society well and suggest levers for interventions that address this behavior. Using economics and psychology to guide the design of improved incentives can often yield implementations that preserve the important economic properties of a policy while helping some consumers make significantly better choices.

Incentive Preserving Rebates are an example of an intervention that preserves incentives and revenues while changing the presentation of incentives to address a significant set of psychological and implementation concerns. The behavioral considerations drive five constraints, while implementation challenges add requirements like using a small number of existing categories.

The evidence suggests that IP rebates are administratively feasible and that coarse, categorical offers can meet the needs of most customers. Most customers will fully fund rights that deliver them consistent rebates. Those who do not fully fund their rights or who do not get get consistent rebates experience deviations in the form of payments at the critical price or reductions in rights from the promised level that are typically less than 1% of their total annual bill.

IP rebates smooth bills and reduce volatility relative to conventional CPP. IP rebates are somewhat sensitive to customer diversity, but not nearly as sensitive as baseline rebate rates are.

Changing the framing of prices is a well recognized tool in marketing. This application to public policy may be the first of many important potential applications to help people make better choices in areas like the purchase of energy efficient appliances and vehicles or choices between owning a car and using public transportation.

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12 Appendix: Notation

- Characteristics that vary by customer – like quantity consumed, $\mathsf{Q_i}$ – appear in sans serif.
- Rate characteritics like P_L and miscellaneous entries appear in the *math* typeface. Rate characteristics reflect local system costs and this document generally takes them as given in designing an IP rebate system.
- Variables that IP rebate designers choose – most notably $\mathbf{Q_D}$, $\mathbf{R}$, and $\mathbf{q_R}$– appear in **bold**.

12.1 Formal Model Notation

object	source	notation
basic objects		
Price	exogenous	P
quantity per month	varies	$\mathsf{Q_i}$
quantity per critical or baseline-setting peak period	varies	$\mathsf{q_i}$
time periods – subscripts and sets		
months	exogenous	m
set of months	exogenous	M
critical peak events – e.g. use during an event	exogenous	c, set is C
baseline setting pd	exogenous	b, B
rate of interest	exogenous	r
	CPP	
counts		
number of critical events, per year	exogenous rate design	N_c
number of critical events, this month	exogenous rate design	N_m
number of days in baseline setting period	exogenous	N_b
rate period subscripts		
offpeak - low	exogenous rate design	L
peak - high	exogenous rate design	H
critical	exogenous rate design	c
time invariant, uniform	exogenous rate design	u

what?	source	notation
IPR features		
value of rights / credit	IPR	$\mathbf{R}$
number of kWh per event protected by rights / credit	IPR	$\mathbf{q_R}$
IPR rebate rate	IPR	$\mathcal{P}_R$
baseline-rebate rebate rate	baseline-rebate	$\mathcal{P}_B$
declining block markup	IPR/exogenous	$\mathcal{M}$
number of kWh marked up by the declining block	IPR	$\mathbf{Q_D}$
bills	Note that B abbreviates baseline, not bill.	
CPP Bill	implication	TC^{CPP}
CPP-IPR Bill	implication	$TC^{CPP-IPR}$
Customer Characteristics		
minimum monthly consumption / ability to buy a hedge, shorthand for $\min_{m\in M}\{Q_m\}$	customer level	$\underline{\mathsf{Q}_\mathsf{m}}$
maximum consumption during an event / hedge need, shorthand for $\max_{m\in M}\{\frac{\sum_{cinC_M} q_c}{N_m}\}$	customer level	$\bar{\mathsf{q}}_\mathsf{c}$
deficit / cumulative under-contribution	customer level	δ_m