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Dockets UE-190529/UG-190530 and
UE-190274/UG-190275 (*consolidated*)
Witness: Jason L. Ball

BEFORE THE WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, **Complainant,** **v.** **PUGET SOUND ENERGY,** **Respondent.**	**DOCKETS UE-190529 and UG-190530 *(consolidated)***
In the Matter of the Petition of **PUGET SOUND ENERGY** **For an Order Authorizing Deferral Accounting and Ratemaking Treatment for Short-life UT/Technology Investment**	**DOCKETS UE-190274 and UG-190275 (*consolidated*)**

EXHIBIT TO TESTIMONY OF

Jason L. Ball

STAFF OF
WASHINGTON UTILITIES AND
TRANSPORTATION COMMISSION

Time-varying and Dynamic Rate Design, RAP

November 22, 2019

Global Power Best Practice Series

4

Time-Varying and Dynamic Rate Design

RAP

Energy solutions
for a changing world

The Brattle Group

ECONOMIC AND FINANCIAL EXPERTS

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Time-Varying and Dynamic Rate Design

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Table of Contents

List of Tables

List of Figures

Acronyms

ACEEE	American Council for an Energy-Efficient Economy
AMI	Advanced Metering Infrastructure
Auto-DR	Automated Demand Response
BGE	Baltimore Gas and Electric
C&I	Commercial & Industrial
CAC	Central-Air Conditioning
CL&P	Connecticut Light and Power
CPP	Critical Peak Pricing
CPP-V	Critical Peak Pricing-Variable
CPR	Critical Peak Rebate
DSM	Demand Side Management
EdF	Electricite de France
EVN	Electricity Vietnam
GHG	Greenhouse Gas
HAN	Home Area Network
IHD	In-home Display
ISO	Independent System Operator
kVA	Kilo-volt Amps
M&V	Measurement and Verification
MW	Megawatt
PCT	Programmable Communicating Thermostats
PG&E	Pacific Gas & Electric
PTR	Peak Time Rebates
RCT	Randomized Control Trial
RTP	Real Time Pricing
T&D	Transmission and Distribution
TOU	Time-of-Use
TRC	Total Resource Cost Test
VPP	Variable Peak Pricing

Foreword

Together, this paper and its companion piece, *Rate Design Using Traditional Meters,* examine the wide spectrum of retail pricing practices for regulated energy services and identify those that have particular promise in contributing to the achievement of critical public policy objectives, which we might broadly categorize as equity, efficiency, and the sustainable use of our finite natural resources. The papers should prove an excellent resource for policymakers, power companies, advocates, and others as they navigate the arcana of utility pricing and engage on a topic that has, by virtue of advances in information technology and changes in the underlying economics of power production and delivery, become at once more complex, more controversial, and, too often, more distracting.

The complexity and controversy are not avoided in these papers. Though for the most part they express views that are consistent with those of the Regulatory Assistance Project, it is not true in all cases. This is a virtue. We embrace the dialectic: over the coming months and years we will continue to work on these issues, follow progress globally, and re-examine our views in the light of new findings. These papers are only our most recent look at the state of the art. There will be others.

Still, a few comments today are warranted. Regulators are constantly told to "get prices right," a refrain whose meaning is more easily understood in the speaker's mind than it is conveyed to those who must put it into practice. In our experience, the prescription must be taken with two doses of realty's practical learning: one, that getting prices "right" is by no means straightforward and, two, that, even if one manages to set prices that in some fashion might be called "right," some of the key objectives of pricing will nevertheless remain unmet. Foremost among them is overcoming society's very serious underinvestment in cost-effective energy efficiency and other clean energy resources, and it is primarily for this reason that we say that pricing reform must be dealt with in a much broader policy context.

But, first, what is "right"? The question has surely been debated since governments began pricing these services "affected with the public interest," but the form of the debate only began to take its modern shape in 1949 with the publication of Marcel Boiteux's "La Tarification des demandes en pointe," which gave renewed currency to certain prerequisites for economic efficiency: one, that those who cause a cost to be incurred should pay that cost and, two, that, by paying, the cost-causers will necessarily comprehend the real value of the resources that they are committing to their consumption.[1] Here was a practical application of neoclassical economic theory to the pricing of networked utility services, and it was very influential.

The seminal work in English on the topic followed in 1961: James Bonbright's *Principles of Public Utility Rates.*[2] In it, Bonbright identifies ten criteria to be considered when setting utility prices and acknowledges, importantly, that they cannot all be entirely satisfied simultaneously. There will always be trade-offs. Nine years later, Alfred Kahn published *The Economics of Regulation,* which, among other things, made the case for subjecting to competition certain regulated services, when those services no longer exhibit the characteristics of natural monopoly.[3] Thus, in two decades, the intellectual foundations for a range of reforms in utility regulation were set and, in the thirty years since, we've seen extraordinary changes in the provision and pricing of air travel, telecommunications, electricity, and natural gas—that is, in essential infrastructural industries—around the globe.

But, for all that, the question of how to get prices right remains. Bonbright can't be evaded. What constitutes economically efficient pricing? Should efficiency be the

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[1] Boiteux, 1949

[2] Bonbright, 1961

[3] Kahn, 1988 (Original work published 1970)

primary objective and, if so, how can it be ensured without a proper accounting of environmental damage costs and other unmonetized externalities, both positive and negative, that attend the production and consumption of electricity and gas? What are the benefits of participation in a network and do they justify approaches to pricing that will, in the eyes of some, offend Boiteaux's injunctions? What is equitable? How does the underlying market structure—monopolistic, regulated, or competitive—affect pricing? Are prices in competitive markets "better" than their administrative analogues? How does pricing influence consumer behavior, and how does that behavior influence utility incentives to invest? How will utility revenues be affected by different pricing structures or, more to the point, how will utility profitability be affected? How complex is the pricing structure? Can it be easily understood by consumers and easily administered by the utility? In short, how are the competing objectives balanced? What kinds of pricing will achieve preferred outcomes?

These are complicated questions all. Their answers deserve careful analysis and even more careful judgment. Dogmatism is unhelpful: the tools of economics, powerful and important, are nonetheless limited. It isn't enough to say "Let the market decide." On the contrary, in certain instances, it's irresponsible. Design matters. Markets may deliver what they're intended to deliver, though not always in ways expected, but rarely do they deliver that which is desired but unvalued. And it's very difficult to fix them after the fact. For proof of this, one need look no further than the United Kingdom, which is facing the unpleasant prospect that its electric markets are unlikely to produce the amounts and kinds of resources that it needs to meet its own climate protection goals. Or New England, whose forward capacity market was the first to permit end-use energy efficiency and other demand response resources to participate in the provision of reliability services, but which worries now that the market fails to properly compensate the providers of those services. Such shortcomings counsel us to move cautiously before trying to drive behavior by the passing-through to retail customers of market prices, if we cannot be confident that the consequences they bear will best serve the public good.[4]

As a general matter, encouraging customers to manage their consumption in response to price signals, so that the efficiency and value of their usage increases, is a good thing. Retail prices should relate to the underlying costs of production—all costs, including those we can't easily calculate. This is the economist's argument—at once academic and practical, for the most part uncontentious, and always invoked. Its implications, however, can overwhelm. If we find that our approach to energy production and use is impossibly sustainable, then it is no longer possible for policymakers to accept the exalted principle *and then promptly ignore it.*

But let's imagine that prices do cover all costs. There are still the practical aspects of pricing to be dealt with. How are those costs best represented in prices? George Bernard Shaw's famous snort —"If all the economists were laid end to end, they'd never reach a conclusion"—is not more aptly demonstrated than by the mavens of regulation who debate this point ad nauseum, and often at a pitch that belies the significance of the effects that their favored alternatives will likely produce. What is the thing sold? How should its prices be denominated? What should be the price's level and periodicity? Should it vary temporally and, if so, at what intervals? Should it pass through, from moment to moment, actual wholesale commodity prices or are there less volatile means of reflecting time- (and, in certain cases, location-) dependent costs? How should the costs of poles and wires be recovered? Should costs that appear fixed in the short term be collected in unvarying and unavoidable fees, unrelated to usage? Should price levels be determined with an eye to elasticities of demand?

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[4] Another example will demonstrate that this is not an abstract concern. Consider that under most market structures firms are rewarded for increasing the utilization of their existing capacity. In the power sector, this means that profitability will increase as system load factors (the ratio of total consumption to maximum potential consumption, given actual peak demand) increase. As a practical matter, this is achieved through the shifting of on-peak demand to off-peak hours, when marginal costs are lower. Total system costs will be lower as well; everyone is better off. But what if on-peak demand is served by low- or non-emitting resources and off-peak demand is served by highly polluting ones? This is precisely the conundrum faced at times in places where on-peak usage may be met at the margin by natural gas and hydro-electric production, while off-peak usage variations are often served by ramping the output of coal-burning plants up and down.

There are other considerations. Some of the more innovative and beguiling price structures being proposed require significant investment in new technology and data telemetry. Establishing that there are positive net benefits from these investments is by no means straightforward, especially when the full effects on behavior of the pricing structures they enable are imperfectly appreciated. And what about the customers who, for whatever reason, cannot react to the signals they are given and thus are harmed? That harm might be appropriate as a general matter (if we are true to the "the cost-causer pays" theme) and the overall public good may outweigh the losses of the relative few, but there are some customers for whom a change in the status quo can have altogether deleterious effects, whose private pain will be, along other dimensions of welfare, disproportionate to the good achieved. What sickness then is this medicine healing?

We recognize that more dynamic, time-varying pricing enabled by smart grid investment holds much promise. But, as we see it today, its value lies not so much in the responsiveness of customers to such pricing (although there is certainly value there) as in the new and expansive opportunities that it offers system operators to design and run the system that we must have, if we are to succeed in the great task remaining before us. That new system will be one in which the variability of supply, variable because the resources that drive it—sun, wind, water—do not submit easily to human timetables, will be matched by variable load, variable not so much because a million individual demanders respond to changes in price but because the exercise of their discretion will have been placed (to be sure, voluntarily) into the hands of system operators and other market actors. A decarbonized power sector will not come about merely because customers respond to price fluctuations. There are too many other influences on behavior that confound "rational" economic thinking on the parts of users. Moreover, as the dynamic pricing pilots around the United States and elsewhere are consistently demonstrating, retail responsiveness to price rarely manifests itself as overall reductions in energy use, but almost entirely in the shifting of use in time—that is, it mostly affects demand for capacity, not demand for energy. Yet, far and away, the problem—the environmental problem—is energy.

Much can be done with current technologies. The United States, for example, has had decades of experience with inclining block, seasonally-differentiated, and simple time-of-use pricing structures. They've sent meaningful, albeit rough, signals about the varying costs of production across time, and have led to significant long-term changes in consumption habits. In 2005, China adopted a policy of "differential pricing," whereby industrial users pay prices that are linked to the efficiency of their manufacturing: the less efficient the process, the higher the unit price for electricity. Five years later, China mandated that residential inclining block pricing be implemented throughout the country, and has instructed provincial regulators to design the blocks so as to best address the particular consumption characteristics of their populations. One size does not fit all.

There is much yet to learn. A number of pilots have been conducted and more will follow. Pricing will evolve over the coming years. The movement toward new forms must be deliberate and considered, calculated to yield the greatest long-term benefit for all. This will be especially challenging in a system that does not allow all the costs of production to be reflected in price and in which the consequences of this failure are not immediately felt. But even this ideal, were it achievable, would not be enough to effect the hoped-for ends. Economics is too uncomplicated a construct to provide sure solutions for so complicated a problem. Anyway, there are at our disposal less expensive means to drive investment and encourage new-shaped behavior. For these reasons and others besides, pricing must remain within the province of thoughtful public policy. Our intent with these papers is to expose to the reader the many and varied approaches to energy pricing that practice and technology afford us, and to sound too a gentle note of caution. All that glitters, as the old saw goes, isn't gold.

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Executive Summary

This report, written largely for regulators and policymakers around the globe, discusses important issues in the design and deployment of time-varying rates. The term, time-varying rates, is used in this report as encompassing traditional time-of-use rates (such as time-of-day rates and seasonal rates) as well as newer dynamic pricing rates (such as critical peak pricing and real time pricing). The discussion is primarily focused on residential customers and small commercial customers who are collectively referred to as the mass market. The report also summarizes international experience with time-varying rate offerings.

The rate design principles presented in this report are based on the authors' first-hand experience in designing and evaluating innovative rate designs over the past three decades, conversations with other experts in the field, and the rate design and pricing literature. While the report is focused on design principles, there is much leeway in the application of the principles. Much of the success of the deployment of time-varying pricing will depend on the attitudes and preferences of the customers in the target market and the effectiveness of activities supporting the deployment by utilities, regulators, and other stakeholders. While there are many potential benefits to time-varying rate deployment, there are also risks and costs that must be addressed through careful thinking and planning. Even though experimentation and full-scale deployment in several parts of the globe have yielded valuable insights that can help mitigate risks, there remains room for additional research to further improve our understanding and facilitate the development of effective solutions to these concerns.

The key findings of the report are summarized below.

Metering technology is rapidly changing, creating the opportunity to provide time-varying rates for the mass market. Smart meters are being deployed increasingly around the globe. Roughly 64 million smart meters are currently in place and 825 million are expected to be installed over the coming decade.[5] Among many potential benefits of this new technology is the ability to provide innovative pricing schemes to retail electricity customers. While traditional electromechanical meters are read manually and on an infrequent basis, smart meters record and digitally communicate electricity consumption data on frequent intervals (e.g., 15 minutes or hourly), thereby allowing for the provision of time-varying rates.

Time-varying rate options present varying risk-reward tradeoffs to consumers. Time-varying rates include time-of-use (TOU) rates, critical peak pricing (CPP), peak time rebates (PTR), and real time pricing (RTP), as well as variations and combinations of these rate designs. Each design provides a different degree of price volatility and uncertainty for customers, and therefore presents a different opportunity to reduce their electricity bill by shifting load from higher-priced hours to lower-priced hours.

There are many potential benefits of time-varying rates. Time-varying rates have played an important role in justifying investment in smart metering. Among the *potential* benefits are avoided or deferred resource costs (including generation capacity and, to a lesser extent, transmission and distribution capacity), reduced wholesale market prices, improved fairness in retail pricing (i.e., providing a better match between the costs that customers impose on the system and the amount they are billed), customer bill reductions, facilitating the deployment of both distributed resources (such as solar electric systems) and end-use technologies (such as plug-in electric vehicles), and environmental benefits (through possible emissions reductions).

Time-varying rates also impose costs on customers. From the customer perspective, there are two main costs associated with time-varying rates. The first is the

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[5] Based on data provided by eMeter.

incremental monthly metering cost that customers would be required to pay. This is often the cost of smart metering net of operational benefits (e.g., avoided meter reading costs). The second cost is the loss of economic welfare associated with reducing usage during a high-cost period (curtailment) or shifting usage to a lower cost period ("hassle factor").[6]

A number of key parameters need to be defined when designing a time-varying rate. How many different pricing periods will be offered? What will be the price level in each of those periods? When will the periods occur? How and when will customers be notified of an upcoming dynamic pricing event? Will the time-varying rate be offered in combination with any other rate structure, such as inclining block (also called tiered or inverted block) rates that charge customers more per unit (kilowatt-hour) for higher levels of usage? While practices in time-varying rate design are still evolving – particularly for the mass market – some general criteria for effective rate design can be established based on theory, intuition and field experience.

Well-designed pilots are critical to proving the benefits of time-varying rates. Before deploying time-varying rates at scale, conducting pilots with a limited number of customers will help to understand what works and what does not. Prudent pilot design involves several key steps, including choosing the right type of pilot, defining the specific rates to be tested, establishing two comparable groups of customers (one enrolled in the new rates and the other serving as a "baseline" for comparison purposes), and identifying the most effective ways to recruit participants into the pilot.

We have learned a lot about time-varying rates through recent pilots. For example, weather, end-use saturation, price level, sociodemographic characteristics, and other factors all affect the degree to which customers shift load in response to time-varying rates. Load shifting increases as the strength of the price signal increases, but at a decreasing rate. Low-income customers have been found to be price responsive, although not always as responsive as the average residential customer. Impacts of time-varying rates have persisted for several years and over consecutive pricing events. And enabling technologies, such as smart thermostats, have been shown to incrementally boost price response.

New research will further inform our understanding. There are still important questions about time-varying rates that remain partially or entirely unanswered. What are customer preferences for the various rate options? Do rebates for curtailment produce the same level of price response as higher prices during peak hours (and lower prices during other hours)? Do time-varying rates lead to energy conservation? Do time-varying prices lead to fuel switching and the use of distributed generation? What is the impact of enhanced energy information on peak consumption? New research will help to answer questions such as these.

There are options for facilitating the transition to time-varying rates. Changing the way electricity has been priced for decades will not be easy. However, several tools exist to assist with the transition to time-varying rates. For example, an intensive, research-based marketing and education effort will help customers to understand the benefits and opportunities of time-varying rates. Temporary bill protection would help customers to learn about the rate first-hand, without being exposed to the risk of higher bills. Improved information about their electricity consumption patterns could provide customers with actionable ways to shift load and lower their bills. And rate designs such as two-part pricing would provide customers with the flexibility to manage the level of price volatility to which they are exposed.

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[6] Note that this loss of welfare should be treated similarly across all demand-side programs that may produce such an effect, and not just limited to time-varying rates.

1. Introduction

For the vast majority of electricity consumers, metering technology has remained effectively unchanged over the past 100 years. With the exception of the largest commercial and industrial facilities, most consumers are equipped with simple electromechanical meters which must be read manually. Due to the high cost of this manual approach to meter reading, meters are typically read no more frequently than once per month. This has acted as a constraint on the types of rates that an electricity provider can offer. "Flat" or "fixed" rates[7] are essentially the only option available, along with some possible alternate variations (such as the ability to increase the price as consumption increases over the course of the billing period). The lack of granularity in electricity consumption data has prevented all but a limited set of time-varying rates from being provided to all but the largest customers. However, the "digital revolution" of the past few decades has produced a new, increasingly cost-effective form of metering that is beginning to change this picture entirely.

Today, smart meters are being deployed increasingly around the globe. Roughly 64 million smart meters are currently in place and 825 million are expected to be installed over the coming decade.[8] Among many potential benefits offered by this new technology is the ability to provide innovative pricing schemes to retail electricity customers that help to foster more responsive customer demand. While traditional electromechanical meters are read manually and on an infrequent basis, smart meters record and digitally communicate electricity consumption data on frequent intervals (e.g., 15 minutes or hourly), thereby allowing for the provision of rates that vary by time of day. These new rates that are enabled by smart meters are referred to collectively in this report as "time-varying rates."

The benefits of time-varying rates have played a pivotal role in justifying investment in smart metering technology. While some smart metering investments can be justified purely on the basis of operational savings (e.g., avoided meter reading costs), many utilities have required the additional benefits of time-varying rates - such as avoided resource costs - to show that the investment would produce a net benefit to consumers. Achieving these benefits, however, requires careful planning, intelligent rate design, and a thorough understanding of the important issues that are emerging as smart meters and time-varying rates are beginning to be deployed internationally.

The purpose of this report is to provide regulators and policymakers around the globe with a resource that highlights important issues in time-varying rate design and deployment. The report also summarizes recent implementation experience with international time-varying rate offerings.

Why offer time-varying rates?

Time-varying rates represent an opportunity to improve over traditional "flat" rates that do not vary by time of day, by providing societal and consumer benefits. Potential benefits of time-varying rates include:

- **Avoided or deferred resource costs:** With prices that are higher during peak hours and lower during off-peak hours, time-varying rates encourage customers to shift consumption away from peak hours and therefore reduce system peak demand. This avoids the need to invest in expensive new peaking plants that are built to maintain a reserve margin but otherwise operate during very few hours of the year. Peak demand reductions can also lead to deferred transmission and distribution (T&D) costs that are peak-driven.[9]

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[7] A "flat" rate design refers to one with a uniform price per kilowatt-hour for all consumption regardless of when the consumption occurs.

[8] Based on data provided by eMeter.

[9] Faruqui, Hledik, Newell, & Pfeifenberger, 2007

- **Reduced wholesale market prices:** A reduction in demand during high-priced hours could reduce wholesale market prices in those hours - a benefit to all market participants.[10]

- **Fairness in retail pricing:** One notion of fairness is that cost-causers should bear their proportionate burden of costs on the system. If the underlying cost of providing electricity varies over time, then time-varying rates provide a better match between costs and bills. Under a flat rate structure, customers who consume more electricity during high-cost hours (i.e., peak hours) effectively rely on customers who consume less during those hours to ensure that all costs are recovered in rates. During time periods when costs are high, traditional flat rate structures result in an effective customer cross-subsidy relative to a well-formed time-varying rate alternative (i.e., the additional costs imposed by one group of customers are borne by other customers.)

- **Customer bill reductions:** In the short run, time-varying rates offer participants an opportunity to reduce their electricity bills by shifting consumption to hours that are priced lower than their otherwise applicable flat rate. In the long run, time-varying rates should improve the system load factor and lead to a lower revenue requirement, compared to what it would be without the demand response from time-varying rates.

- **Facilitating deployment of distributed resources:** Time-varying rates improve the economic attractiveness of certain types of distributed resources such as rooftop solar and energy storage, which allow owners to avoid consuming electricity during higher priced peak hours. Time-varying rates may also be a way to encourage more efficient charging of electric vehicles.[11]

- **Environmental benefits:** If time-varying rates reduce consumption or shift it to hours when power plants with lower emissions rates are on the margin, they can result in a net environmental benefit. This will depend on the specific characteristics of the system in which the time-varying rates are being offered.[12] To the extent that time-varying rates play a role in facilitating the integration of renewable resources, there would be associated environmental benefits as well.

Time-varying rates are not a new concept. In fact, this approach to pricing is already utilized in many other industries. Airlines, hotels, and car rental companies are some of the most common examples of industries that dynamically vary prices in response to fluctuations in demand. Commuter trains and subways often vary the price by time of day (e.g., Washington, D.C.'s Metro, which has three tiers of pricing). Some bridge and road tolls vary by time of day, such as the Bay Bridge in San Francisco and congestion charging on major roads in parts of London. Parking meters typically apply a charge only during times of high demand (generally during business hours), and in some emerging pilots the price of a parking meter is a function of the number of meters in the network that are being used. Sports teams are beginning to vary the price of tickets depending on the quality of the opponent, time of game, and other factors. In other words, the concept of time-varying rates is something that many electric utility customers already experience on a near-daily basis.

The scope of this report

While there are many potential benefits of time-varying rates, there are also significant challenges to be addressed in their implementation. For example, what are the most effective rate designs? How should the rates be developed? How should they be deployed to encourage customer adoption? These and many other issues must be addressed through careful planning before deployment. To provide guidance based on industry observation and experience, this report addresses several key topics and is organized as follows:

Section 2 provides a description and assessment of the advantages and disadvantages of the various time-varying rate options.

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[10] The Brattle Group, 2007

[11] Faruqui, Hledik, Levy, & Madian, 2011

[12] See sidebar for further discussion of potential environmental benefits.

Section 3 includes a discussion of criteria for time-varying rate design, pricing pilot design, and methods for addressing barriers to time-varying rate deployment.

Section 4 provides an overview of international experience with time-varying rate implementation, including a survey of time-varying rate pilots and lessons learned from these studies.

Section 5 includes full-deployment case studies for the United States, France, China, and Vietnam.

Section 6 presents a blueprint for full-scale time-varying rate deployment.

Section 7 concludes with a synthesis of the key points in the preceding sections, as well as insights for future research needs.

This report does not focus on rate designs that could be offered in the absence of an upgrade from a traditional electromechanical meter. For example, the report does not include inclining block rates, which are commonly used as an alternative to a flat rate to promote conservation and do not require a smart meter. Seasonal rates, which vary by time of year but not by time of day, are another example of rates that do not require advanced metering. Principles for designing and offering these types of rates are the focus of another paper titled Rate Design Using Traditional Meters. We do, however, discuss issues related to integrating these rates with time-varying rates.

The report includes static time-of-use (TOU) rates as well as dynamic rates, which both require an upgrade from a traditional, one-period electromechanical meter. TOU rates are different than dynamic rates because they are not "dispatchable," instead adhering to a schedule established in the retail tariff. With true dynamic pricing, on the other hand, the timing, price levels, or both are only made available to the customer on a day-ahead or day-of basis. While this distinction is important, both forms of time-varying rates are included in this report.

The scope of the report includes time-varying rates for all customer classes. We have a particular focus on time-varying rate issues for the residential class, which has only recently begun to receive the metering technology necessary to offer time-varying rates. As a result, many of the emerging issues and new research on time-varying rates are centered on the customers in this segment.

The Environmental Impact Of Time-Varying Rates

With growing concern over the sustainability of worldwide electricity consumption, there is interest among some policymakers about the potential environmental benefits of time-varying rates. Generally, the conservation impact of time-varying rates on the environment is expected to be small. This is mostly because high prices that would induce significant changes in a customer's electricity consumption are encountered during relatively few hours per year. For example, a critical peak pricing (CPP) design exposes customers to a higher price during only 50 to 100 hours of the year, and customers receive a discounted rate during other hours. Further, recent studies have found that while time-varying rates induce significant reductions in electricity demand during peak periods, much of that reduction is offset by increases in consumption during periods when the price is discounted. The result is little or no conservation effect from time-varying rates alone.[13]

Still, there may be environmental benefits from time-varying rates. Even in the absence of a net reduction in consumption, load shifting could result in a net emissions reduction, depending on the characteristics of the applicable generating resource mix.[14] Further, time-varying rates may encourage greater adoption and facilitate the integration of variable renewable energy resources. Basic categories of environmental impacts from time-varying rates are discussed below.[15]

Change in greenhouse gas (GHG) emissions: Whether there is a net reduction in GHG emissions from time-varying rates depends on the emissions rate of the marginal unit during peak and off-peak hours. For example, if load were shifted from hours when an inefficient oil- or natural gas-fired peaker was on the margin to hours when a more efficient gas-fired combined cycle unit was on the margin, one could expect a net decrease in GHG emissions. However, in a different service territory, there might be a gas-fired peaker on the margin during peak hours and a coal plant on the margin during off-peak hours. In this situation, an increase in GHG emissions could arise. One study of different regions in the U.S. found that the impact could range from a decrease of 0.9 percent to an increase of 0.3 percent.[16]

Change in criteria and hazardous air pollutants: Peak period load reductions from time-varying rates could also reduce other types of generator emissions such as criteria and hazardous air pollutants. In the U.S., these reductions would be particularly valuable in designated non-attainment areas where predetermined emissions levels cannot be exceeded.

Minimization of impact to wildlife and sensitive ecosystems: To the extent that peak demand reductions result in avoided investment in new generation capacity or T&D capacity, the result would be a smaller geographical footprint of the grid. This would reduce the impact to wildlife, habitat, and sensitive ecosystems.

Facilitating adoption of renewable resources: Time-varying rates could facilitate the adoption of renewable sources of energy. For example, a strong TOU rate could improve the economics of a rooftop solar system to the extent that the peak period aligns with the time of highest output from the system. Additionally, to the extent that time-varying rates result in more flexible demand, particularly through the adoption of technologies that automate load changes in response to prices, this could be valuable for integrating variable renewable energy resources.[17] However, the integration benefit still remains to be proven on a large scale.

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[13] This is the finding of recent time-varying rate pilots in California, Maryland, and Connecticut. However, a survey of much older TOU pilots did find that, on average, the rate design induced some conservation. See King, & Delurey, 2005.

[14] Some market operators publish information on the emission rate of marginal generating units, which would allow for this analysis to be conducted. For example, PJM (in the eastern United States) publishes this information on a monthly basis for peak and off-peak periods: http://www.pjm.com/documents/~/media/documents/reports/co2-emissions-report.ashx.

[15] For details, see Environmental Defense Fund, 2009

[16] Hledik, 2009. Also see Pratt, et al., 2010

[17] Cappers, Mills, Goldman, Wiser, Eto, 2011

2. The Rate Options

A time-varying rate can be designed in a number of ways, depending on one's ratemaking objectives and the sophistication of the target market. The specific dimensions across which a time-varying rate design can vary are summarized in Table 1.

The most common categories of time-varying rates are TOU, CPP, Peak Time Rebates (PTR), and Real Time Pricing (RTP). Each of these rate types is described below, along with a discussion of the general advantages and disadvantages of each.[18]

Table 1

The Dimensions of Time-Varying Rate Design

Dimension	Description
Number of pricing periods	The price may change anywhere from once per day to once every hour (or even more frequently).
Timing of pricing periods	The applicable hours of each pricing period are typically designed to coincide with load and price patterns of the service territory.
Price level	Time-varying rates are almost always cost-based and revenue neutral, but within these constraints there is some flexibility in establishing the price level for each pricing period, depending on how costs are determined.
Notification	The time that elapses between when customers are informed of upcoming prices and the applicability of those prices (often on a day-ahead basis with many dynamic pricing deployments, but ranging anywhere from near-instantaneous notification to fixed TOU prices that could remain unchanged for a multiyear period between rate cases).
Incentive	Time-varying rates can include incentive schemes involving high prices for high-cost hours and low prices for low-cost hours or, alternatively, rebate payments for targeted load reductions.[19]
Combination	Time-varying rates can be combined with other rates (e.g., layered on top of an inclining block rate or flat rate).

A. Time-Of-Use

A static TOU rate divides the day into time periods and provides a schedule of rates for each period. For example, a peak period might be defined as the period from 2 pm to 6 pm on weekdays and Saturdays, with the remaining hours being off-peak. The price would be higher during the peak period and lower during the off-peak, mirroring the average variation in the cost of supply. In some cases, TOU rates may have a shoulder (or mid-peak) period, or even two peak periods (such as a morning peak from 8 am to 10 am, and an afternoon peak from 2 pm to 6 pm). Additionally, the prices might vary by season. With a TOU rate, there is certainty as to what the rates will be and when they will occur.

A variation on the traditional TOU rate that has been explored by some utilities is a "super peak TOU rate." This design includes a very short super peak period (typically only

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[18] For additional discussion of the advantages and disadvantages of each approach, see Borenstein, Jaske, and Rosenfeld, 2002.

[19] Some strict definitions of time-varying rates do not include rebate payments, but they are included under this paper's broad definition of time-varying rates as something that could not be offered in the absence of a technological upgrade.

a couple of hours) with a much higher price than the other periods, and only applying to a few months of the year. It may be an attractive option in hot, dry climates with a needle peak that is contained to relatively few hours of the day in the summer.

Advantages: TOU rates encourage permanent load shifting away from peak hours. They have a simple design that is predictable and easy for customers to understand (e.g., it is analogous to the pricing of cell phone minutes). TOU rates also could be used to encourage adoption of plug-in electric vehicles, solar photovoltaic systems, and distributed energy storage technologies by providing lower rates during the optimal time of charging (off-peak) and higher rates during the time of discharge or selling back to the grid. In fact, many utilities are offering specific TOU rates for electric vehicle owners. It should also be noted that offering TOU rates does not necessarily require deployment of advanced metering infrastructure (AMI), although it does require that electromechanical meters be able to record consumption during multiple time periods.

Disadvantages: TOU rates are not dynamic in that they are not dispatched based on the changes in actual wholesale market prices or in reliability-related conditions. They are therefore less useful for addressing specific events on the grid and integrating variable renewable energy resources. TOU rates don't provide as large a peak load reduction as dynamic rate designs due to the price signal being averaged over a large number of peak hours instead of a relatively limited number of very high-priced hours.

B. Critical Peak Pricing

Under a CPP rate, participating customers pay higher prices during the few days when wholesale prices are the highest or when the power grid is severely stressed (i.e., typically up to 15 days per year during the season(s) of the system peak. This higher peak price reflects both energy and capacity costs and, as a result of the capacity portion of those costs being spread over relatively few hours of the year, can be in excess of $1 per kWh. In return, the participants receive a discount on the standard tariff price during the other hours of the season or year to keep the utility's total annual revenue constant. Customers are typically notified of an upcoming "critical peak event" one day in advance.

Two variations on the CPP rate are CPP-variable (CPP-V) and variable peak pricing (VPP). CPP-V is similar to the CPP rate, with the exception that the window of critical peak hours is not fixed. The specific hours of the event are provided to participants at the same time that they are notified of the upcoming critical event (on a day-ahead basis). This provides utilities and independent system operators (ISO) with the flexibility to respond to emergencies and high-priced periods of varying lengths occurring at different times of the day. It is also possible to vary the critical peak price, rather than locking it in at a pre-specified level. CPP rates with this characteristic are called VPP rates.[20] Due to the uncertainty in timing and price level, both VPP and CPP-V can present a challenge in ensuring that the rate will recover the revenue requirement.

Advantages: Like the TOU rate, the CPP rate is simple for customers to understand. It provides a strong price signal and has produced some of the highest observed peak reductions among participants. In addition, it exposes customers to higher prices during only a very limited number of hours.

Disadvantages: Political acceptance of the rate is sometimes limited due to the relatively high critical peak price. Furthermore, some customers consider the CPP rate to be more intrusive than a TOU rate because customers are contacted each time a critical event is called.[21] Some utilities have expressed concern that they will under-collect revenue relative to their authorized revenue requirement by pushing a larger share of their fixed costs into a higher price that occurs during relatively few hours of the year.[22]

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[20] A further variation of VPP rates combines traditional TOU rates with RTP rates. The on- and off-peak periods are fixed, as is the off-peak price. The on-peak price varies each day, based on day-ahead market prices. See http://www.smartgrid.gov/sites/default/files/pdfs/cbs_guidance_doc_4_rate_design.pdf.

[21] This concern can partly be addressed by allowing customers to designate how they would like to be contacted (e.g., phone, pager, email, text, or other options). The use of enabling technologies, which automate the customer's load reductions during critical peak events, can also help to alleviate this concern.

[22] Decoupling utility revenues from sales is one way to address this concern. Another way to avoid under-collection of revenue is to call all critical peak price events for which the approved tariff rates are designed.

C. Peak Time Rebate

If a CPP tariff cannot be rolled out because of political or regulatory constraints, some parties have suggested the deployment of a peak time rebate (PTR, which is also known as critical peak rebate or CPR). Instead of charging a higher rate during critical events, participants are paid for load reductions (estimated relative to a forecast of what the customer otherwise would have consumed). If customers do not wish to participate, they simply pay the existing rate. There is no rate discount during non-event hours. The PTR has mostly been offered through pilots, with opt-out deployments approved for residential customers in Maryland, Washington, D.C., and California.[23]

Advantages: While all forms of time-varying rates are designed to provide customers with the opportunity to save on their electric bill, the PTR provides a level of bill protection that is not embedded in these other rates. Because it provides a rebate during critical events but does not increase the rate during other hours, a customer's bill can only decrease under the PTR in the short run. As a result, the PTR rate is often more acceptable to regulators and policymakers. The concept is also generally easy for customers to understand. It provides a significant incentive to reduce peak demand, similar to the CPP.[24]

Disadvantages: PTR requires the calculation of each customer's baseline usage, which is necessary for determining individual rebate payments. This process is inherently inaccurate. In some instances, it can lead to payments to customers who did not actively change their electricity consumption. One study estimated that as much as 40 percent of a utility's total rebate payment would be simply due to the inaccuracies associated with estimating individual customer baselines.[25] In other cases, it may result in underpayment to customers who made significant changes. While in the short-run a PTR is a "no lose" proposition for all participants, in the long run it is possible that rates will need to increase to cover the cost of the rebate payments. The magnitude of that rate increase will depend on the accuracy of the baseline estimation method.

Further, while a PTR provides an incentive for reducing demand during the peak period, it does not convey the true time-varying cost of providing electricity and does not provide the price signal necessary to encourage adoption of plug-in electric vehicles or rooftop solar systems. There are also concerns about the potential for customers to artificially inflate their baseline energy usage in order to receive a higher rebate payment. For these reasons, the rate is considered by some to be an option for transitioning to time-varying rates and encouraging participation, rather than an ideal long-term solution.[26]

D. Real Time Pricing

Participants in RTP programs pay for energy at a rate that is linked to the hourly market price for electricity. Depending on customer class, participants are made aware of hourly prices on either a day-ahead or hour-ahead basis. Typically, only the largest customers (above one megawatt of load) in specific regions face hourly prices. However, there are two utilities in the United States that offer RTP to residential customers: Ameren and Commonwealth Edison.[27] These programs post prices that most accurately reflect the cost of producing electricity during each hour of the day, and thus provide the best price signals to customers, giving them the incentive to reduce consumption at the most expensive times.

Advantages: The main advantage of RTP rates is that they provide the most granularity in conveying accurate hourly price signals to customers. These rates also provide a dynamic price signal that responds to changing market conditions. They have a long history of full-scale deployment among large commercial and industrial (C&I) customers.

Disadvantages: Generally, without automating technologies it is difficult for customers to respond to prices on an hourly basis – response tends to happen at a less granular level.[28]

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[23] It should be noted here that the opt-out provision from a PTR initiative is, as a practical matter, unnecessary because PTR already protects customers from rate increases. Nevertheless, it exists in certain pilots as yet additional assurance of protection.

[24] For further discussion of the incentives provided by CPP and PTR rates, see section "CPP versus PTR" in Section 4.

[25] Williamson & Marrin, 2008

[26] A U.S. DOE-funded pilot underway in Vermont will be testing the effectiveness of this transition strategy.

[27] See, for example, Star, Isaacson, Haeg, Kotewa, 2010

[28] For example, see Navigant Consulting, 2011

E. Rate Combinations

The rate options described above can also be offered in combination to take advantage of the relative advantages of each. One common combination is CPP and TOU. The TOU component of the rate reflects the average daily variation in peak and off-peak energy prices. The CPP component during a small percentage of hours each year reflects the cost of capacity during the seasonal system peak. Together, these rates can facilitate greater energy awareness among customers and provide a greater opportunity for bill savings through a more heavily discounted off-peak rate. However, the added complexity of a combination rate design means that additional customer education is necessary for the rate to be effective and improve customer satisfaction.

It is also possible to layer time-varying rates on non-time-varying rate designs. Some time-varying rate pilots, such as the California Statewide Pricing Pilot, have measured the effect of time-varying rates combined with an inclining block rate. Combining a time-varying rate with an inclining block rate can encourage peak load reductions as well as conservation. Where rates are unbundled – in other words, separate prices for energy and delivery services – it is straightforward to implement an inclining block delivery rate and a TOU/CPP power supply rate in a fairly transparent fashion, since prices are already separated along those lines. However, without rate unbundling, there are challenges associated with communicating this rate structure to customers in a way that is easy to understand. The utilities in California have used a two-step approach to simplify this message. First, the inclining block rate is presented to customers as their volumetric rate and their consumption is billed using this structure. Then, they receive a credit for consumption during off-peak hours, and a surcharge for consumption during peak hours. The net result is their final bill.

Seasonal differentiation can also be effectively integrated into TOU or dynamic rates. In regions that are distinctly summer-peaking, for example, it may be desirable to offer higher peak period prices only during summer months. This concentrates the events during the window of time when they are most beneficial to the system. A discount could then be provided and spread over the remaining hours of the year, or instead constrained to the summer season in order to provide a greater incentive for load shifting.

Typically, the existing rate for medium and large C&I customers will be structured differently than that of residential and small non-residential customers. For example, larger customers often have a demand charge, and mass market customers typically do not. Class differences will need to be recognized when developing the time-varying rates, whether they are layered on top of the existing rate or replacing it. For example, some or all of the capacity cost that is recovered through demand charges for C&I customers might instead be recovered through the critical peak price of a CPP rate.

F. Enabling Technologies

Technology options are available to help customers manage their electricity consumption in response to time-varying price signals. These are typically referred to as “enabling technologies.” For example, for residential customers, devices such as programmable communicating thermostats (PCTs) can receive a signal during a critical peak pricing event and automatically reduce air-conditioning usage to a level that is specified by the customer. This ability to “set it and forget it” reduces the need to manually respond to high-priced events. This concept could be extended to control other end-uses and appliances through a home area network (HAN). For larger C&I customers, automated demand response (or “Auto-DR”) technology works in a similar fashion, allowing customers to automate electricity consumption reductions in a range of processes and sources of load through integration with the facility’s energy management system.

Enabling technologies can also help customers manage their electricity consumption by providing new information about energy use that the customers otherwise would not have access to. For example, in-home displays can give customers information such as the amount of electricity that they are using, what this is costing them, how that translates into their carbon footprint, how close they are to energy savings goals, and other such data. The information could be provided through a smartphone, website, plug-in device, or other means. A discussion of how enabling technologies have helped customers respond to time-varying rates is provided in Section 4.

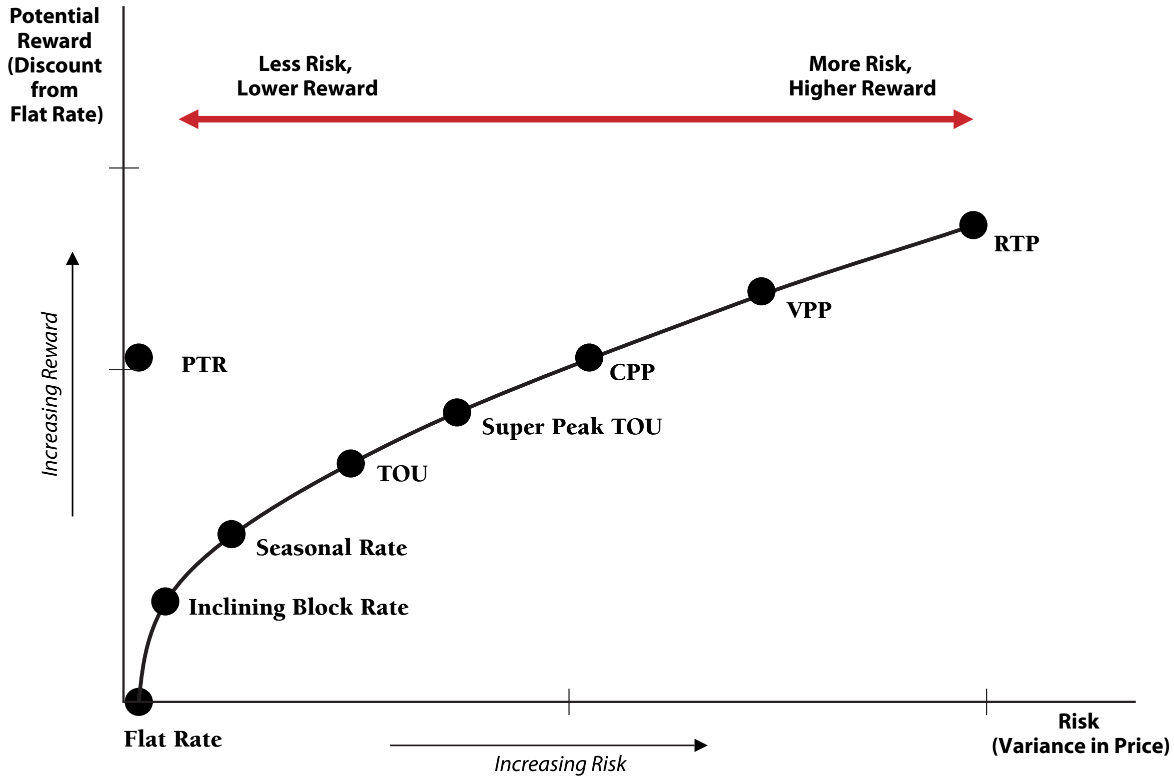
G. The Risk-Reward Tradeoff Of Time-Varying Rates

From a customer's perspective, the time-varying rate options can all be organized across the classic spectrum of risk and reward. Generally, those rates offering the most reward (in terms of bill savings potential) are also the most risky (in terms of exposing the customer to the volatility of wholesale electricity markets). Which rates customers select will be determined by their risk tolerance. This risk-reward tradeoff is illustrated in Figure 1.The figure is illustrative and not intended to provide precise estimates of the risk and reward associated with each rate option.

It should be noted that the short-term view represented in Figure 1 presents a PTR as a risk-free option for participants, relative to the flat rate. However, in the longer term there is risk to participants and non-participants alike, because an overall rate increase may be needed to cover the cost of the rebate payments. This would be the case if the capacity and energy savings from the program prove not to be greater than the cost of rebates and administration, due largely to baseline inaccuracies and potential overpayments.

Figure 1

Conceptual Representation of the Risk-Reward Tradeoff in Time-Varying Rates



3. Design Criteria

Just as there are many different types of time-varying rates that can be offered, there are also many ways in which to design a specific rate. While there will be specific ratemaking objectives that are likely to vary by jurisdiction, there are some common qualities that have been observed in effective design of time-varying rates.

Once the rates are chosen and designed, it is common practice to test their effectiveness through a pilot if not enough is known about the likely impact of the rates in full-scale deployment. The design of the pilot will determine the statistical validity and usefulness of its results. To provide assistance in rate and pilot design, this section presents general recommendations based on deployments around the globe.

A. Time-Varying Rate Design Criteria

The following are elements of effective time-varying rates, as observed or otherwise established by this report's authors through experience in assisting various industry stakeholders in designing and implementing time-varying rates.

Short peak period: The on-peak period should be kept as short as possible while still reasonably spanning the period during which the system peak occurs. A shorter peak period makes it easier for customers to shift load to the lower-priced off-peak period. For example, a four-hour peak period, say from 2 pm to 6 pm, would reasonably allow customers to shift the use of some of their appliances, such as dishwashers or clothes dryers, before or after the period's duration. A long peak period would be less likely to induce response, as customers would need to shift usage to the early morning or late night hours, requiring more significant behavioral changes. Many voluntary TOU rates in the industry feature very long peak periods and very few customers are enrolled in such rates.

Strong price signal and opportunity for significant bill savings: For rate designs targeting capacity reduction during peak demands, the rate should convey a strong price signal to customers. In other words, the differential between peak (or critical peak) and off-peak prices should be large (as long as it is economically justified, including the cost of capacity). This large differential gives the customer a significant incentive to reduce consumption when the price is high, and produces the opportunity for greater bill savings by creating a large off-peak discount. The customer needs to notice that there is a substantial difference in prices during these two periods. A small differential sends a weak price signal to customers and could be too insignificant for them to care about changing their consumption patterns. Examples of the relationship between the strength of the price signal and the magnitude of customer response are discussed in more detail in Section 4.

Customers are less likely to voluntarily enroll in the time-varying rate if they do not see an opportunity for material bill savings. Similarly, once customers are on the rates, they are more likely to produce large peak reductions if doing so allows them to save material amounts of money through load shifting. To create such a rate, the off-peak discount should be substantial and applicable during hours and seasons when participants have control over discretionary load (and therefore an ability to shift their electricity consumption).

Rates should reflect system costs: While a significant price signal is important, the rate should still reflect the cost of providing power to the customer. The peak period rate should reflect both the higher average variable cost of generation, as well as the cost of capacity necessary to meet peak demands. The off-peak rate is a reflection of the lower average cost of meeting customer demand during hours with lower loads. This is what drives the differential between the peak and off-peak rates.

This approach is generally the same in both restructured (liberalized) markets and non-restructured regions, although there are some nuanced differences. In regions where there are robust wholesale energy and capacity markets, the market prices typically serve as the cost-basis for the rates when they are developed by the default service provider.[29] In restructured markets with retail competition, the rates could be offered in a variety of forms by competitive retail suppliers. In non-restructured areas, marginal energy costs are typically based on hourly modeling simulations, and marginal capacity costs are based on projections from the utility's long-term resource procurement plan or other estimates of the cost of installing or contracting for new peaking capacity.

Simplicity is important: Time-varying rates should be easy for the customer to understand. If the customer does not understand how the rate works, or is overburdened with information, then he or she will not be able to appropriately respond to the price signals and shift load.

Rates should account for the "hedging premium": Flat rates – those that do not vary by time of day– are costly for suppliers to service, because they transfer all price and volume risk from the customers to the suppliers. To remain profitable, the utility or retail supplier has to hedge against the price and volume risk embodied in such an open-ended fixed price contract. The supplier can compensate for the cost of doing so by estimating the magnitude of the risk and charging customers for it through an insurance or hedging premium. The risk and associated cost depend on the volatility of wholesale prices, the volatility of customer loads, and the correlation between the two. Empirical work suggests this risk premium is higher when the existing rate is fixed and time-invariant, and smaller when the existing rate is time-varying or partly dynamic.[30] To the extent that the risk premium can be quantified or is generally known by the retail electricity provider, customers who move to time-varying rates should be credited for the premium.[31]

B. Pilot Design Criteria

Pilots are used to draw statistically meaningful and generalizable conclusions about the impacts of time-varying rates on customer usage patterns. These results help policymakers to determine which rate designs are more effective at altering these usage patterns in a way that produces the largest benefits to the utility, its ratepayers and the participating customers. While a well-designed pilot is informative and defensible, there are many potential threats to the validity of pilot studies, in general, that must be addressed through careful planning and execution. This section discusses recommendations for pilot design, based on the experience and observations of this report's authors.[32]

It is important to note that there is not one single "right" way to design a pilot. Often, the theoretically ideal approach can impose requirements that are too strict given available budget, time, resources, and other practical considerations. Often tradeoffs must be made to satisfy these practical constraints while sacrificing as little as possible in the validity of the results. Identifying the optimal way to make the tradeoffs is often more art than science.

Generally speaking, there are six steps in setting up a pricing pilot. These are summarized in Table 2 (page 20).

1. Choosing the right type of pilot

The first step in setting up a pilot to assess a time-varying rate proposal, with or without smart grid involvement, is to decide on the type of experiment. This will largely be determined both by the objectives for the experiment and by constraints on time and resources. The three types of pilots are demonstrations, quasi-scientific experiments, and controlled experiments.[33]

Demonstration pilots are used when the primary goal of the pilot is to prove that a given technology or set of technologies can feasibly be implemented in a real-world setting. At the other end of the spectrum are *controlled experiments*. These are rigorous studies that are designed to estimate the impacts of a future full-scale smart grid

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[29] Adjustments to these prices may still need to be made to ensure neutrality relative to the utility's existing revenue requirement.

[30] Neenan, Cappers, Pratt, & Anderson, 2005

[31] For guidance in quantifying the risk premium, see Faruqui, Hledik, & Neenan, 2007.

[32] An additional useful reference on pilot design is a collection of guidance documents listed in Appendix A.

[33] For further discussion of approaches to pilot design, see the U.S. DOE's guidance document on this topic: http://www.smartgrid.gov/sites/default/files/pdfs/cbs_guidance_doc_7_randomized_experimental_approaches.pdf.

Table 2

Major Steps in Designing a Time-Varying Rate Pilot

Step	Description	Key Questions
1	Choose type of pilot	Will it be a demonstration, quasi-experiment, or controlled experiment?
2	Define treatments	What rates and technologies will be tested? Why? What are the performance metrics of interest? What is the ultimate pilot objective?
3	Establish experimental and control group or quasi-experimental control design, as applicable	Is there a control group representative of the greater population of customers? If so, will the control group know that it is "participating"? In quasi-experimental designs, what are the techniques for controlling for non-treatment factors?
4	Recruit customers	Will customers be asked to opt-in, opt-out, or be required to participate in the pilot? How will self-selection bias be addressed?[34]
5	Collect pre-treatment data	What is the timeframe over which data can be collected?
6	Compare treatment & control	Are the two groups statistically comparable? Are the differences statistically significant and practically meaningful?

program on a broad population of customers. *Quasi-experiments* fall between demonstrations and controlled experiments. While quasi-experiments typically do not involve the same level of rigor of a scientific experiment, they often include enough participants to draw some statistically meaningful conclusions, but may be limited in their ability to be generalized.[35]

Controlled experiments typically span a timeframe of more than one year (to capture seasonal and persistence effects in the study) and involve a large number of participants (hundreds or thousands).[36] They involve a comparison of treatment groups (customers who are enrolled in one or more pricing programs) against a control group (customers who are comparable to the treatment group customers, but are not enrolled in any new pricing programs). There are strict requirements about the way in which participants are recruited and the type of information and incentives that they can be given, in order to minimize various forms of bias that would make the results otherwise not representative of the larger population.

2. Selecting the appropriate treatments

There are several important factors to keep in mind when determining which treatments to test in the pilot.

Anticipate the importance of measuring incremental impacts. In testing the impact of a combination of rates and technologies, there is often interest in the incremental impact of one product relative to another. For example, a customer on a time-varying rate, with an in-home display (IHD) and a PCT, may reduce his or her peak demand in response to a critical peak pricing signal. To determine how much of the peak reduction is attributable to the PCT, how much is attributable to the IHD, and how much is attributable to other actions taken in response to the time-varying rate,

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[34] "Self-selection bias" refers to a situation where various factors cause specific types of customers to enroll in the pilot, with these enrollees not being representative of the larger population of customers.

[35] In technical terms, this implies that quasi-experiments may have internal validity, but lack external validity. Internal validity refers to the ability to accurately assess cause and effect with respect to the study population. External validity refers to the ability to extend the established relationships to a broader population.

[36] The longer the pilot lasts, the greater the ability to measure persistence and control for the effects of anomalous external factors such as weather.

the technologies would need to be tested in isolation and in sequence. It may be discovered that the impact of one rate or technology is made redundant by the other, or that the impact from the application of a combination of rates and technologies is not the same as the sum of the incremental impacts of each.

Emphasize side-by-side testing of alternatives. A utility or regulator may be choosing between two alternative rate options. The best way to inform this choice is to test both in the same pilot. For example, there has been ongoing debate in the industry over whether rebates or time-varying prices are more effective for achieving peak demand reductions. Until fairly recently, the two approaches had not been tested side-by-side at the same utility, so there was no definitive way to answer the question. It is only in the newest generation of pilots that the two alternatives are being tested together on participants drawn from the same pool of customers.[37]

Engage in market research. A lower-cost alternative to including many treatments in a pilot is to instead gauge customer preferences or response rates through market research. For example, rather than offering two rates as separate treatments in order to determine customer preference, a sample of customers could be surveyed about which they think they would adopt if given a choice. This approach is less effective than an actual price offering in a pilot setting, because it will capture customers' *stated* preferences rather than their *demonstrated* preferences. However, it could still be an effective approach to learning which treatments to exclude from the pilot due to limited resources.

3. Establishing a control group

In addition to including a number of treatment groups, a well-planned pilot, based on controlled experimental design principles, will also have a control group. The control group is a collection of customers who do not receive any new programs, technologies, or information. Often, the control group is not aware of their "participation" in an experiment in order to avoid influencing their behavior as a result of feeling that they are being "watched." The purpose of the control group is to establish a "baseline" against which the impact of the various treatments can be measured. Throughout the experiment, the behavior of the control group is considered representative of what the customers in the treatment groups would have done in the absence of the introduction of the treatment. In other words, the control group helps to isolate the impact of the treatment and account for the influence of external factors (such as changes in the weather or the economy).

4. Recruiting participants

Another key aspect of pilot design, which is subject to some debate, is the way in which participants are recruited into the pilot. Ideally, customers should be recruited into a pilot in the same way that the program will be offered when it is deployed full-scale. If the ultimate deployment plan is to offer a program on an opt-in basis, then that should be the same mechanism by which customers enroll in the pilot. Alternatively, if in the future customers may be automatically enrolled in a program with the option to proactively elect not to participate, then opt-out recruitment (which is still voluntary) may be used.

Regulators and utilities are often unwilling to enroll residential customers in a pricing pilot using opt-out recruitment. However, if customers are simply enrolled on an opt-in, first-come-first-served basis, then the participants will likely be dominated by "early adopters" who are not representative of the larger population of customers. This is one form of "self-selection bias." The dilemma, then, is how best to recruit participants who approximately represent the larger population of customers in a way that is acceptable to regulators and customers.

A voluntary, opt-in recruitment method called *random selection with affirmation*, or *random encouragement design,* helps to approximate the impacts of large scale deployment by minimizing self-selection bias. With this approach, individual customers are randomly contacted and invited to participate in a pilot. If they accept, they are randomly assigned to a treatment cell. If they decline, another customer is randomly contacted and invited to join. The process continues until the desired number of participants

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[37] This has been tested in recent pilots by Baltimore Gas & Electric and Pepco (in Washington, D.C.). It will also be tested in pilots that are funded by the U.S. DOE. See Faruqui, Sergici, & Akaba, 2011 and eMeter Strategic Consulting, 2010.

is reached. Importantly, the "decliners" are tracked as part of the "treatment" group in order to avoid sample bias. A control group is established outside of this recruitment process by randomly selecting customers from the greater population in a manner that ensures a representative sample from the larger population.

A twist on this approach that has recently garnered attention in smart grid pilots is called the "randomized control trial" (RCT). Customers are randomly invited to participate in the study, just as in the random selection with affirmation approach. However, upon accepting the invitation, customers are randomly assigned to a treatment group or the control group. In theory, this is a better way to establish comparability between the control and treatment group participants. However, there are practical challenges associated with inviting customers to participate in a pilot and then assigning them to a control group with no new technologies or features. This can be addressed by managing the potential participants' expectations up front, so that they know that they could be assigned to either group. Alternatively, a "recruit and delay" approach could be used, which informs customers that they may not be in the treatment group in the first year, but that everyone will have a chance to participate in the treatment group in the second year.

It is common practice to provide pilot enrollees with a small appreciation payment for their participation in the pilot. This is considered compensation for the added effort that they must provide for activities such as filling out pre- and post-pilot surveys and as compensation for the perceived risk of being "experimented upon." However, appreciation payments run the risk of introducing bias into the pilot results because they are presumably not something that would be provided to all customers in a full-scale program rollout. Ideally, they would not be offered for this reason. However, if appreciation payments are deemed necessary to sufficiently meet recruitment goals, then there are a few key things to keep in mind to minimize the introduction of bias in the pilot:

- Keep the payment relatively small, to avoid making it the primary reason for participation.

- Provide the payment at the end of the pilot, to avoid free-riders who sign up, receive the payment, and then drop out. This will help to minimize the pilot's attrition rate (and will in fact provide an additional incentive to remain enrolled).

- A one-time cash payment is the best incentive. Gift cards or other types of gifts can influence the types of customers who sign up. For example, a gift card for products purchased online would only be useful to people with frequent internet access. It is important never to provide the incentive in a way that would encourage customers to use energy differently, such as a rate discount.

- Frame the payment as an "appreciation/thank you" payment. Disassociate the payment from energy use to avoid having any effect on electricity consumption behavior.

5. Collecting Pre-Treatment Data

Data should be collected on all of the pilot participants before the pilot begins. This would include, for example, hourly electricity consumption patterns. Pre-treatment data collection is important, because it provides a reference point against which to compare the participants' behavior after they have been exposed to a treatment.

External factors, such as weather differences, could also lead to pre- and post-treatment differences. This is why it is also important to have a control group, which can be used to control for the impact of external factors. It is important to collect pre-treatment data for both the treatment and control groups. Ideally, pre-treatment data would be collected for at least a full year for these customers. That allows for capturing the full impact of seasonal effects.

6. Testing Treatment and Control Groups for Comparability

Once treatment and control groups have been recruited, and once data have been collected for these customers (e.g., through load research data, surveys, and a pre-treatment data collection effort), an important final step is to confirm that the groups are comparable. The objective is to identify, and then determine the best approach to address and minimize, any underlying differences between the treatment and control groups, the impact of which could be mistakenly attributed to the treatment itself.

There are a few ways to compare the treatment and control groups. Variations on these basic tests can be used to varying degrees of statistical rigor:

- **Seasonal consumption patterns.** Compare average daily usage between the groups, by month, to identify any differences in the size and seasonal consumption patterns of the two groups.

- **Weekly consumption patterns.** Compare average daily consumption across the groups for each month to determine whether there are any differences in weekly patterns of consumption.

- **Daily consumption patterns.** Compare average hourly consumption profiles for each group to determine whether there are differences in the way electricity is used over the course of a day.

- **Sociodemographic characteristics and appliance saturations.** Using pre-pilot surveys and other market research information, compare the distributions of sociodemographic characteristics across the groups such as income, age, education, family size, and dwelling type. The comparison should also consider the distribution of appliance saturations, including central air-conditioning, window air-conditioning, electric heat, and heated pools, for example.

If the characteristics of the treatment and control groups are largely similar, then the control group can be considered a fair representation of the "baseline" behavior of the treatment groups.[38] If there are some dissimilarities between the two groups that are primarily related to consumption, then these differences can typically be addressed through statistical techniques in the measurement and verification (M&V) phase of the pilot. However, large differences in sociodemographic or appliance saturation characteristics may need to be addressed in advance through additional recruitment or sampling activities.

C. Addressing Barriers To Time-Varying Rates

In this section, we discuss commonly encountered barriers to adoption of time-varying rates and identify methods for addressing them. Specifically, we focus on the following barriers:

- Regulatory/market coordination issues
- Rate freezes, price caps, and other legislative constraints
- Lack of AMI
- Customer fear of price volatility
- Ineffective rate designs
- Concerns about impacts on low-income households

Regulatory/market coordination issues

In regions with traditional markets and vertically integrated utilities, retail rates are established by regulators, the utilities' boards, or oversight agencies. In these regions, utilities can establish time-varying rates to reflect the hourly marginal costs of generation and the associated marginal capacity costs for generation, transmission and distribution.[39] If wholesale contracts mask the hourly variation in marginal energy and capacity costs, then it becomes difficult to transmit time-varying cost-based price signals to customers at the retail level.

The picture becomes more complex in restructured markets where system operators or power exchanges run wholesale markets. Retail rates are still set by local entities but key elements - the cost of energy and generation capacity - are set in wholesale markets. Depending on how those wholesale costs are developed and allocated, it may be easy or difficult to create time-varying retail rates that reflect wholesale market conditions. In this case, coordination across the various entities may be improved through forums and workshops that bring key staff together to discuss and address the issues.[40]

Rate freezes, price caps, and other legislative constraints

Another problem for time-varying rates arises if retail rates are frozen or subject to price caps and other legislative/regulatory constraints. For example, in response

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[38] There are specific statistical methods that can be used to measure the differences between the two groups. For details on these methods, see: http://www.smartgrid.gov/sites/default/files/pdfs/cbs_guidance_doc_5_impact_evaluation.pdf.

[39] For distribution-only utilities, generation costs can be based on short-term and long-term contracts for power purchases, and transmission costs can be similarly based on contracts for transmitting power.

[40] The U.S. Federal Energy Regulatory Commission has initiated such an effort with its National Action Plan on Demand Response. FERC Staff, 2010.

to the California energy crisis of 2000-2001, the California Assembly froze the rates in the first two tiers of the residential inclining block rate (through Assembly Bill 1X). This effectively makes it impossible to roll out time-varying rates as the default rate. The rate freeze will be lifted once the long term power supply contracts entered into by the state expire.

How can the challenge of rate freezes and price caps be addressed? The answer will depend on the specific requirements of the policy. In California, time-varying rates can still be offered on an opt-in basis, and that is one approach being pursued by the utilities. Additionally, peak time rebates, which leave the retail rate unchanged, can be offered as a proxy for time-varying rates.

Lack of AMI

As described in Section 1 of this report, time-varying rates cannot be offered in the absence of the appropriate metering technology. Without AMI, time-of-use rates can be offered as a proxy to genuine dynamic rates, although this still requires a meter that can track at least two billing periods – peak and off-peak. Also, non-pricing programs such as utility control of selected end-uses like central air conditioning, pool pumps and water heating can be offered to address peak load concerns. Alternative rate options, such as inclining block rates, could be used to achieve policy goals related to conservation and may provide some peak load reduction.[41] Financial incentives for investing in AMI, such as tax credits or accelerated depreciation of the technology, could be pursued depending on the specific policy goals of the region.

Customer fears of price volatility

Many customers equate time-varying rates with price volatility, and some simply equate it with high prices. This perception may stem, in part, from a concern that time-varying rates could eventually become the mandatory rate offering. However, this concern over price volatility is a perceptual problem that can be remedied through customer engagement and education. It is important to convey the message that time-varying rates are not simply an invention of economists for the electricity sector. They are a byproduct of the normal workings of a competitive market and promote efficiency in the use of scarce resources. To identify the specific message that would best resonate with customers and be the most effective in furthering understanding of the benefits of time-varying rates, focus groups and other market research could be conducted. This is a common early-stage practice among utilities that are beginning to implement dynamic pricing pilots.

In addition to developing a clear and effective educational message that resonates with customers, there are other ways to help customers understand and benefit from the volatility in time-varying rates. One is to provide temporary bill protection (meaning that the customer's bill on the time-varying rate could be no higher than it would have been under the otherwise applicable tariff). This would give customers a chance to become familiar with the rate and experiment with approaches to energy conservation and load shifting before being exposed to the risk of a bill increase. Additionally, customers could be provided with enhanced information about their energy use and potential to shift peak load, whether through a detailed bill insert, a web portal, or by some other means. This information would advance their understanding of their energy consumption patterns and help them identify ways to reduce their electricity bills.[42]

Another way to help customers manage the volatility in time-varying rates is to offer "two-part rates." In this approach, customers are allowed to buy a predetermined amount of power at a fixed rate (analogous to how most customers buy their electricity today). The remaining amount of power that they consume is purchased according to the time-varying rate. This would add flexibility by allowing more risk-averse customers to purchase a larger share of electricity at the predetermined rate, and less risk-averse customers to purchase more electricity at the time-varying rate.[43]

Ineffective rate designs

Time-varying rates need to be designed carefully to accurately reflect costs and they also need to be designed so that they are easily understood by customers. Furthermore, the rates need to enable customer response. For example, if the rates are designed with broad peak periods, they may make it difficult for customers to respond. Ultimately, each

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[41] Faruqui, 2008

[42] American Council for an Energy-Efficient Economy (ACEEE), 2010

[43] Berg, 1999

customer is different, especially when it comes to trading off lower bills for higher price volatility. See the earlier section in this section titled "Time-Varying Rate Design Guidelines" for more information on qualities of effective rate design.

Regulators and utilities that wish to promote time-varying rates for residential and small nonresidential customers can offer a spectrum of rates, from flat rates to conventional time-of-use rates to dynamic rates such as critical peak pricing. If regulators wish to increase up-take of time-varying rates, they should consider opt-out enrollment, which garners significantly higher levels of participation.[44] Under this approach, all customers in the rate class would be placed on a time-varying rate but can opt out at any time to a flat rate.

Concerns about impacts on low-income households

It is sometimes argued that low-income households would be adversely affected by time-varying rates. However, empirical work to-date has shown that low-income households are likely to come out ahead with time-varying rates, due both to flatter-than-average load shapes and a demonstrated ability to shift load to lower-priced off-peak periods.[45] Still, measures can be taken to limit the exposure of these customers to bill volatility. The approaches described above, such as increased access to energy information, temporary bill protection, and two-part rate designs, are all applicable options.

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[44] Momentum Market Intelligence, 2003

[45] See Section 4 for a detailed discussion of these observations.

Issues In Cost-Benefit Analysis of Time-Varying Rates

Some regard time-varying rates as good business practice, not requiring a cost-benefit analysis. In other words, they are on par with activities such as load research and cost-of-service studies, none of which are subjected to such analysis. These proponents say that if time-varying rates require a cost-benefit analysis, then flat rates, the current norm, should also be subjected to a cost-benefit analysis because flat rates cannot be carried out without the installation of analog meters and appropriate billing systems.

However, not everyone agrees with this viewpoint. The contention is made that because time-varying rates cannot be carried out without AMI, a cost-benefit analysis should be performed, akin to analyses for conventional demand-side management programs. In such analyses, costs and benefits are evaluated from multiple perspectives.[46] The dominant perspective often is the total resource cost (TRC) test, which takes a holistic view. If programs pass this test, then additional insights are gained by looking at the participants' perspective and the utility's perspective and also the perspective of non-participants. If the benefits are evaluated using social measures of avoided cost that account for externalities and which use a "social" discount rate, then the holistic test becomes a societal test. Since trade-offs often exist between these perspectives, regulators in each state have established their own set of priorities. Some states have long given priority to the total resource cost test while others have given priority to the non-participant test. In the academic literature on cost-benefit analysis, the perspective that is most taken is to compute changes in the "social surplus," defined as the sum of consumer surplus and producer surplus.[47] However, this test is rarely used in regulatory proceedings.

In the case of time-varying rates, from a holistic perspective the main cost element is the cost of AMI, which includes the cost of meters as well as the cost of associated software and billing systems and communications equipment. And as discussed below, customer costs or inconvenience incurred to help secure some of the promised energy and capacity benefits would also be included in a holistic measurement of costs and benefits. The benefits are the avoided cost of capacity (generation plus transmission and distribution) and energy, plus all monetizable non-energy benefits. Environmental impacts of dynamic pricing are discussed

continued on next page

Issues In Cost-Benefit Analysis of Time-Varying Rates

continued from previous page

in Section 1, and can be positive or negative, depending on the marginal resources in the area where they are implemented.

It should be noted that, while AMI is the key cost-driver in this scenario, there are additional benefits associated with smart meters that should be "netted out" of its full cost.[48] These benefits are operational savings such as avoided meter reading costs, reduced outage management costs, and the ability to remotely connect and disconnect accounts. These benefits typically range between 50 percent and 100 percent of the cost of AMI. In cases where the operational benefits do not exceed the costs, then the benefits of time-varying rates must make up the difference in order to be deemed cost-effective.

From the participant perspective, there are two main cost elements for time-varying rates. The first is the incremental monthly metering cost that customers would be required to pay. This is often the cost of AMI net of operational benefits. The second cost is the loss of welfare associated with reducing usage during a high-cost period (curtailment) or shifting usage to a lower cost period (hassle factor).[49] These are often valued at one-half of the difference between the price before CPP (which does not trigger behavioral change) and the price after CPP which does trigger this change. The benefit is the reduction in the monthly bill. Note that this result would not be identical to changes in consumer surplus which provides an alternative view of participant benefits.

From the utility perspective, the focus is on measuring changes in revenue requirements (or aggregate customer bills). The benefits are the same as in the total resource cost test. The costs include all the AMI-related costs and any incentive payments that are made to recruit customers.

From the non-participant perspective, the focus is on measuring changes in average rates. The benefits are the same as in the total resource cost test. On the cost side, in addition to all the elements included in that test, the cost of any incentives that will be paid by the utility to recruit and retain customers is included (as in the utility cost test) and so is any revenue loss that would accrue to the utility.[50]

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[46] California Public Utilities Commission, 2001

[47] Harberger, 1971

[48] Electric Power Research Institute, 2010

[49] Note that this loss of welfare should be treated similarly across all demand-side programs that may produce such an effect, and not just limited to time-varying rates.

[50] Revenue loss could result, for example, if the time-varying rate produces an overall conservation effect in which customers consume less electricity than expected under the utility's revenue projection. Of the economic perspectives discussed, such revenue losses are relevant only to the non-participant measurement of costs.

4. Time-Varying Rate Pilots

Time-varying rates have been available to large C&I customers for decades. Many of these large customers – particularly those in restructured markets - are placed on a default real time pricing rate. Others have the option of choosing RTP rates with day-ahead or hour-ahead notice. However, for residential customers, access to time-varying rates has mostly been limited thus far to pilots, with some options to enroll in voluntary TOU or CPP rates.[51]

In the late 1970s and early 1980s, the first wave of electricity pricing experiments was carried out under the auspices of the U.S. Department of Energy and its predecessor agency, the Federal Energy Administration. Those experiments were focused on measuring customer response to simple (static) time-of-day and seasonal rates.[52] Five large experiments were analyzed collectively in a project carried out by the Electric Power Research Institute.[53] The results were quite conclusive: customers responded to higher prices during the peak period by reducing peak period usage, or shifting it to less expensive off-peak periods, or both. The results were consistent around the country after normalizing for weather conditions and appliance holdings. Customer response was higher in warmer climates; response was higher for customers with central air conditioning systems.

However, despite the conclusive findings, time-varying rates were not widely accepted. In part this was due to the high cost of TOU metering at the time. It was also because the peak periods that were offered in these rate designs were much too broad for customers to cope with and produced price differentials that did not induce customers to want to cope with them. This lack of acceptance was also because the cost of peaking capacity did not vary sufficiently from the cost of off-peak capacity to bother offering TOU. Further, the rates were not heavily marketed due to concern that they could result in a loss of revenue to the utilities.[54]

The California energy crisis of 2000-2001 rekindled interest in time-varying rates. A variety of academics, researchers and consultants called for the institution of rates that would be dynamically dispatchable during critical-price periods.[55] These occur typically during the top one percent of the hours of the year where a significant amount of annual peak demand could be concentrated. It is very expensive to serve power during these critical peak periods and even a modest reduction in demand during such periods can be very cost-effective.[56]

The following sections summarize the results of several new time-varying rate experiments that have been carried out in North America, Europe, and Australia. The review of these pilots reveals that time-varying prices are effective in reducing electricity usage.

A. Survey Of Pilot Results

Our survey included 24 recent residential pricing pilots that were conducted by utilities in North America, Europe, and Australia between 1997 and 2011. Durations of the pilots lasted anywhere from a single season to four years. In total, the pilots tested 109 combinations of time-varying rates and enabling technologies (each combination is referred to as a “treatment”). The number of participants in each treatment cell ranged from as few as 70 to thousands. Rates tested included TOU, CPP, PTR, and RTP. Enabling

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[51] For example, Arizona Public Service offers a voluntary TOU rate that has achieved 50 percent enrollment among residential customers. Electricite de France has offered a residential CPP rate since the late 1990s. PG&E offers a residential CPP rate option. See the case studies in this paper.

[52] Faruqui & Malko, 1983

[53] Caves, Christensen, & Herriges, 1984

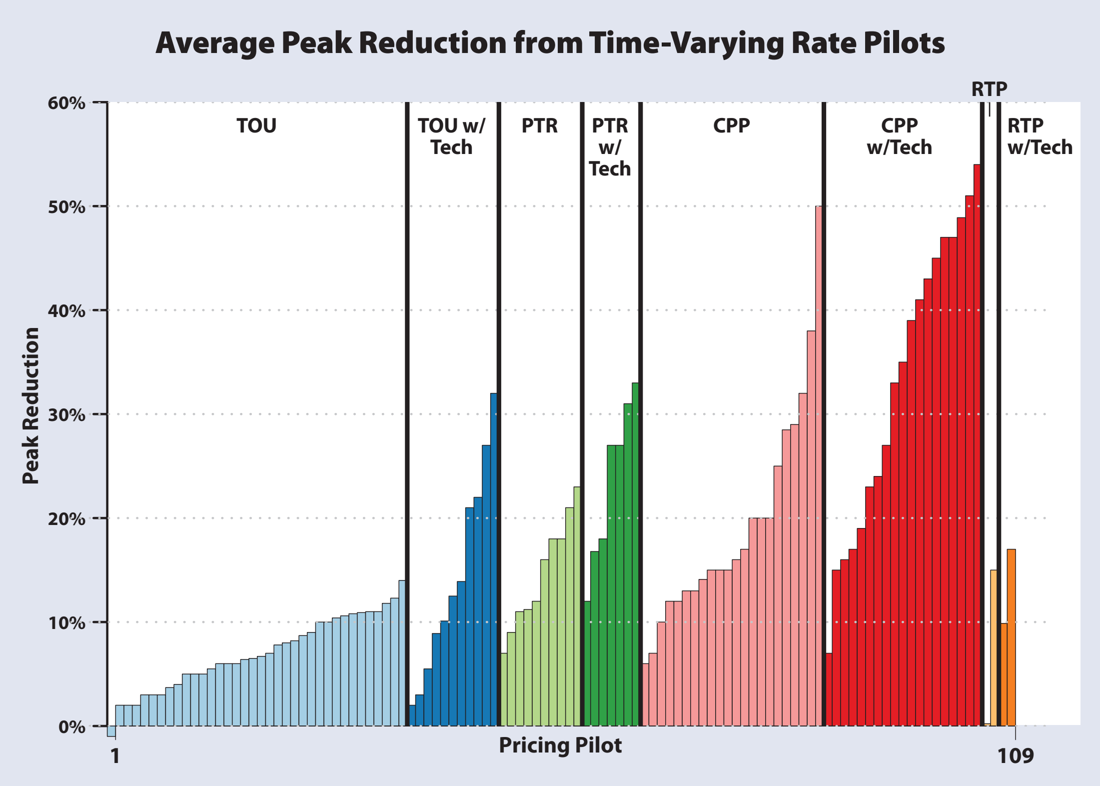
[54] Methods for addressing this concern are discussed in Borenstein, Jaske, and Rosenfeld, 2002.

[55] Bandt, et al., 2003

[56] Faruqui, Hledik, Newell, & Pfeifenberger, 2007

technologies included smart thermostats, air-conditioner switches, and in-home information displays. Results of the impact of each treatment are summarized in Figure 2.[57]

Figure 2



Across the pilots, it is apparent that time-varying rates induce peak load reductions. In general, CPP programs supported with enabling technologies that automate the customers' response result in the largest reductions in load. However, CPP programs alone (without an enabling technology) also achieve significant reductions in load. TOU programs without enabling technologies reduce load somewhat; however, when TOU programs are supported with enabling technologies, the average load reduction is larger.

There are several explanations for the observed variation in rate impacts:

- **Pilot design:** Some pilots have a more scientifically valid design than others and do a better job of addressing issues like self-selection bias.
- **Price signal:** The peak-to-off-peak price ratio is a key driver of customer response, because a large price differential provides greater savings opportunities and more incentive to shift consumption.
- **Central-air conditioning (CAC) saturation:** CAC is a large load that can easily be curtailed during a pricing event, with pre-cooling during the peak or critical peak period.
- **Type of enabling technology:** Control technologies like programmable communicating thermostats, which enable consumers to pre-set heating and cooling equipment to automatically adjust temperature in response to price signals, tend to produce larger load reductions than enhanced information, which still requires manual action by the customer.
- **Weather:** Heat and humidity both affect price responsiveness. Hotter days tend to elicit a higher response, but more humid climates have tended to produce smaller load reductions (all else equal).
- **Sociodemographic factors:** Factors such as age, income, and education may impact a customer's price responsiveness.
- **Marketing/incentives/education:** Pilots pursued varying degrees of customer education and outreach.

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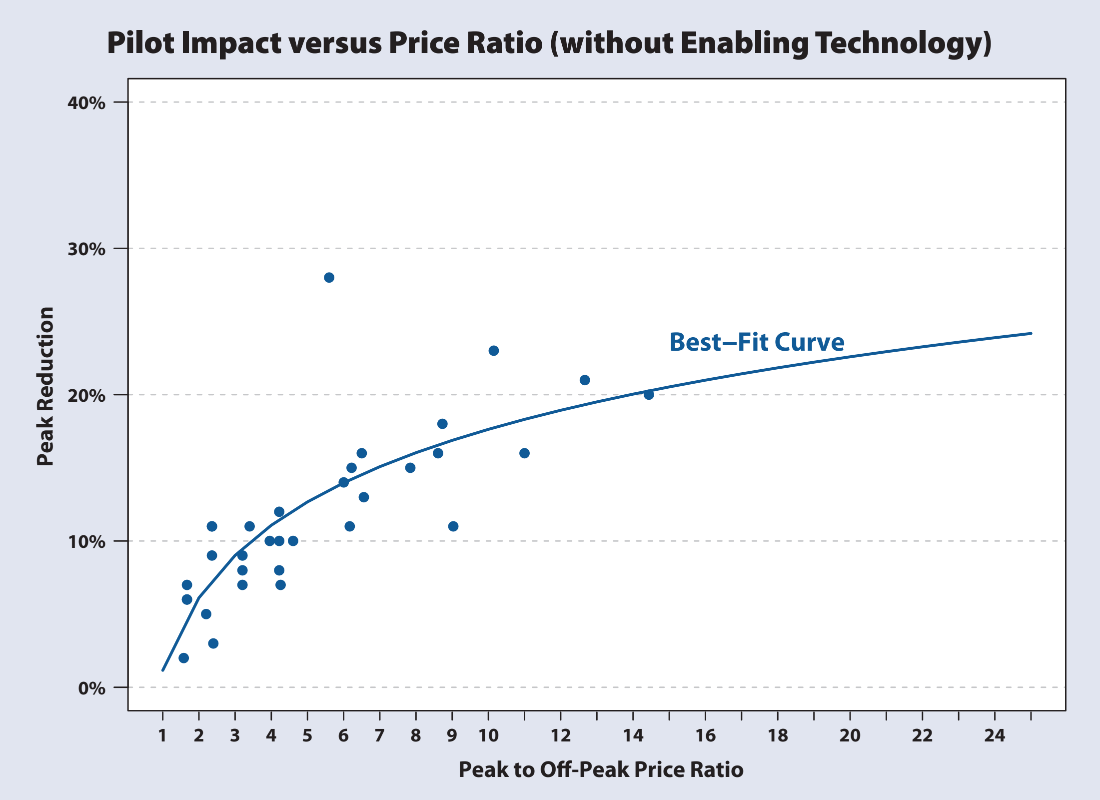
[57] For more information about the pilots discussed in this section, see Faruqui & Sergici, 2010.

Figure 3



Pilot Impact versus Price Ratio (without Enabling Technology)

Of these factors that influence customer response, the price signal is of particular importance. As illustrated in Figure 3, across pilots without enabling technology, response increases with price ratio, but at a decreasing rate.

B. Lessons Learned From Time-Varying Rate Pilots

Beyond simply demonstrating that customers reduce electricity consumption when exposed to higher prices, recent time-varying rate pilots have provided new and interesting insights. These insights specifically relate to the impact of time-varying rates on low-income customers, the persistence of time-varying rate impacts over several years, and the impact of enabling technologies on price response.

Impacts on Low-Income Customers

There is significant debate in the industry about the impact of time-varying rates on low-income customers, and the issue deserves careful attention by regulators. Some consumer advocates are concerned that because low-income households typically use less power than other residential customers, they have little discretion in their power usage and are thus unable to shift load depending on price. As a result, those consumer advocates are concerned that low-income customers would be hurt by time-varying rates.[58]

However, empirical evaluation has indicated that most low-income customers would immediately save money on their electricity bills from time-varying rates. First, across the residential class as a whole, we expect roughly half of the customers placed on a revenue-neutral time-varying rate to immediately see bill increases and half to see bill decreases. Customers who use more electricity in the peak hours than the average customer would see higher bills, while customers who use less electricity in the peak hours than the average customer would see lower bills.

The electricity bills of a representative sample of low-income households and residential customers (as a whole) from a large urban utility were calculated using flat and CPP rates.[59] As expected, roughly half of the residential customers had higher bills on the time-varying rates, and half had lower bills. However, because low-income customers tend to have flatter load shapes, roughly 65 percent of the low-income customers were immediately better off on the CPP rate than on the flat rate, according to the calculations. In other words, even without any change

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[58] For example, see AARP, et al., 2010

[59] See Faruqui, Sergici, Palmer, 2010. While the magnitude of the bill changes is dependent on the specific rate design (i.e., the peak-to-off-peak price differential), the share of customers experiencing higher or lower bills is fairly robust across rate designs.

in electricity usage, more than half of low-income customers are better off on a time-varying rate. The results for the CPP rate are shown in Figure 4.

There are a number of tools available to address the concern that customers could experience a bill increase under time-varying rates, especially during a transition period, such as temporary bill protection, "shadow bills" in advance of rate application that show what the customer would pay under future rate options, additional information about ways to conserve energy and reduce bills, and rebates for energy efficiency measures.

Second, results from several studies show that low-income customers do reduce peak load in response to time-varying rates. A review of 10 pilots reveals that low-income customers are responsive to time-varying rates and that their degree of responsiveness relative to that of average customers varies across the studies reviewed.[60] Some studies found that low-income customers were equally as price responsive as higher-

Figure 4

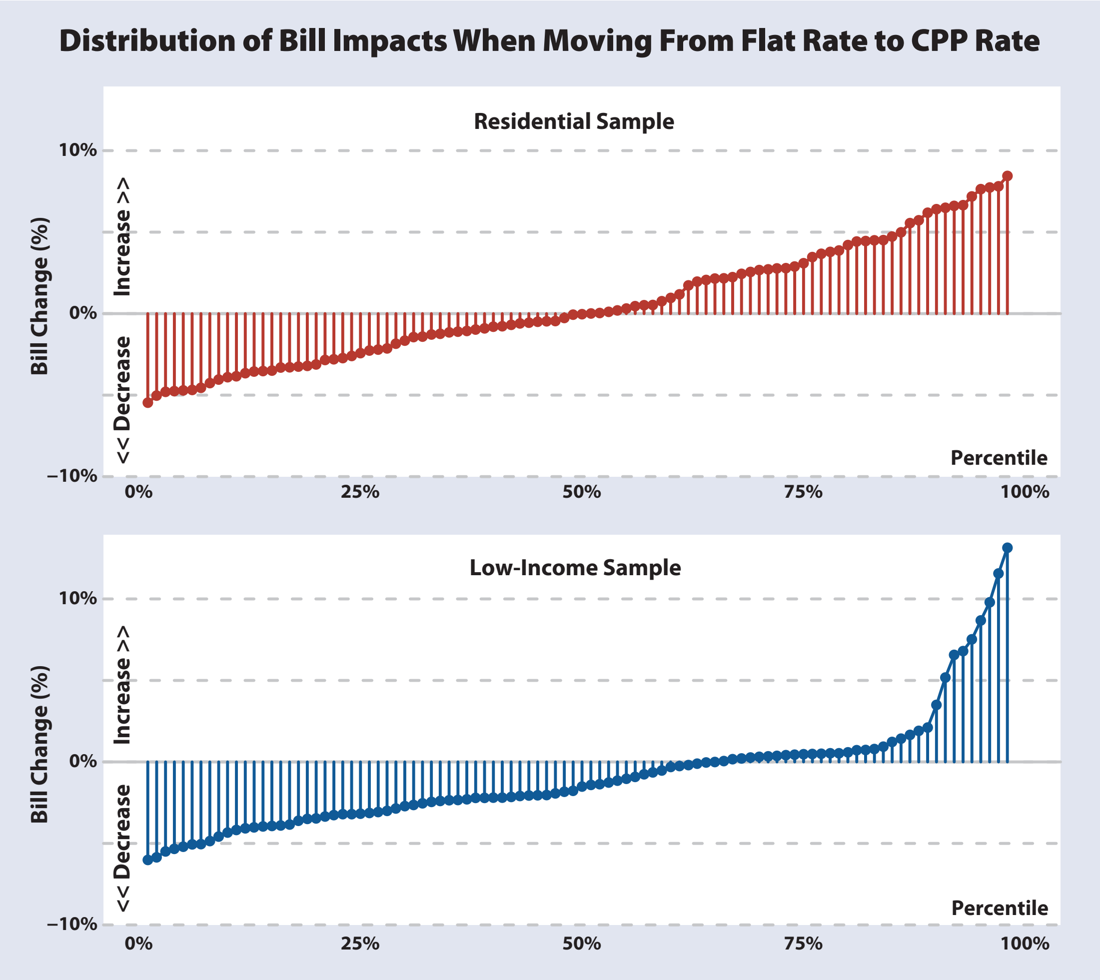
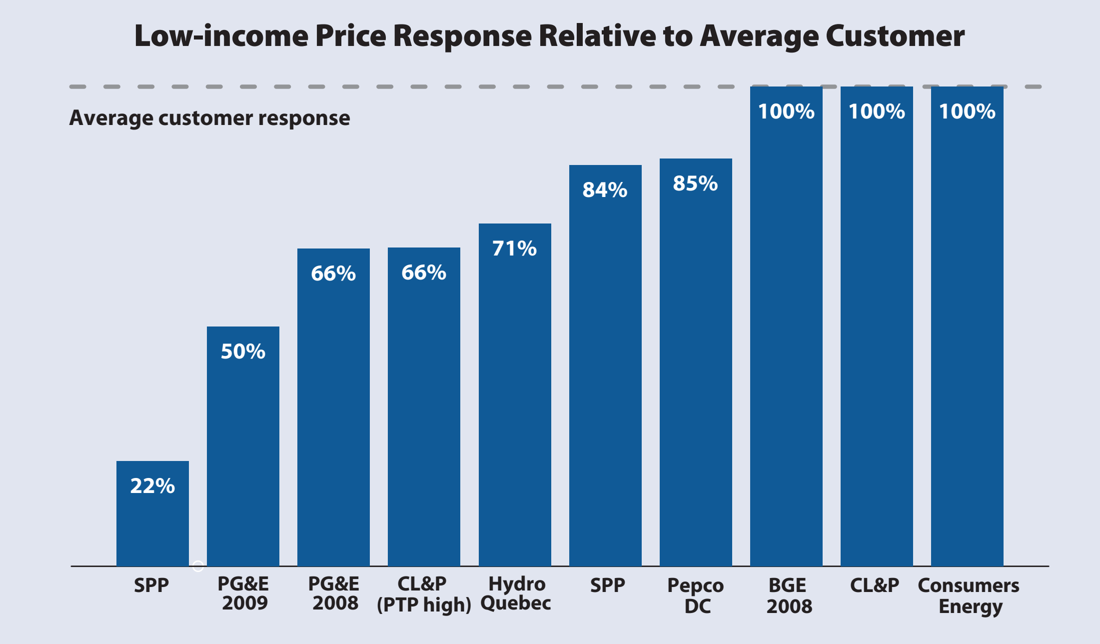

Distribution of Bill Impacts When Moving From Flat Rate to CPP Rate

Figure 5


Low-income Price Response Relative to Average Customer

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60 Faruqui, Sergici, Palmer, 2010

income customers (as in the Connecticut Light and Power (CL&P), Baltimore Gas and Electric (BGE), and Consumers Energy programs); others found they were less responsive compared to higher-income customers (but still with statistically significant peak reductions).[61] Figure 5 shows how the low-income customers responded relative to the average customer in each of the 10 pilots.

Persistence of Time-Varying Rate Impacts

It is important to understand the extent to which time-varying rate impacts will persist over a multiyear horizon. Persistence across multiple years has been demonstrated most significantly in a recent pilot in Maryland. At BGE, thousands of customers have participated in a PTR pilot over four summers (the pilot began in 2008 and is still running).[62] To test persistence, the PTR rate was offered during each summer to the same set of 400 customers. Econometric analysis revealed that these customers maintained the same level of price responsiveness across all four summers.[63]

Significant peak reductions also appear to persist over time in full-scale rollouts. In May 2008, Pacific Gas and Electric (PG&E) began to offer its CPP program (called "SmartRate") to all residential customers as part of a full-scale rollout. Enrollment exceeded 10,000 customers by the end of that year. By the end of summer 2010, 24,500 customers were enrolled. Analysis showed the average peak reduction impact to be 15.0 percent in 2009 and 14.1 percent in 2010.[64] A case study of the SmartRate program is provided in Section 5. Additionally, in Illinois, ComEd's residential RTP program has reported significant and persistent peak load reductions in every year between 2005 and 2010.[65]

Time-Varying Rates, Customer Feedback, and Enabling Technologies

During the past few years, a variety of new technologies have been introduced to help customers understand their usage patterns (through web portals and in-home displays, for example), to automatically control the function of their major end-uses such as central air conditioning and space heating equipment (smart thermostats), and to manage all their other appliances and plug-loads (home energy management systems). Empirical evidence shows that enabling technology enhances the impacts of time-varying rates on electricity consumption patterns.

BGE's time-varying rate pilot tested a variety of time-varying rates with and without enabling technologies in the years 2008 and 2009. The technologies included an "energy orb" that changed color depending on the price of electricity, and a switch for cycling central air conditioners when rates reached a specific price. It found that the peak impact with the energy orb was greater than the peak impact with price alone, and that the peak impact with both the energy orb and the air conditioner switch was even greater. Other analogous information or customer feedback systems have been used in automobiles and other energy displays, including plug meters, personal computer web displays, and audits. These feedback systems help to spur a phenomenon that is sometimes referred to as the Prius Effect, where consumers are challenged and motivated to alter behavior through the provision of timely information about energy consumption. For example, in 2008, the peak reduction with the PTR alone was estimated to be 21 percent. Adding the energy orb led to a peak reduction of 27 percent, and adding enabling technology on top of that led to a peak reduction of 33 percent. This demonstrates that both information and automating technologies can play a significant role in increasing customer price responsiveness.

Similarly, CL&P's Plan-It Wise Energy Program, conducted in the summer of 2009, tested multiple rates with the following technologies: smart thermostats, air-conditioning switches, energy orbs, and in-home displays. While the energy orbs and in-home displays were not found to have a statistically significant incremental effect on-peak reductions beyond what was achieved through time-varying rates, the presence of an air-conditioning switch or smart thermostat increased the impacts for the CPP and PTR groups. The air conditioning switch and smart thermostat increased the peak reduction from 11 percent to 18 percent for residential PTR customers,

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[61] Titles of the impact evaluations for these pilots are provided in the Additional Reading section of this report.

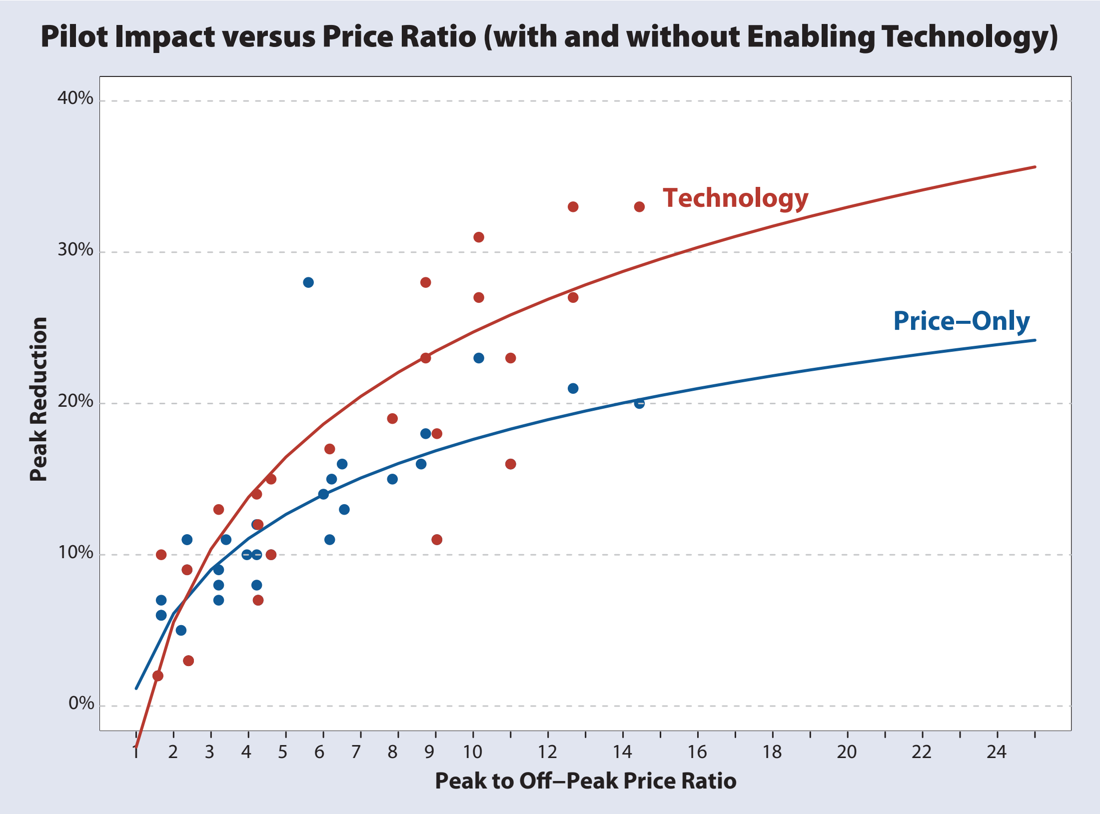
[62] Faruqui & Sergici, 2011

[63] Results will be published in a forthcoming report, "Impact Evaluation of the 2011 SEP Pilot" (expected publication date early-2012).

[64] Faruqui, Sergici, Akaba, 2011

[65] Navigant Consulting, 2011

Figure 6



and from 16 percent to 23 percent for residential CPP customers. Similar relationships were observed among small commercial and industrial customers.

For pilots that tested time-varying rates with and without enabling technology, a plot of price response against the peak-to-off-peak ratio shows that impacts with enabling technology tend to be higher than without. This is illustrated in Figure 6.

C. Questions That Remain To Be Answered

Despite all that we have learned from time-varying rate pilots, there are still important questions that remain to be answered through further study. In the next few years, it is anticipated that some of these questions will be addressed through a new wave of pricing pilots that have been funded in part by the U.S. Department of Energy.[66]

Customer preferences for rate types: One of the areas most critically in need of further research is that of customer adoption rates. In the absence of full-scale deployments, limited information is available regarding the share of customers that are likely to voluntarily sign up for a new time-varying rate, or the share that might opt-out of a rate. Additionally, little empirical research has been conducted to date regarding customer preferences when presented with a menu of rate options. Effective market segmentation and marketing approaches for promoting time-varying rate adoption are important areas for future research as well.

Impact of CPP versus PTR: While several pilots have tested equivalent CPP and PTR rates side-by-side, there is not yet conclusive evidence as to whether the two produce the same impacts from participants. Pilots in California, Michigan, and Maryland have found no statistically significant difference in price response from customers enrolled in these two rates. However, pilots in Connecticut and Washington, D.C., have both found that CPP induces a larger response (in one case, the response was more than twice as large). These results are summarized in Figure 7.[67] Also important to consider is the cost of CPP versus PTR programs, as discussed earlier in this paper.

One school of thought is that the “opportunity cost” of not reducing peak demand on a PTR rate is equivalent to the higher price paid during the peak period of a CPP rate, so the two should produce the same response from rational customers. Others believe that customers inherently respond more dramatically to a perceived penalty than to a reward, and therefore are more price responsive on the CPP rate.

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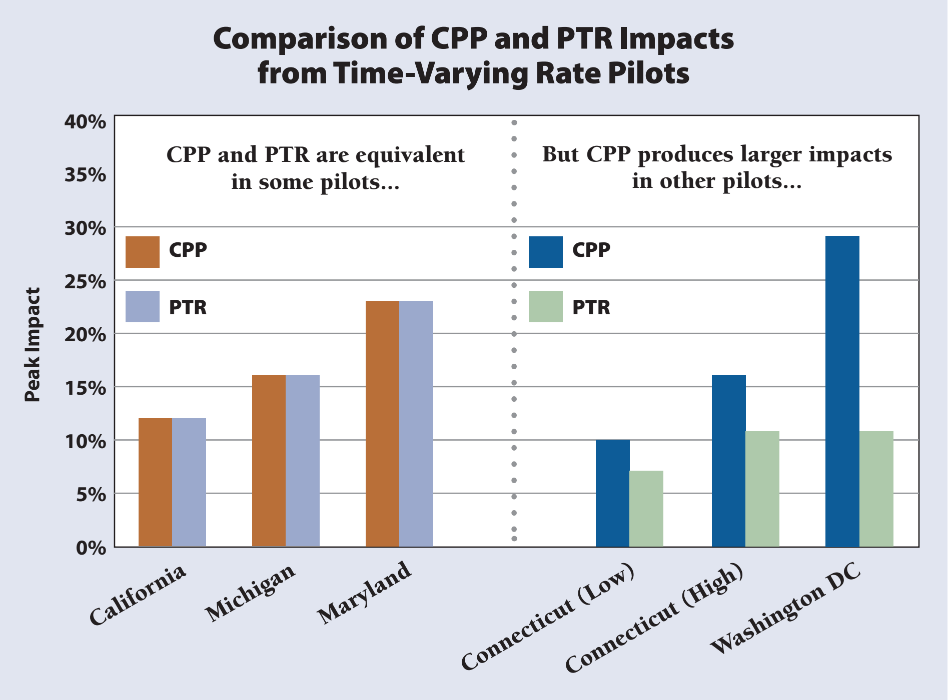
[66] More information can be found at www.smartgrid.gov.

[67] For California, Michigan, and Maryland, CPP impacts are simulated using a PTR-equivalent rate design and price elasticities from the respective pilots.

Conservation impact of time-varying rates: Most of the recent time-varying rate pilots have not found a significant conservation impact from time-varying rates (it is typically less than 1 percent).[68] However, the results of older TOU pilots suggested that the conservation impact could be between two and four percent.[69] One possibility is that conservation impacts will be observed to increase over time, as customers become increasingly aware of the cost of energy and transition from behavior-based load reduction activities to technology-based load reduction.

Figure 7



Fuel switching impacts: Another issue to be examined is whether high prices in a time-varying rate would encourage customers to utilize backup generation rather than purchasing electricity from the grid. From an environmental impact perspective, this could be negative if the source of backup generation was a diesel-fired turbine.[70]

The impact of enhanced information on peak demand: While a couple of pilots, such as those of BGE and CL&P, have tested the impact of in-home displays on peak demand reductions, the results have largely been inconclusive. Further study is needed on the peak impacts of enhanced energy information, both coupled with time-varying rates and also in the absence of new rate designs.

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[68] See the pricing pilot impact evaluations provided in the Additional Reading section of this report for details.

[69] King & Delurey, 2005

[70] One way to address this concern is illustrated in RAP's model rule for distributed generation emissions. See RAP, 2003. See, www.raponline.org/docs/RAP_Weston_ModelAirEmissionsRule_2002_10_31.pdf.

5. Full Deployment Case Studies

Full-scale deployments of time-varying rates have primarily been offered to large C&I customers that are exposed to hourly market prices in restructured electricity markets, and through TOU tariffs that are available to these customers as well as (to a lesser extent) some smaller customers. Otherwise, experience with full-scale deployments of innovative time-varying rates is fairly limited. Therefore it is not possible to discuss time-varying rate developments in some regions that are of interest, because thus far there has been little activity in this area. This may change as AMI deployments increase around the globe. However, to provide an overview of time-varying rates that have been practically deployed on a large scale, this section presents four brief case studies of countries with diverse power sectors, economies, and political environments. The countries are the United States (California), France, China, and Vietnam.

A. The United States (California)

Residential time-varying rates are an area of significant interest among many industry stakeholders due to the large role that they play in many AMI business cases. In the United States, the largest residential CPP deployment is offered by PG&E, which serves much of northern California. Due to strict reporting requirements in California, extensive information is available regarding the rate's impacts.[71]

PG&E began offering its CPP rate (called "SmartRate") in May 2008, with the initiation of its system-wide smart metering deployment. As of April 2011, enrollment in the rate had reached 24,500 customers. The rate is being offered on a voluntary (opt-in) basis, meaning that customers must take the initiative to move from their current rate to the new CPP rate. Eligibility to enroll in the CPP rate is expanding as smart meters continue to be deployed across the service territory.[72]

Rate features

Specific features of the rate are as follows:

- Applicable season: Summer (May 1 through October 31)
- Timing of peak period: 2 pm to 7 pm
- Maximum number of peak events: 15 per summer
- Notification of peak event: 3 pm the preceding day
- Peak surcharge: 60 cents/kWh
- Off-peak discount: 3 cents/kWh to 4 cents/kWh
- Implied peak-to-off-peak price ratio: Ranges from 4-to-1 to 11-to-1[73]
- Overlay: The rate is an overlay on other residential rate offerings (including an inclining block rate and an inclining block rate/TOU combination) using the surcharge and credit approach described in Section 2 of this report

Peak impacts

In 2010, PG&E called 13 peak events. Across all participants and all 13 events, the average reduction in demand during peak hours was 14 percent. This adds up to more than 6 MW of load across the participants. There was no discernible change in overall energy consumption (in other words, there was no "conservation effect").

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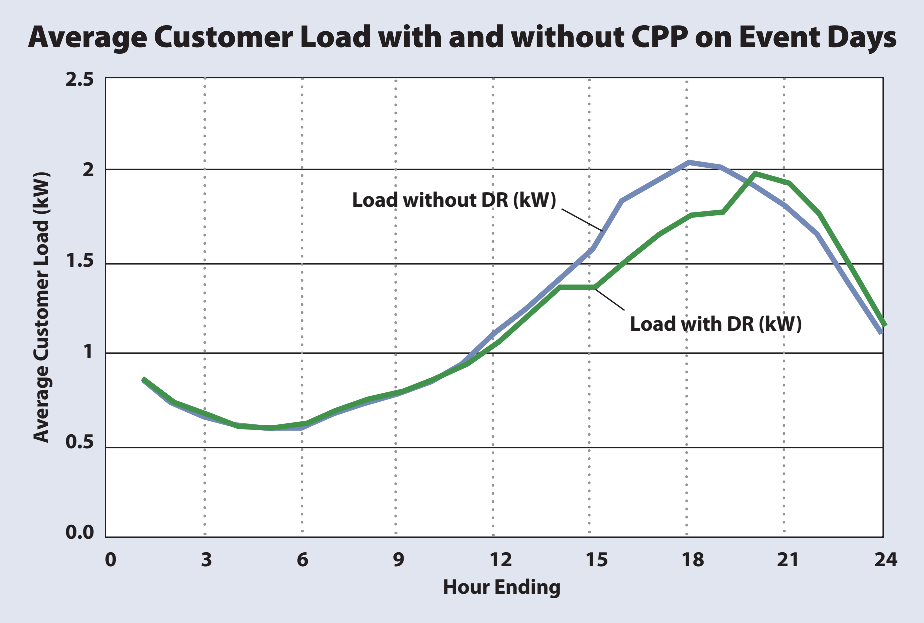
[71] Much of the information in this section is derived from George, Bode, Hartmann, 2011.

[72] The SmartRate will be replaced with a different CPP rate design, as ordered by the California Public Utilities Commission. The transition is pending. For more information, see the California Public Utilities Commission's November 2011 decision on this topic: http://docs.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/153342.htm.

[73] Due to the underlying inclining block rate design, the price ratio depends heavily on whether the customer is a large user (and therefore in the more expensive tiers of the inclining block rate) and whether the customer receives a low-income discount.

Figure 8 illustrates the average customer load on a peak event day with and without a CPP rate.[74]

Figure 8



Across events, the average peak reduction ranged between six and 21 percent. A failure to deliver notification to a large segment of customers contributed to the low end of this range of impacts. Otherwise, the low end was in the range of 10 percent to 12 percent.

Bill impacts

During summer months, when the CPP surcharge and discount applied, customers saved an average of $53 (8.2 percent) compared to their otherwise applicable tariff. Overall, 88 percent of participants reduced their electricity bill. Presumably as a result, the vast majority of customers who signed up for the rate have remained on it. Over more than two years, the average attrition rate for the program was 0.3 percent per month.

Low-income customer impact

The CPP rate was offered to customers in PG&E's low-income program, which provides a rate discount to qualifying participants (the same CPP surcharges and credits still apply). As a percent of peak demand, these customers provided reductions that were roughly one-third of that of the average customer who is not in the low-income program. However, once the low-income response was normalized for factors such as central air-conditioning ownership, it was found that there was no statistically significant difference between the load reductions.

B. France

A CPP rate has also been offered to residential customers in Europe, and for much longer than in California. Electricite de France (EdF) began offering its CPP rate (called the "Tempo Tariff") to residential customers across France in 1996. Since then, roughly 400,000 customers have enrolled in the rate.

Rate features

The Tempo rate is a bit different than a conventional CPP rate in the sense that both the peak and off-peak prices are not known to participants until the preceding evening. Each evening, customers are informed that one of three different price schedules will be in place the next day. Each day is assigned a color depending on the price schedule:[75]

Table 3

Tempo Tariff Rate Structure

Day Designation	Peak Price (Euro Cents)	Off-Peak Price (Euro Cents)	Applicable Days per Year
Blue	3.8	3.0	300
White	7.8	6.5	43
Red	35.5	12.4	22

Other rate design features are as follows:

- Applicable season: Winter (November 1 through March 31)
- Timing of peak period: Very long, from 6 am to 10 pm
- Trigger: Load forecast (red days called on expectation of highest load)

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[74] Figure is reproduced from George, Bode, Hartmann, 2011.

[75] Prices are presented as defined by EdF in 2005.

- Notification: 8 pm the evening before
- Method of notification: Many customers are equipped with a plug-in device that changes color depending on the pricing period and the announcement of the next day's color; others receive notification via phone or the internet

EdF also offers various options for customers to sign up to have their appliances automatically controlled to run only during lower-priced periods and days.

Peak Impacts

The total peak load reduction that has reportedly been achieved through the Tempo program is 450 MW. This is due to an average peak load reduction of 45 percent from participants on red days (and 15 percent on white days). This level of price responsiveness is much higher than that which has been observed in pricing pilots in other parts of the world, possibly due to the program's long history, an extensive customer education program (including in-home visits), and the wide range of load control technologies and informational devices that are offered.

Bill Impacts

Participants have reportedly achieved an average bill savings of 10 percent relative to other rate options. EdF estimates that as many as 7 million of France's customers could benefit by enrolling in the tariff, but that many do not appear to be willing to do so unless it could save them more than $150 per year. Overall, 90 percent of the program's participants report to be satisfied with the tariff.

C. China

In the past decade, the People's Republic of China has developed various demand-side management (DSM) programs to address increasing electricity demand, declining load factors, and power shortages. Most load management in the country has been compulsory load shedding, with mandatory load reductions ordered by the government. To a limited extent, the new load management strategies have focused on more customer-friendly options, including TOU pricing and inclining block rates, which vary by region.[76] The following are descriptions of these programs in various Chinese provinces, to the extent that information is publicly available.[77]

Beijing

In Beijing, where the load factor had been steadily decreasing, DSM programs have enabled the load factor to remain around 81 percent from 1997 to 2003. Roughly 62 percent of the population was on TOU rates by the end of 2003, causing 700 MW to shift to off-peak hours. Beijing has also added 443 ice storage air-conditioning units and heat storage boilers, which have reduced peak load by more than 300 MW and benefit from the peak-to-off-peak price differential inherent in the TOU rate.

Guangdong

Guangdong has had three-period TOU prices for industrial customers since 2001, with variation in rate design between cities. The TOU rates have led to total peak reduction of about 500 MW. Due to a year-long power shortage in 2004, Guangdong also implemented involuntary load interruption for industrial customers, leading to a peak reduction of half of a percent in peak hours and an increase of two percent in off-peak hours.

Hebei

Like many of the other provinces, Hebei is experiencing a decline in load factor, due to an increase air conditioning load. Facing a gap of about 3,000 MW between power supply and demand, Hebei has implemented some important DSM programs. 40,000 customers (about half of all sales) are on TOU rates. The TOU rates have reduced peak load by about 1,100 MW. Additionally, Hebei has instituted a mild CPP rate, with a critical peak price 10 percent higher than the standard peak price.

Jiangsu

TOU pricing, which had been applied to industrial customers since 1999, has been offered to residential customers on a voluntary basis since 2003.

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[76] China has a nationwide policy of TOU pricing for industrial customers. TOU pricing for residential customers is newer and only available in some provinces.

[77] This section is largely derived from Charles River Associates, 2005 and Wang, Bloyd, Hu, & Tan, 2010. Some of the programs described here may have changed or been replaced with newer programs.

Shanghai

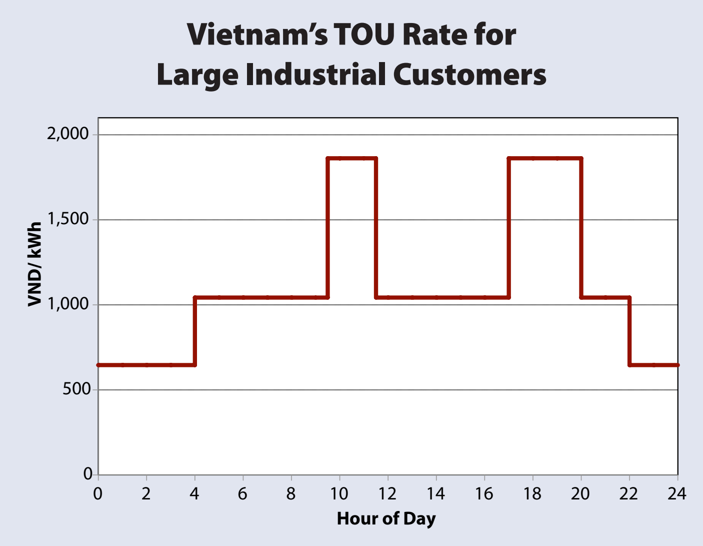
In Shanghai, customers face a TOU rate with a 4.5-to-1 peak to off-peak price ratio.[78] Additionally, during the period from 1 pm to 3 pm, the maximum load of large customers must be lower than 90 percent of their daily maximum demand; otherwise, the price doubles.

D. Vietnam

Vietnam experienced demand growth at the staggering rate of over 20 percent per year throughout the 1990s, and it is expected to continue to grow at a rate of 14 percent per year through the coming decade. The capitalization needed to support this growth in demand for both electricity and other commercial energy sources has placed a tremendous strain on Vietnam's financial resources. To address this peak demand problem, reduce instances of supply shortage, and avoid costly investment in new power plants, the national utility (Electricity Vietnam, or EVN) has implemented TOU pricing for its largest customers.

EVN first introduced a TOU tariff in 1998 and has supported this with the purchase and installation of TOU meters for all customers with loads over 50 kVA or consumption in excess of 5,000 kWh per month. By the end of 2001, EVN and its power companies had installed about 5,600 TOU meters in customer premises, and by December 2002, over 20,000 customers had received TOU meters. Economic growth is expected to increase the number of eligible customers by about 8.5% annually. An illustration of the TOU rate is provided in Figure 9.

Figure 9



This is a mandatory program for larger customers, and early indications are that many customers have responded by shifting loads from peak hours to off-peak periods. With the support of the external funding, EVN will continue encouraging large customers to shift their energy consumption, and will deploy TOU meters for all commercial, service and agricultural (irrigation) customers with transformer capacity over 50 kVA. The cutoff for eligibility is expected to drop in order to encourage additional participation over the coming decade. The total estimated peak load reduction from this program is about 70 MW, sufficient to save $46 million in new capacity investments.

A key program element is marketing and information campaigns that would accompany the TOU meter installations, so customers could understand the TOU tariff and meter and receive information on load shifting and energy efficiency options they could avoid an increase in their overall electricity bill. EVN initially experienced customer resistance to TOU pricing due to a lack of understanding of the potential benefits of the rate. For example, a number of customers have responded by installing stand-by generation units and disconnecting from the grid during peak times to avoid the higher peak price. This customer pushback has led to additional efforts by EVN to reach out to medium and large customers with energy and bill saving suggestions.

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[78] As of December 2003.

6. A Blueprint For Offering Time-Varying Rates

Section 6 consolidates the recommendations that have been discussed in the preceding sections into a concise blueprint for deploying time-varying rates across a service territory. The blueprint assumes little experience with time-varying rates and introduces several steps for arriving at a point where rates can be rolled out to all customers. The steps are: understand the impact of today's rates, develop a consistent and comprehensive set of ratemaking objectives, identify the menu of possible rate options, perform preliminary assessment of potential impacts, conduct preliminary market research, conduct time-varying rate pilots to identify preferred options, and as appropriate, deploy time-varying rates at scale.

Step 0: Understand the Impacts of Current Rates

Before beginning the transition to innovative rates, it is first necessary to focus on understanding the impacts of the current rates. To evaluate the load impacts of existing rates, load research data should be collected for a representative sample of customers in each rate class. With robust data extending over a sufficient time horizon, econometric modeling can be used to evaluate the load impacts of recent rate changes (if any) after controlling for economic and weather variables. This would potentially provide valuable insight regarding customer price responsiveness.

Additionally, focus groups and surveys could be conducted to determine customer perception and awareness of recent rate changes. How many customers claim to have noticed the rate change? And what is their overall attitude toward the new rates? This subjective analysis would provide insights regarding how they might react to a more significant transition to new rate forms and could inform the customer education plan for that transition.

Step 1: Develop A Consistent and Comprehensive Set of Ratemaking Objectives

Ratemaking objectives should be established to advance the policy goals of the state or region. It is important to ensure that ratemaking objectives do not conflict. There is not a single rate that can accomplish all goals. Specifically, policymakers should ask whether there are specific needs, rather than merely broad welfare objectives, that need to be met. It is also important to consider developing a second tier of objectives that would be specific to individual customer classes. Initiating internal focus groups, customer interviews, and stakeholder meetings would be one way for getting started on this journey.

An intelligently designed rate can be effective in accomplishing a number of different objectives. In the 1960s, James Bonbright established ten criteria that have served as guiding principles in electricity ratemaking for the past half century.[79] For details on these objectives, see Rate Design Using Traditional Meters.[80] Generally, reasonable ratemaking criteria can be collapsed into four broad requirements: promote economic efficiency, promote equity (or current perceived equity), facilitate customer choice, and clearly and effectively communicate prices and costs.

Step 2: Identify the Menu of Possible New Rate Options

With the ratemaking objectives established, the next step is to develop a deeper internal knowledge base of the potential future rate options that could be provided. This includes researching innovative rate designs that are currently being examined by other utilities as well

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[79] Bonbright, Danielson & Kamerschen, 1988

[80] Additionally, see Weston, 2000

as surveying ongoing experimental pricing pilots and AMI filings. In conducting this review, consider the distinguishing characteristics of the various rate forms and screen out any options that are entirely infeasible or not in line with the state's or region's energy strategy and policies.

All of the rate designs described in Section 2 provide varying degrees of opportunities for customers to reduce their bills through demand response and also expose the customers to varying degrees of price volatility. Generally, "flatter" rates provide customers with a hedge against price volatility and provide less opportunity for bill savings.

Appropriately designed time-varying rates will account for the level of risk that the customer assumes by enrolling in the rate (or not opting out). For example, a customer on an RTP rate assumes the full risk implicit in the volatility and uncertainty of the hourly wholesale market prices. For these customers, the utility can simply pass the wholesale prices through to the customer. The utility itself does not incur any risk associated with hedging to provide the customer a fixed price. Thus, the cost for the utility to serve RTP customers is typically lower than the cost to serve customers on a flat rate. The spectrum of rates between the flat rate and the RTP reflects varying degrees of risk avoidance from the utility's perspective.

Step 3: Perform Preliminary Assessment of Potential Impacts

For each customer class of interest, develop illustrative rate designs using real system data. The potential impacts of these rates should be simulated using the best available models tailored to the utility's system conditions. Sensitivity analysis should be performed through the course of these simulations to capture the range of uncertainty in the projections. Ultimately, use the simulations to develop a preliminary strategy for the pricing transition and to narrow down the range of potential rate offerings.

There are two steps in developing estimates of time-varying rate impacts: developing illustrative rates based on system data, and then identifying the appropriate models and assumptions to tailor the simulation results to specific conditions.

Designing Illustrative Rates

Begin by designing illustrative rates that are representative of the types of rates that might be offered once the pricing transition is complete. These rates would be developed using existing load research and system cost data. There are several key elements to designing successful time-varying rates that produce both significant peak reductions and high customer acceptance rates. Refer to Section 3 for more information.

Simulating Rate Impacts

Estimating demand response to time-varying rates requires an understanding of the empirical studies on price-driven customer response as well as the ability to tailor the information in these studies to the utility's specific system conditions.

To generate meaningful simulations for a given utility service territory, the results of recent pricing pilots should be calibrated to the utility's system characteristics, such as weather conditions, load profiles, saturation of central air conditioning and existing rates.[81] When combined with a forecast of the number of customers participating in the rate, the result is a system-wide forecast of annual peak demand reductions. The peak demand reductions are expected to yield supply-side benefits, such as lower capacity and energy costs, as well as additional benefits like mitigation of high wholesale market prices.

Step 4: Conduct Preliminary Market Research

Market research is necessary to avoid repeating the mistakes that have already been encountered by other time-varying rate deployments. First, survey the international experience with time-varying rate design and develop a list of "lessons learned" through recent pricing pilots (some of which are summarized in Section 4 of this report). Then, conduct primary market research to understand customer reactions to the rate designs through interviews, surveys, and focus groups. This will serve as a departure point for beginning the customer education process.

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[81] The Price Impact and Simulation Model (PRISM) is designed to assist with this calibration. See The Brattle Group, 2008. The model is available on the web: http://www.eei.org/industry_issues/electricity_policy/advanced_metering_infrastructure.htm.

Specific objectives of the focus groups could be to:

- Gauge customer understanding of the time-varying rates
- Assess customer interest in and concerns about different time-varying rate options in terms of both the prices and the rate structure
- Identify information that would be most useful to customers on the time-varying rates
- Obtain customer reactions to bill savings under alternative rate designs
- Determine effective ways to communicate about the time-varying rates to customers
- Determine effective ways to notify customers about critical days
- Gather customer reactions to control technologies and an information display, and
- Obtain feedback on how to effectively recruit customers for the pilot (including appreciation incentives)

The survey instruments could include questions to gather information on customer demographics, customer satisfaction, understanding of the rates, understanding of the bill impacts, understanding of information presented, recruitment strategies, importance of enabling technologies, and customer acceptance. The survey could also be used to gather reactions to and additional information on alternative prices, times of day, durations, frequencies, types of automation mechanisms, and information delivery.

Step 5: Conduct Time-Varying Rate Pilots

With an understanding of the various innovative pricing options and their potential impacts, the next step is to conduct pilots in the relevant service territory. First, establish objectives for the pilot. Then, determine the final rates to be tested in the experimental pricing pilot. The number of customers to be included in the treatment and control groups will need to be defined in a way that will provide statistically significant results. The sampling plan should be designed to ensure that the participants are representative of the applicable customer base. Then, identify data to be collected through the pilot, including demographic characteristics of the participants and hourly load data. Final steps are to develop customer recruiting instruments for the pilot and a schedule for pilot implementation. Guidelines for effective pilot design are provided in Section 4 of this report.

Step 6: Full-Scale Deployment of Innovative Rates

Upon evaluating the pilot results, identify the rate types to be offered to each customer class. The appropriate rate deployment plan (opt-in, opt-out, mandatory) will also need to be determined. Finally, it will be necessary to identify key barriers to adoption of the new rates through focus groups and stakeholder interviews and to develop a strategic approach to addressing the barriers before, during, and after rate deployment.

Rates can generally be offered in three ways. The first is opt-in deployment, in which customers would have to proactively select to leave their current rate and sign up for the new rate. The second method of deployment is opt-out recruitment. Customers would automatically be enrolled in the new rate, but would have the option not to accept the new rate and thus stay on the current rate. The third option is mandatory deployment, in which customers are given only one rate choice and that is the new rate. Flexibility could be incorporated into the mandatory rate offering, in which customers are required to sign up for a new rate but are given the option of two or more rates to choose from. Choice of multiple rate designs could also be applied to opt-in and opt-out rate deployment plans.

Generally, it has been found that the deployment plan for a specific rate has a significant effect on its ultimate adoption, and customer participation rates can vary widely as a result. A general rule of thumb that has been developed through experiments such as the California Statewide Pricing Pilot is that participation in an opt-out rate could be as high as 80 percent of the eligible population, while participation in an opt-in rate might be closer to 20 percent.[82] The individual regulatory climate and specific corporate goals would both play a significant role in ultimately determining how the new rates will be offered.

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[82] Momentum Market Intelligence, 2003

7. Conclusions

This report has discussed a variety of ways in which time-varying rates can be designed, evaluated and deployed. It has surveyed empirical results from pilots, experiments and full-scale deployment from around the globe. The discussion has focused on customers in mass markets that traditionally have had access to time-varying rates.

Given the rapid rate at which AMI is being deployed throughout the globe, it has become feasible to offer time-varying rates to customers in the mass market segment. However, while AMI is a prerequisite for the deployment of most types of time-varying rates, its existence by itself does not suffice to make these rates available in the mass market.

All the key stakeholders in the rate making process have to buy into the provision of these rates. These include utilities, regulators, governing bodies and ultimately the customers themselves. Rate design is rarely a single-step process; the initial design is often going to create "winners" and "losers" and trigger debate.[83] By modifying the initial rate design to accommodate the interests of the various parties, better solutions can be found. However, it will rarely be the case that a win-win solution will be found that will please everyone.

Changes in rate design have been fraught with controversy from the beginning of the electricity industry. The British writer D. J. Bolton put it well when he noted in the preface to his 1938 textbook on "Costs and Tariffs in Electricity Supply":

> *There has never been any lack of interest in the subject of electricity tariffs. Like all charges upon the consumer, they are an unfailing source of annoyance to those who pay, and of argument in those who levy them. In fact, so great is the heat aroused whenever they are discussed at institutions or in the technical press, that it has been suggested that there should be a "close season" for tariff discussions. Nor does this discussion exaggerate their importance. There is general agreement that appropriate tariffs are essential to any rapid development of electricity supply, and there is complete disagreement as to what constitutes an appropriate tariff.*[84]

The discussions become particularly acrimonious when it comes to time-varying rates. This was noted in 1971 by William Vickrey, a noted economist at Columbia University who went on to win the Nobel Prize in 1986. He said the main difficulty with such rate designs was "likely to be not just mechanical or economic, but political." He felt that despite living in the twentieth century, people still believed in the medieval notion of a just price as an ethical norm, and that prices that varied according to the circumstances of the moment were intrinsically evil. Vickrey opined prophetically:

> *The free market has often enough been condemned as a snare and a delusion, but if indeed prices have failed to perform their function in the context of modern industrial society, it may be not because the free market will not work, but because it has not been effectively tried.*[85]

So the design of time-varying rates has to be viewed as an iterative process that will only converge when the multiple objectives of the various participants in the process have all been met up to a certain point that implementation becomes practical.

The most frequently cited objective in rolling out time-varying rates is to improve efficiency in the allocation of scarce capital and fuel resources to the electricity sector. But it is important to state what specific type of efficiency improvement is being considered. Is it economic efficiency (maximize the social surplus, defined as the sum of consumer and producer surplus), energy efficiency

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[83] Sioshansi, 2012

[84] Bolton, 1938

[85] Vickrey, 1971

(minimize energy consumption), demand response efficiency (maximize load factors) or environmental efficiency (such as reducing greenhouse gas emissions)? Each one has different consequences for rate design and it will be the job of the rate analyst to quantify these and lay them out in a manner that can help policy makers make a well-informed choice.

Another major objective is equity. Rates should reflect costs, and customers that cost more to serve should pay higher rates and those that cost less to serve should pay lower rates. Some people argue that the purpose of time-varying rates is simply to transmit cost-based price signals, regardless of whether they improve efficiency.

Policy makers may wish to pursue time-varying rates due to one or both objectives. In all cases, they will need to grapple with another major issue: how many customers should be placed on time-varying rates? If the rates are mandatory, then all customers will be on those rates. That has been the practice for large commercial and industrial customers in many regions. If time-varying rates are the default rates, then a high percentage of customers will stay on those rates and a low percentage will optout to alternative rates. If instead time-varying rates are offered on an opt-in basis, then it is likely that a low percentage of customers will take them.

In most cases, overall efficiency and equity benefits will rise in proportion to the number of customers who receive electricity service on time-varying rates. But moving everyone simultaneously and abruptly from standard to time-varying rates is likely to engender chaos and backlash. So a way has to be found to make a gradual transition.

One approach is to move all customers to the time-varying rate but to simultaneously provide them bill protection during the first few years of the transition period. In the first year, they could be given full bill protection and pay the lower of the two bills – the bill they would have paid had they stayed on the traditional rates or the bill they would pay on the time-varying rate. This bill protection would then be phased out after a transition period during which customers have adapted to the new pricing regime.

Another approach is to offer a two-part pricing signal, the first part non-time-varying and the second part time-varying. The main question is how to construct the first part. In one approach, it is set based on historical usage patterns either of the class as a whole or of individual customers. The first part would be served on the standard rate. As long as customers consume at a level equal to their historical pattern, they would pay the same bill. The second part would apply to variations from their historical pattern. It would be priced on a time-varying basis. If customers use more during peak periods than their historical pattern, they would pay a rate that reflects the full marginal costs of providing peak power. If customers use less, they would get a credit. Alternatively, customers can pick their own first part and "buy" it based on forward prices, and then buy their second part based on market prices.

In mature economies, much has been learned about how customers respond to time-varying rates, based on pilots and experiments, but even in these regions, relatively little is known about how customers will respond in full-scale deployments. There is no substitute for field experience and only time will provide this. Moreover, in developing countries similar pilots and experiments have not been carried out and it would be useful to do so. They are a prerequisite to full-scale deployment.

Another area in which research is needed pertains to customer preferences and understanding of time-varying rate options. What type of rate appeals to which customer segment and why? What can be done to improve customer understanding of how different rate choices will affect their economic well-being? How are customer participation rates going to differ between opt-in and opt-out deployment scenarios? Even in developed countries these questions are poorly understood today and the area remains ripe for further work.

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Appendix A:

Additional Reading

The reports and articles presented in this appendix are intended to provide a few helpful starting points for further research on time-varying rate issues. This is not intended to be a comprehensive list of every relevant report on the topic.

Pricing Pilot Impact Evaluations

Pricing pilot impact evaluation reports are a helpful source for understanding the impacts of time-varying rates on customer electricity consumption patterns and electricity bills. The reports typically also provide detail on the design of the pilot and how it was implemented. Examples of some comprehensive pilot impact evaluations are provided below:

- *Impact Evaluation of the California Statewide Pricing Pilot*, prepared by Charles River Associates (2005, March 16).

- *Impact Evaluation of the SEP 2010 Pilot*, by A. Faruqui, S. Sergici, & L. Akaba (2011, March 22). Prepared for Baltimore Gas and Electric Company.

- *PowerCentsDC Program Final Report,* prepared by eMeter Strategic Consulting (2010, September).

Full-Scale Deployment Studies

In addition to pilot results, studies on the impacts of full-scale pricing deployments also provide useful insight regarding time-varying rate impacts. These also include useful information about customer adoption. Three such studies are as follows:

- *A Survey of Utility Experience with Real Time Pricing,* by G. Barbose, C. Goldman, & B. Neenan (2004). Lawrence Berkeley National Laboratory: LBNL-54238.

- *2010 Load Impact Evaluation of Pacific Gas and Electric Company's Time-Based Pricing Tariffs,* by S. George, J. Bode, & E. Hartmann (2011, April 1). Prepared for Pacific Gas & Electric.

- *Evaluation of the Residential Real Time Pricing Program, 2007-2010,* by Navigant Consulting (2011, June 20). Prepared for Commonwealth Edison Company.

The Value of Time-Varying Rates

Several studies have been conducted on the value of time-varying rates. Many of these are in the context of utility business cases that are filed to support AMI investment. One example business case, as well as two whitepapers, are provided below:

- *Southern California Edison Company's (U 338-E) Application for Approval of Advanced Metering Infrastructure Deployment Activities and Cost Recovery Mechanism.* Application A.07-07-__ filed with California Public Utilities Commission on July 31, 2007.

- *Quantifying the Benefits of Dynamic Pricing in the Mass Market,* by A. Faruqui & L. Wood (2008, January). Prepared for the Edison Electric Institute.

- *Quantifying Demand Response Benefits in PJM,* by The Brattle Group (2007). Prepared for PJM Interconnection, LLC and the Mid-Atlantic Resources Initiative.

Other Resources

FERC's annual survey of the status of AMI deployment and time-varying rates in the United States:

- *2011 Assessment of Demand Response and Advanced Metering,* by FERC Staff (November 2011).

The Brattle Group's survey and concise summary of the results of recent international residential dynamic pricing pilots:

- *Household Response to Dynamic Pricing of Electricity: a Survey of 15 Experiments*, by A. Faruqui & S. Sergici (2010). Journal of Regulatory Economics 38:193-225.

A collection of U.S. Department of Energy Guidance Documents for designing and implementing time-varying rate pilots:

- DOE website: http://www.smartgrid.gov/recovery_act/reporting_resources

The state of California's authoritative document on cost-effectiveness tests for evaluating demand-side programs:

- *California Standard Practice Manual: Economic Analysis of Demand-Side Programs and Projects* (October 2001).

The University of California Energy Institute's overview of dynamic pricing issues and fundamentals:

- *Dynamic Pricing, Advanced Metering, and Demand Response in Electricity Markets*, by S. Borenstein, M. Jaske, & A. Rosenfeld (October 2002).

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