Guidance for Utilities Commissions on Time of Use Rates:

A Shared Perspective from Consumer and Clean Energy Advocates

Electricity Rate Design Review Paper No. 2

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Introduction & Executive Summary

As rapidly evolving renewable and energy efficiency technologies and economics drive ongoing transformation of America's power sector, advocates from consumer, clean energy and environmental organizations are working together to provide guidance for utilities commissions and other stakeholders grappling with issues of electricity rate design. In prior papers, groups from these communities have jointly analyzed the problems with fixed customer charges and residential demand charges,[1] and also outlined good process principles[2] for evaluation and decision-making on rate design proposals. In this paper, authors representing a diverse range of consumer and clean energy perspectives assess the use of time-varying rates for billing residential electricity customers, with a particular focus on time-of-use rates ("TOU rates"), and offer guidance for regulators and others considering this rate design approach.

Time-varying rates are proposed to address a range of issues, including economic efficiency, peak load reduction, and equitable cost allocation across the customer base. If properly designed and implemented, TOU rates may allow individual consumers to reduce their energy bills, improve system utilization and reduce peak demand. And if enough individual consumers respond to the price signals that TOU rates provide, they may also generate supply and delivery cost savings for all. However, TOU rates can have adverse impacts on consumers, especially on those who may have less ability to shift their usage to capture the benefits of TOU pricing, and on those who have trouble budgeting for bills that exhibit greater monthly volatility. This potential for adverse bill impacts, as well as for negative health and safety repercussions if electricity prices spike during times of maximum need for electric cooling or heating, has led some consumer groups to oppose the use of default TOU rates. Moreover, there may be alternative solutions to reduce system peaks that do not require installation of new meters or charging higher prices during peak demands.

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[1] Chernick, P., Colgan, J., Gilliam, R., Jester, D., and LeBel, M. 2016. *Charge Without a Cause? Assessing Electric Utility Demand Charges on Small Consumers. Electricity Rate Design Review Paper* No. 1. Note: in this paper, we use the term "fixed charges" to refer to both fixed monthly charges as well as monthly demand charges.

[2] Letter to Hon. Travis Kavulla, President, NARUC, from a representative group of consumer, low-income, environmental and technology-specific advocates outlining what "good" rate design looks like. June 2016 download at: http://blogs.edf.org/energyexchange/files/2016/06/Good-Rate-Design-Process-Letter-to-NARUC.pdf

In concert with advice in the NARUC Manual that regulators be mindful of changes that are rushed and may bring unintended consequences,[3] public utility commissions should weigh TOU rates meticulously – and other alternatives to achieving similar goals – with special attention paid to ensuring that any implementation does not disproportionately harm low-income consumers, elders, and others who are particularly vulnerable to adverse health effects of unsafe indoor temperatures.

Following are key points and recommendations that emerge from this paper for public utility commissions considering residential TOU rate proposals:

- Require explicit up-front identification of the utility system and policy objectives to be achieved with a TOU rate, such as economic efficiency, deployment of DER technologies, peak load reduction, emissions reduction, and/or more equitable cost/benefit allocation.
- Identify and evaluate the costs and benefits associated with the full range of alternatives to achieving identified goals, such as tiered rates, utility direct load control programs, peak time rebates, or greater efficiency spending, rather than confining evaluation to TOU rates alone.
- In evaluating impacts on customer bills, carefully consider the drivers of new generation as well as new transmission and distribution capacity in the relevant jurisdiction, and study the degree to which a change in overall residential load profile may occur and impact those drivers and cost allocation to the customer class.
- To help make TOU rates both effective and understandable, keep the rate design to a relatively few time periods (e.g. 2-3) that are well-synced with underlying system costs; ensure the pricing differences are appropriate; and consider closely the length of the on-peak price period to facilitate customer adoption and load response.
- Ensure customers have the advance education and technology they need to respond. Use the following types of programs to achieve this: pilots such as implementing TOU rates with segments of customers with larger loads that are easier to control, like electric water heaters or electric vehicle charging; shadow billing for a year to give customers a chance to understand how they will be affected; and distribution of smart appliances such as timer controls or grid-integration for electric water heaters, or smart thermostats for space conditioning, if such distribution is found to be cost-effective based on incremental demand response benefits.

[3] NARUC Manual on Distributed Energy Resources Rate Design and Compensation. Prepared by the NARUC Staff Subcommittee on Rate Design. 2016. Hereinafter referred to as "NARUC Manual".

- If emissions reductions are a stated goal, carefully study what resources will run more as a result of load shifts – such as gas vs. coal vs. hydro or solar or wind – to inform structuring of periods that will result in maximum potential emissions cuts.
- TOU rate design is generally consistent with customer-sited solar deployment, but the extent to which they are compatible for the residential consumer is highly dependent on the rate design that applies to the self-generation. While TOU peak pricing periods often coincide with solar photovoltaic (PV) peak production periods, this will vary from utility to utility, state to state and region to region.
- TOU rates can easily be combined with inclining block rates to provide a more powerful price signal, as has been done in several states including California and Washington.

1.0 Overview of Time Varying Rates & Summary of Time of Use Rate Characteristics

Overview of Time Varying Rates

Since the passage of the Public Utilities Regulatory Policies Act (PURPA) in 1978, most utilities have implemented residential and small commercial rates with a small customer charge to cover billing and collection costs, and a flat or tiered inclining block energy charge to recover all other distribution, transmission, and power supply costs. Recently, utilities have promoted significant changes to residential and small commercial rates to address flat and in some cases declining year over year sales, particularly on a use per customer basis. As illustrated below, this energy sales trend accelerated with the great recession beginning in 2008, and the growth of alternative energy-related choices[4] for small customers, notably residential and small commercial customers on volumetric energy rates.

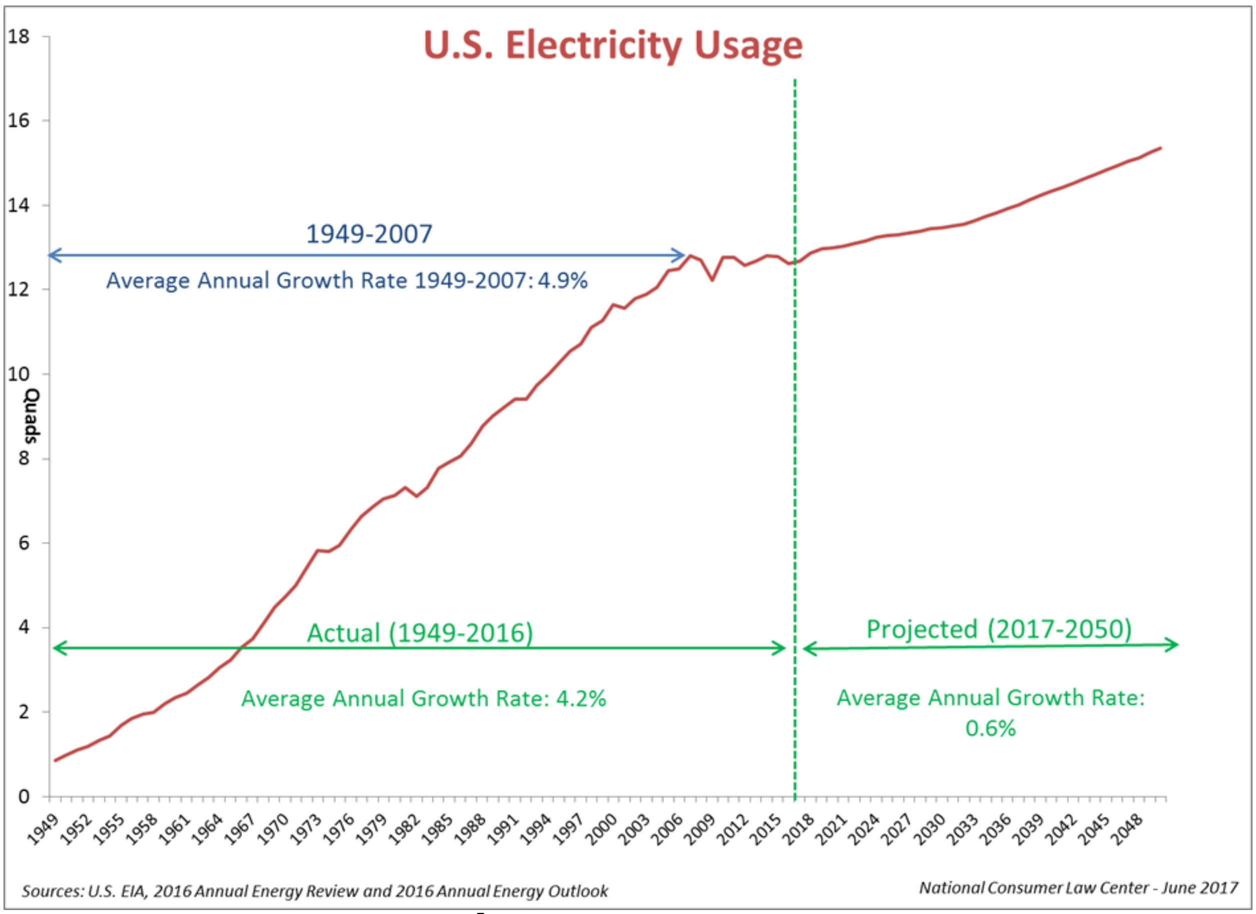

Figure 1: U.S. Electricity Usage[5]

[4] Such choices include technologies that can reduce energy consumption, shift energy consumption from one time to another, shift specific devices to another energy source such as natural gas, and generate energy.

[5] Source: National Consumer Law Center

Utilities have frequently advocated for greater recovery of costs through fixed charges including increased monthly customer charges (a.k.a. basic service), tiered customer charges, or even mandatory residential and small commercial demand charges. In response, consumer, clean energy and environmental advocates have generally pushed back against these proposals[6] – defending current rate structure forms, including inclining block rates. Time-varying rates ("TVR") have been proposed by some as a way to potentially bring down utility costs in line with declining revenues, and/or as a path toward goals such as bill savings, emissions reductions, better integration of variable renewable resources such as wind and solar, and lower utility capital requirements for construction. This paper focuses on the potential pros and cons of TVR while also considering inclining block rates ("tiered rates") as an alternative to traditional flat volumetric rates.

Generally, TVRs charge customers a higher price during peak hours and a lower price during off-peak hours, recognizing time-based differences in a utility's generation costs and taking marginal costs into account for different hours, days, or seasons (See NARUC Manual, pp. 26-31). Consequently, unlike flat or inclining block rates, customers need to be aware of the timing of their usage during the differentially-priced times in order to respond to the price signals in a TVR and minimize their bills.

There are several variants of TVR rates, including time-of-use (TOU), critical peak pricing (CPP) and real time pricing (RTP). The most common form of residential TVR rates in use are TOU rates, which establish different specified prices for certain pre-set periods of time. The time periods and charges are established in a formal general rate case (GRC). CPP rates charge very high prices for only a few hours (perhaps 60-100 hours) of the year, usually based on day-ahead power forecasts.[7] CPP rates are intended to reduce customer usage and shave system peak demand during periods when wholesale prices are very high, generally during times of extreme outdoor temperatures. In most cases, the number and duration of CPP "events" in a given season is pre-set by the utility, and customers get advance notice – usually about 24 hours – before an event is called. Peak Time Rebates (PTR) are a variant of CPP rates and represent the carrot approach by providing a *credit* for load reduction during the peak period, rather than a surcharge for consumption during the specific limited hours. RTP rates pass along the hourly wholesale prices, thus allowing customers to respond as they see fit to short-run wholesale prices.

A regulator may consider a variety of time-variant pricing options: each option provides the regulator with the ability to reflect a variety of goals, such as cost causality and load shifting (NARUC Manual, p. 26). The options fall into three generic TVR categories:

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[6] See *Charge Without a Cause?* by Chernick, et al., 2016.
[7] These would be the 100 hours forecast as having the highest system electric demand.

	TOU	CPP / PTR	RTP
Time Periods	Pre-set	Dynamic	Dynamic
Price establishment	Pre-set	Pre-set	Dynamic

It is important to note that CPP and RTP rates are examples of "dynamic pricing," where the hourly pricing is not fixed for all hours. Furthermore, use of such rates, as well as TOU rates, requires the presence of some form of metering that can record consumption separately for each time period within a billing cycle. For any TVR rate to be effective, it is important to carefully consider some means to communicate to consumers when the variously-priced periods will occur so that customers have actionable knowledge of the price signals.

Goals of TOU Rates

TOU rates have the potential to achieve or contribute to a number of stated goals. Depending on a number of regional, state and utility-specific factors, these can include:

a) Reducing consumption during high-cost hours to avoid potential future utility system capital investment and/or operating costs to meet peak demand;
b) Encourage shifting usage to hours when low-cost clean resources are available for dispatch;
c) Helping consumers reduce electricity bills by shifting usage to low-cost hours; and
d) Aiding the integration of variable renewable resources by enabling more flexible consumption that follows resources more closely.
e) Following cost-causation principles by having retail rates connected to wholesale prices or marginal generation costs.

Many of these stated goals will be assessed and referenced over the course of this paper, but at the outset it is important for stakeholders to understand the impact of a TOU rate on utility financials, as it is quite distinct from that of a fixed charge rate design proposal. Whereas a fixed charge rate seeks to increase guaranteed utility revenues – and is a highly flawed approach in the assessment of most consumer, clean energy and environmental advocates – a TOU rate is designed *not* to provide revenue assurance or stability to the utility but rather to more closely reflect the timing of cost incurrence in an effort to drive more stable utility *earnings* over the long run. In other words, reductions in revenue that occur in response to higher cost TOU rate peak pricing periods should also result in reduced utility system capital investment and operations costs.

Characteristics of TOU Rates

The key parameters of a TOU rate include the number of price differentiated periods (e.g. on-peak, shoulder, off-peak), the duration of each period, the potential seasonality of the periods, the coincidence of on-peak periods with peak system demands (or cost), and the ratio of prices between periods. All of these features can impact customer behavior, customer acceptance and the size and volatility of customer bills.

Historically, most TOU rates have been simple designs, with separate fixed rates for one on-peak and one off-peak period. In many cases, these were as simple as daytime hours being considered on-peak and nighttime hours off-peak. Rates structured with long peak periods of this type are burdensome to stay-at-home seniors, and others who have high and somewhat inflexible daytime usage. Moreover, such rates are generally not reflective of utility costs within the periods, resulting in relatively small price differentials. Customers that did respond saw little impact on their bills. As noted by NARUC, a lack of cost-effective interval metering technology, as well as poor design, have hindered the wider development of TOU rates, but utility roll-out of advanced metering technology across many jurisdictions can help facilitate the implementation of a TOU design (NARUC Manual pp. 26-27).

Many state policy goals are established to encourage efficient use of energy, protection of low and fixed income customers, use of distributed resources, use of indigenous resources, and promotion of economic development. These goals can affect the characteristics and structure of TOU rates and should be taken into account by regulators.

Number and Duration of Periods

The selection of time periods should be based on system load patterns, and designed to have the on-peak periods encompass the expected hours of a system's highest loads while taking into account state policy goals.[8] This will vary from utility to utility, state to state and region to region. While most systems peak on hot summer days, some systems peak during winter heating months.

On most utility systems, there are a limited number of hours when the system is under high stress, and more when the system is under higher loads. As a result, a number of utilities (particularly summer-peaking utilities) have implemented TOU rates that differentiate prices across three periods in the summer months (on-peak, shoulder or mid-peak, and off-peak) when loads and prices are higher, and two periods (on-peak, off-peak) in the non-summer months when loads and prices are lower. The summer peak hours are sometimes constrained to weekdays, as weekends (and holidays) often have lower loads. The increased granularity of three periods in peak summer months provides improved cost-causative price signals that should result in reduced utility costs if customers respond. In winter-peaking regions, a different period, based on local system conditions, will be appropriate.

The duration of price-differentiated usage periods can be a two edged sword. Generally, pricing periods should reflect the underlying costs. Shorter periods, e.g. 2-4 hours, allow more easily for larger price differentiations and closer ties to utility costs. They are also easier for customers to

[8] For example, regulators in states promoting electric vehicles may want to consider a "super off-peak" rate that reflects very low rates within times of low usage off-peak periods, to encourage charging at night (or mid-day on solar-rich systems).

engage and respond to a price signal. In contrast, long periods, generally greater than 5 or 6 hours, tend to dilute both cost recovery and the attendant price signals and present more difficulties for customers to engage and respond.

The pricing periods should ideally be designed so that customers can avoid usage in the highest-cost periods through manual or automated modification of their behavior, but without a significant compromise of health, safety, or lifestyle. The goal for regulators should be to find a balance that is reflective of utility costs and is actionable by the consumers.

<u>Seasonality of Periods</u>

Seasonality is an important consideration in jurisdictions where the peak season is readily differentiated based on higher loads or higher costs. In such jurisdictions, it would be appropriate to also differentiate the number of periods, with more periods during the higher load or cost season(s). Seasonal strategies can be employed to reduce complexity in both the development of prices and understandability of rates, such as developing an off-peak rate that remains constant year round, and a non-summer peak rate that is equivalent to the summer shoulder rate. In other words, there would be two TOU rates in effect all year with a higher on-peak rate applicable only during the peak summer season, recognizing that the time periods themselves would vary between summer and non-summer months. The optional TOU rate of the City of Burbank, California, is an example of this:

	Summer (Jun 1-Oct 31)	Non-Summer (Nov 1-May 31)	Time Period
On-Peak	$0.25	Not Applicable	Summer 4 – 7 PM Only
Mid-Peak	$.1666	$.1666	All other hours
Off-Peak	$.0833	$.0833	11 PM – 8 AM

<u>Pricing of Periods</u>

One of the most common tenets of establishing rates is to set prices based on underlying costs. This premise holds true for TOU pricing, by period, with several other important considerations. These considerations include assuring that pricing differentials are large enough to matter as a price signal to the customer, taking into account state energy policy goals and objectives, and evaluating the impact of pricing on low and fixed income customers.

On most utility systems, there are a limited number of hours when the system is under severe stress. These are generally the hottest (or coldest) days of the year, but may occur at times when some resources are unexpectedly out of service during milder conditions. These stressful periods frequently drive utility and wholesale market decisions for additional capital investments in generation, transmission and distribution assets to relieve the stress and assure grid reliability. However, the stressful periods for distribution do not necessarily occur during the same time period as for generation, and may thus not correlate with TOU on-peak periods. Regulators should consider these differences.

TOU rates for peak periods are often designed to reflect marginal costs so that as customers respond to the price signal, the need for these capital investments decreases, resulting in cost savings for all customers. At the same time, off-peak periods should be priced at a rate attractive enough to encourage the shifting of consumption to such periods. Therefore the differential in prices should be large enough to support these policy objectives.[9]

However, as discussed in Appendix A below, the amount of demand response drops off rapidly as on/off peak price ratio goes approximately above 2.0. Moreover, as discussed under Bill Volatility Impacts in Section 3.0, large on/off peak differentials greatly increase bill levels and bill volatility. In designing rates to reflect marginal costs and cost causation, regulators can and should consider impacts on affordability and bill volatility. The goal should be to adopt price differentials that motivate consumers to shift load, but without causing excessive bill impacts. A customer-friendly approach is to offer a menu of voluntary TOU rates that may have different characteristics.

Critical Peak Pricing (CPP), or Peak Time Rebates (PTR), explicitly target the hours of severe stress, by the utility notifying the customer of a high-cost event, and then charging a high price, or crediting customers who reduce usage.

[9] Chitkara, A., Cross-Call, D., Li, B., and Sherwood, J. 2016. *A review of Alternative Rate Designs: Industry experience with time-based and demand charge rates for mass-market customers.*

The table below compares illustrative example pricing for the various types of TVR rate design, including TOU, CPP and PTR:

Rate Element	Flat Rate	2-Period TOU	3-Period TOU	TOU & CPP	PTR
Customer Charge	$7/month	$7/month	$7/month	$7/month	$7/month
Off-Peak 10 PM - 7 AM	$.12/kWh	$.08/kWh	$.08/kWh	$.08/kWh	$.12/kWh
Mid-Peak 7 AM - 4 PM 7 PM - 10 PM	$.12/kWh	$.15/kWh	$.12/kWh	$.11/kWh	$.12/kWh
On-Peak 4 PM - 7 PM	$.12/kWh	$.15/kWh	$.18/kWh	$.18/kWh	$.12/kWh
Critical Peak (max 15 events 3 hours / event)	Based on time periods above	Based on time periods above	Based on time periods above	$.75/kWh	Credit of $1.25/kWh of load reduction from baseline

As is evident, the more complex rates more precisely target the costs associated with service in each time period. The CPP and PTR rates require AMI, because the utility must measure actual usage in a critical peak event, and, in the case of a PTR rate, compare that usage to usage during the same hours in non-event days.

Variant: Combining Time-Varying Rates with Inclining Block Rates

About half of electricity consumers in North America are served by utilities with default inclining block rates, where usage above a threshold is priced higher than the essential needs usage in the first block or blocks. These rates reflect a variety of costs and policies, with some reflecting limited low-cost (typically hydro) in the first block, some attempting to reflect the time and seasonal load characteristics of high-use (air-conditioning or space heating) consumers, others focused on aligning end-block rates with total system long-run incremental costs, and still others taking a policy-directed approach to encourage energy conservation and avoidance of excessive usage. By itself the inclining block rate does not reflect the hourly or daily changes to the cost of electricity and a customer may overpay for electricity as compared with its otherwise basic cost of service (NARUC Manual, p. 25).

Inclining block rates can be combined with time-varying rates in at least two ways. First, a TOU rate can be the underlying rate design, and a baseline credit (or high-use surcharge) can be deployed to constrain the cost of the first block, whenever it occurs. Alternatively, an inclining block rate can be the underlying rate design, with an “on-peak” surcharge for all power used during high-cost periods. Examples of these two approaches are shown below:

Time-Varying Rate With Baseline Credit		
Rate Element		
Customer Charge		$7.00/month
Off-Peak Usage	9 PM - 7 AM	$.09/kWh
Mid-Peak Usage	7 AM - 5 PM	$.13/kWh
On-Peak Usage	5 PM - 9 PM	$.20/kWh
Baseline Credit	First 400 kWh	($.05)/kWh

Inclining Block Rate With On-Peak Surcharge		
Rate Element		
Customer Charge		$7.00/month
First 400 kWh		$.09/kWh
Over 400 kWh		$.13/kWh
On-Peak Surcharge	5 PM - 9 PM	$.10/kWh
Off-Peak Credit	9 PM - 7 AM	($.05)/kWh

3.0 Evaluating the Pros and Cons of TOU Rates

In this section, the relative merits of TOU rates are evaluated in the context of consumer, clean energy, and environmental goals.

Potential benefits of TOU rates include:

- Prices tied more directly to certain marginal utility costs
- Actionable price signals
- Environmental benefits of reduced emissions if off-peak generation mix includes cleaner power plants
- Potential for increased or stable adoption of other customer-side clean energy resources

Potential costs and harm of TOU rates include:

- Higher bills for customers with peak-oriented load profiles
- Loss of economic welfare / comfort
- Additional infrastructure costs for metering, data collection and data management
- Hassle factor of managing load
- Bill volatility with increased exposure to wholesale electricity markets
- Potential for reduced adoption of rooftop solar and other DER, depending on TOU rate structure and prices
- Environmental costs of increased emissions if off-peak generation mix includes dirtier power plants

Prices Tied to Cost Causation

A primary characteristic and justification for TOU rates is that they are more closely related to utility cost incurrence than "flat rates," due to the fact that peaking generation and transmission costs are most appropriately recovered during certain well-defined peak periods that tend to drive overall utility costs of providing service.[10] Residential and small commercial retail electricity prices that more closely reflect cost causation should provide actionable price signals that promote "economic efficiency," based on the expectation that consumers will use less electricity when prices are high, and more electricity when prices are low.

In evaluating the relative benefit of advancing economic efficiency through TOU rates, a commission should keep in mind several considerations. First, the efficiency argument is generally based on (but not necessarily tied to) a consideration of marginal generation and transmission costs. Distribution costs are less likely to be impacted by a TOU rate based on system peaks, since such costs are driven by localized peak loads, which may occur at hours other than during system peak periods. Second, the economic efficiency argument is based on the

[10] Transmission capacity costs are generally tied to bulk generation costs and frequently allocated on the same basis.

underlying assumption that consumption is influenced by marginal prices.[11] Thus, if overall consumption increases because customers use more off-peak electricity, that result is not relevant (either positive or negative) from the economic efficiency perspective.

Different customer classes peak at different times, and the system peak load may be more closely associated with one class or another depending on the relative loads of each class. Presented below are peak day hourly load charts for three utilities – one each from California, Colorado, and Michigan – which show both similarities and distinctions among the classes.

The figure immediately below, for a California utility, shows that the commercial class peaks in the early afternoon, and the residential class in the early evening. The system peak occurs in-between the two class peaks, when both classes are close to, but not at, their peak demand, forming a broad system peak that bridges the two periods. What is important here is that the individual customer class peaks, which affect the distribution circuits serving these classes, are different from the system peak.

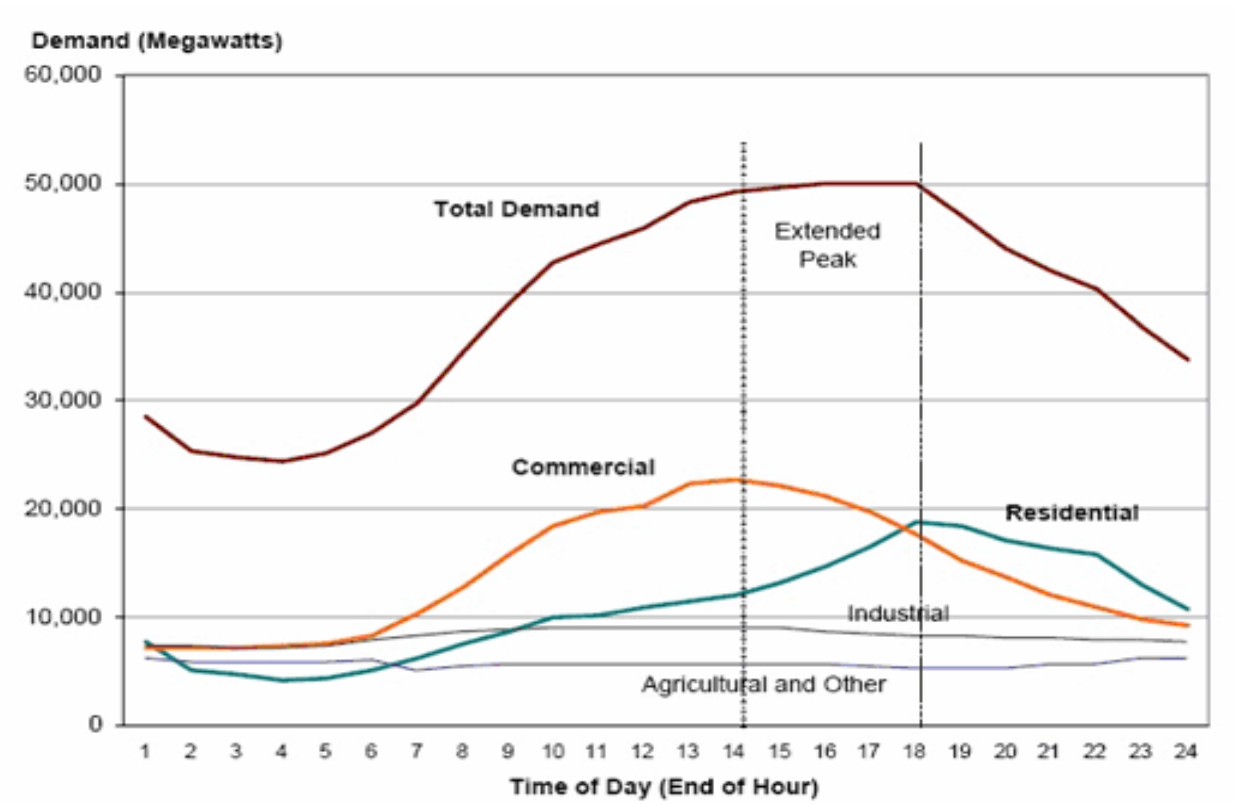

Figure 2: Illustrative Utility Daily Load Profile[12]

[11] Marginal prices generally do not explicitly consider social or environmental goals.
[12] Source: Sacramento Municipal Utility District.

In the intermountain west, Xcel Energy subsidiary Public Service Company of Colorado shows similar load patterns by customer class. In the unitized chart below, there is a strong correlation between the load patterns of the small and large commercial and industrial classes, while the residential class peaks somewhat later. The system peak hour, however, is more closely associated with the larger C&I loads, as can be seen in the chart.

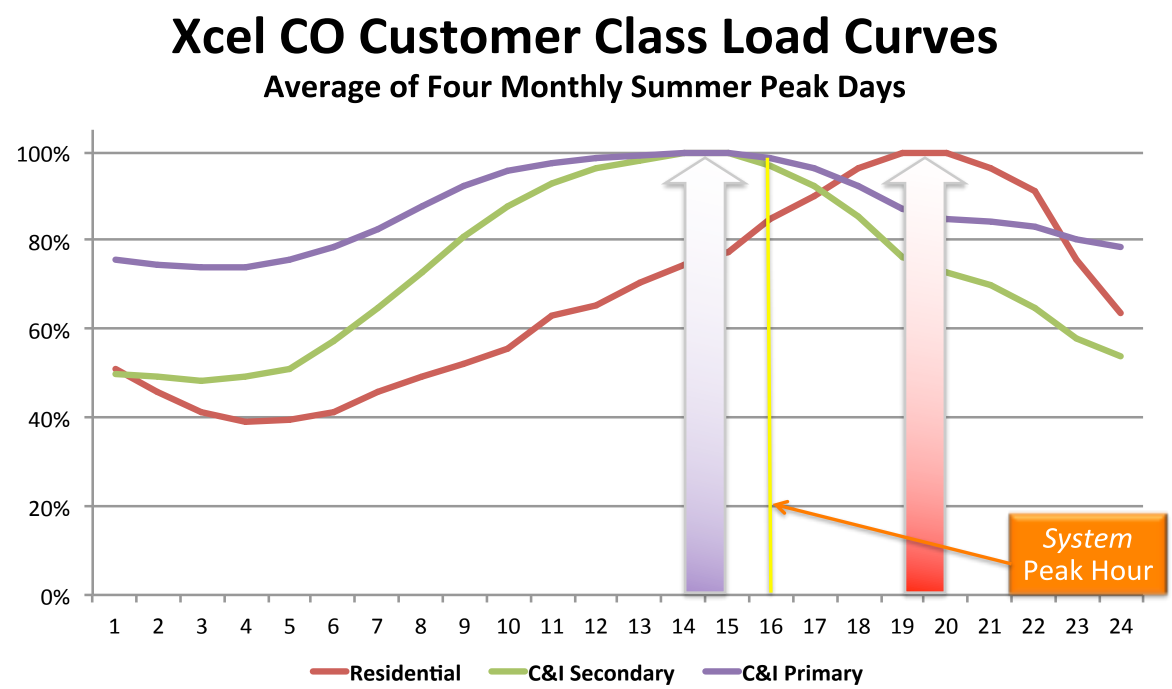

Figure 3: Xcel CO Customer Class Load Curves Source[13]

Thus the on-peak time periods of properly designed TOU rates in Colorado should be minimally coincident with the residential class peak demand given the three to four hour separation of peak demand time frames.

In another example, the general customer class load patterns for Consumers Energy in Michigan are similar to the other two utilities, but the system peak occurs closer to the residential class peak due to the relative proportions of load contributions from each customer class. Here, one might anticipate the on-peak period to encompass more of the higher load hours of the residential class.

[13] Source: Public Service Company of Colorado, 2015 data.

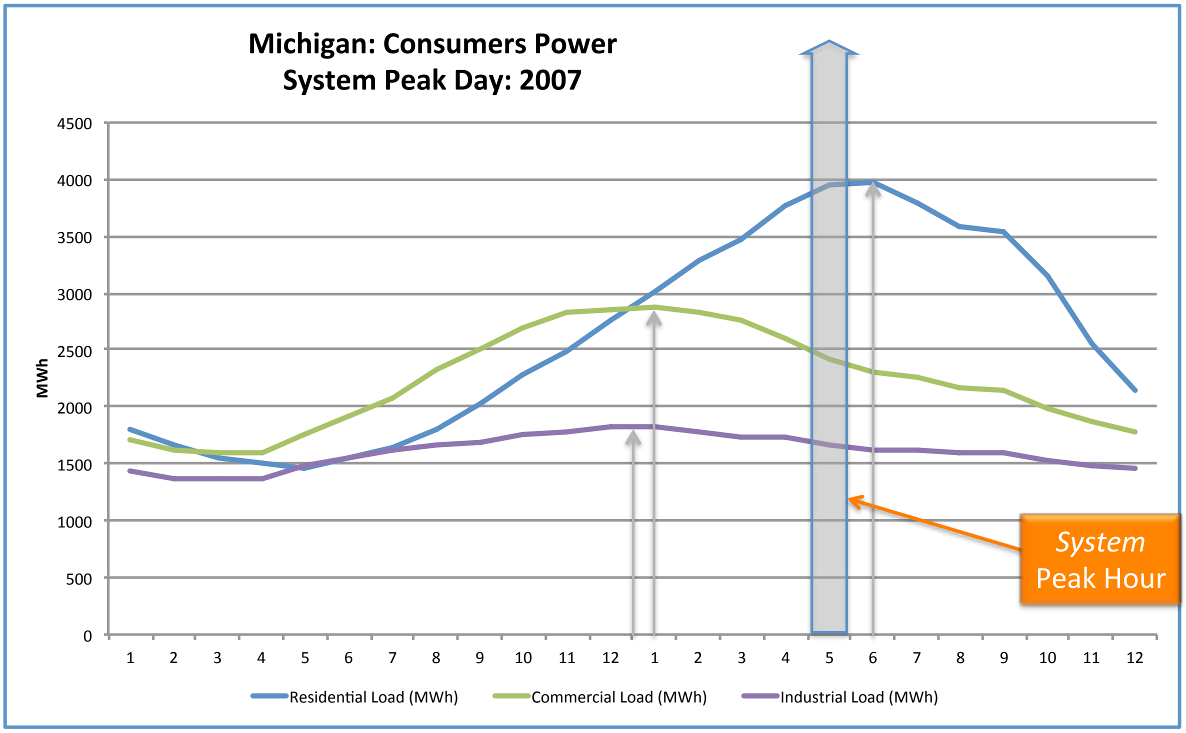

Figure 4: Michigan: Consumers Power

In sum, peak loads tend to drive costs for the utility, particularly at the generation and transmission functional levels, and will impact the selection of on-peak periods and the application of higher rates in a TOU regime. The correlation of aggregated residential peak loads with those of the system will thus influence the degree to which residential loads drive peak hours and associated costs and prices. Distribution costs are driven more by localized peak loads, which may not follow the relatively smooth curves depicted above for residential customers and occur at different times for different circuits.

Customer Response to TOU Reduces Costs

A related rationale in favor of TOU rates is the utility cost savings that result when customers respond to the signal to shift load and reduce peak power consumption.[14] Reducing peak load could reduce the need for new generation capacity, purchasing short-term power on the open market, or for running less efficient plants. These results would lower generation capacity and energy costs for consumers. Furthermore, reducing loads during system peak hours should

[14] It should be noted that in some locations, shifting load to lower cost periods actually means encouraging consumption at times of high wind or high solar availability, and not necessarily peak load reduction.

reduce the basis for allocation of utility costs to the residential or small commercial class. This can reduce rates over time, as well as improve the overall system load factor.

The basis for the assumption that TOU rates will reduce peak load is the assumption that customers will change their consumption patterns in response to price signals due to the price elasticity of demand. The theoretical basis of price response and the practical results of numerous TOU pilots are summarized in Appendix B. In addition, case studies are identified in the NARUC Manual, pp. 27-30.

Here it is noted that numerous opt-in pilot studies have demonstrated that residential customers exhibit a small but consistent elasticity of demand in response to price signals, with peak load reductions generally in the range of 3-10% without additional enabling technologies. As such, TOU pricing can be expected to produce peak load reductions, reduced and shifted energy consumption, improved system reliability, and improved power quality.

As discussed under *Equity and Distributional Bill Impacts* in Section 3, low-income customers have exhibited smaller load shifting response. Whether low-income customers benefit through reduced utility bills will depend on both their load profiles and their ability to shift loads. Regulators should carefully weigh the benefits of potential load shifting with potential negative bill impacts on different customer groups.

It is important to note that the effectiveness of different TVR designs varies considerably. Figure 5 shows a comparison of pilot program peak reduction results for a variety of time-varying rate forms. CPP rates show the greatest promise of delivering strong peak reductions by customers.

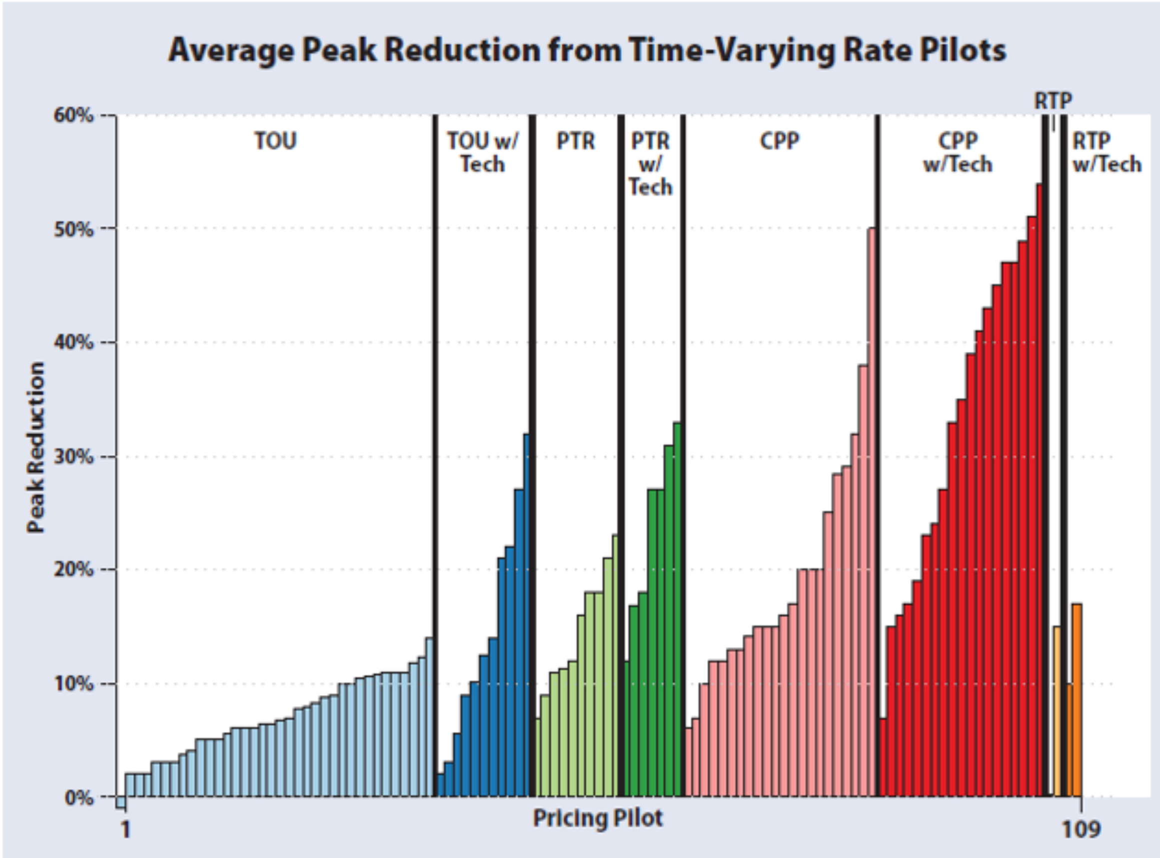

Figure 5: Average Peak Reduction from Time-Varying Rate Pilots[15]

However, there is dispute regarding the validity of extrapolating the results of short-lived opt-in pilots. There is significant evidence that opt-in customers perform better than the average customer.[16] Indeed, the average peak load reduction from the only full-scale implementation of a default TOU rate in Ontario, Canada, was less than 2%, but this was only measured in the second year of the program, and when short-run elasticity is expected to be low.[17] On the other hand, there is an expectation that over the long-term customers may make additional changes or investments that will reflect higher long-term elasticity of demand.

As evidenced by Figure 5 above, the benefits of load shifting are greatly enhanced by technology-enabled automation. Indeed, the proponents of time-varying rates often envision a world where household appliances and motors are interconnected and can respond automatically to price signals concerning the current wholesale price of electricity, or some approximation

[15] Source: Time Varying and Dynamic Pricing, RAP, 2012.
[16] USDOE, Sacramento Municipal Utility District Smart Pricing Final Evaluation, September, 2014.
[17] The Brattle Group, "Year Two Analysis of Ontario's Full Scale Roll-Out of TOU Rates," December, 2014.

thereof. However, the simplest automation – a programmable thermostat – is inexpensive at about $20 and is easily set for specific time periods.[18] Most dishwashers, washing machines and dryers built since 1995 have "4-hour-delay" buttons that can shift this usage. Timer controls on electric water heaters (about 45% of US residences have electric water heaters) can provide very rapid payback, and advanced grid integrated water heating control systems can provide ancillary service benefits as well.[19] Smart appliances are only beginning to appear on the market and may be able to provide additional benefits. They will likely have higher up-front costs and are unlikely to be acquired by low-income households without utility system incentive programs.

Therefore, to realize the benefits of customer response to TOU price signals, regulators should consider programs that promote technology and behavioral solutions for demand response as part of any public purpose spending on energy efficiency and demand response. Regulators should compare the incremental benefits of such programs, considering both load shifting and energy reduction benefits, with the potential incremental costs of the programs.

Emissions

A key objective of TOU rates is to shift usage from high-cost periods to low cost periods. In general, this will result in shifts of load from periods when inefficient power plants are the marginal resource to periods when more efficient plants are at the margin, and the environmental impacts will be beneficial. However, if the time periods are selected strictly on the basis of utility accounting costs, i.e. without taking into account the change in emissions, in regions with extensive coal capacity, TOU can shift loads from periods when natural gas is the marginal resource to periods when coal is the marginal resource. If this occurs, environmental impacts may be adverse and air quality impacts may be localized, significantly affecting local populations. Studies have found that the impact of load shifting varies geographically, depending on the resource mix and customer usage patterns.[20]

It is also important to take into account hourly and seasonal emission profiles of existing resources for the utility or region in question, for reducing emissions (and costs) along with the optimum time periods for adding load (that has been shifted). It may be far more beneficial from an emissions perspective to encourage load shifting to time periods during which the utility may have high levels of solar or wind generation availability, even if those time periods are not periods of lowest load.

[18] Pricier "learning" smart thermostats – cost about $200 retail, not including installation.
[19] See The Hidden Battery, Brattle Associates for NRDC, NRECA, and PLMA, 2016.
[20] Holland, S. and Mansur, E. May, 2016. *The Short-Run Effects of Time-Varying Prices in Competitive Electricity Markets.*

Effect on Behind-the-Meter DER Technologies

Changing rate structures and the timing of pricing differentials can have a significant impact on the customer-deployed technologies on their side of the utility meter. Such differential pricing will change the economics of DER and, in theory, can encourage those technologies which reduce energy consumption during higher-priced periods.

Conservation and Energy Efficiency

There is limited specific empirical research on the effects of time-of-use rates on conservation or energy efficiency. Studies of the effects of time-varying rates in combination with automated price response technology have shown some reduction of energy consumption as well as time-shifting.[21]

Theoretically, given the price elasticity for residential customers described above, TOU rates should affect the relative rates at which various energy efficiency measures are adopted but the effects on overall energy use are ambiguous. As discussed above, TOU rates will typically include higher rates at higher load times and lower rates at lower-load times. High load is driven, in part, by weather that induces use of heating or cooling. Thus, TOU rates should increase the private returns to measures that improve the efficiency of building heating and cooling, building shell, and other weather-dependent loads. In contrast, time-varying rates will generally be lower when averaged over time (not weighted by load) so that the average cost of electricity for near-constant loads, such as refrigeration, will be reduced and thereby reduce the private returns to measures that improve the efficiency of such end-uses. Theory does not inform the relative elasticities of these different uses (or times), so the net effect remains an empirical question.

There are very few studies of the time-specific elasticity of electricity demand.[22]

Self-generation

The effect of TOU rates on the economics of retail customers deploying rooftop solar self-generation depends on the structure and pricing of the rate design that applies to the self-generation. Net energy metering, as commonly implemented, bills customers with self-generation at a fixed rate applied to the net of energy inflow to and outflow from the customer. Net energy metering is not well defined with time-varying rates within a billing period.

The most natural adaptation of net metering for time-varying rates is to use a form of net billing, where inflows are charged and outflows are credited to the customer at the time-specific rates at the times of the flows. The effect of net billing using TOU rates depends upon the relative timing

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[21] Faruqui, A., S. Sergici, and L. Akaba. 2011. *Consumers Energy's Personal Power Plan Pilot.* Brattle Group.

[22] Lijesen, M. *The real-time price elasticity of electricity.* Energy Economics 29(2) pp.249-258.

of the consumption versus generation load profile. For example, in a jurisdiction with a peak pricing period from 12 to 6 p.m., any solar generation during that period would be credited at the on-peak price on the customer's monthly bill and may help the utility mitigate peak demand, avoiding system capacity costs including distribution capacity. Thus, a customer who was generally not present in the house on weekday afternoons, and thus consumed proportionately off-peak, would be able to credit higher-priced on-peak generation against lower-priced consumption.

With higher penetrations of self-generation, the economics of self-generation depend even more on how time-of-use rates are constructed. In Hawaii, for example, the current level of solar generation is high enough that the peak period of consumption net of solar generation is changing to later in the day due to large amounts of retail and wholesale solar generation[23]. In that context, TOU rates designed to signal the utility's relative cost based on customer inflows, i.e. a peak period of 5 p.m. to 10 p.m., result in midday (pre-5 p.m.) solar output receiving reduced credit. Indeed, Hawaiian Electric has introduced an opt-in TOU rate design with the lowest prices during the solar day, and the highest prices after.

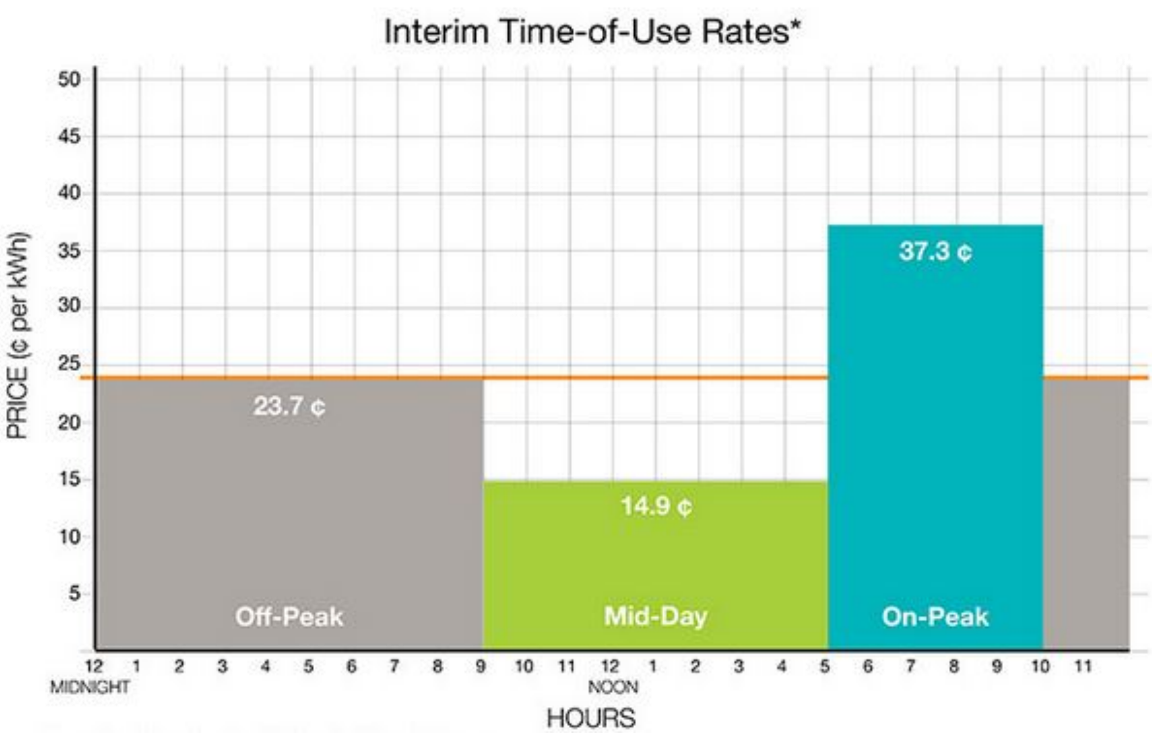

Figure 6: Interim Time-of-Use Rates[24]

[23] Denholm, P., et al. 2015. *Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart.* NREL/TP-6A20-65023. National Renewable Energy Laboratory.
[24] Source: Hawaiian Electric.

Applied to solar customers, this rate would credit solar production at a lower rate, and charge them at a higher rate for consumption during the non-solar hours, thus lowering the benefits from rooftop solar. The effect would be to collect a significant contribution to the utility system from solar customers who produce as many kilowatt-hours as they consume, without imposing a fixed charge or demand charge on these customers that would discourage efficiency. Some states have considered creating opt-in TOU rates for all customers, but making them mandatory for customers with on-site generation.

The appropriate design of time-of-use rates under high penetration of non-dispatchable generation is an unsettled question. These TOU rates in Hawaii can still work for solar customers given the high overall level of rates. In states with lower costs, similar higher solar penetration levels resulting in similar TOU structures could result in stretching any payback period beyond a customer's personal economic threshold or potentially eliminate any financial benefit for installing rooftop solar. In these situations, integration of other forms of DER, including demand response and storage technologies, with rooftop solar may be the only option for continued deployment of rooftop solar over the longer term.

Considerations Regarding Advanced Metering

Many jurisdictions have considered the roll-out of advanced metering infrastructure (AMI), aka "smart metering." Smart metering generally includes a digital meter capable of recording hourly consumption, a data collection and communications network for transferring that data remotely to the utility, and a meter data management system to make the data useful.

Benefits cited by proponents of AMI often include the following operational benefits:

- Reduced distribution company operating costs of meter reading, service disconnection and service restoration
- Transformer right-sizing to improve reliability and reduce losses
- Line phase-balancing to reduce losses
- Offering of critical peak pricing or demand response programs to reduce peak demand
- Better outage detection and service restoration
- Improved capture and availability of interval energy usage data

Concerns with AMI include the following issues:

- The cost of meter replacement, two-way communication systems, and data management systems, and the extent to which projected benefits will be achieved
- The extent to which AMI represents the most cost-efficient means of achieving state utility system and policy objectives
- Threats to the economic security of lower-income residential consumers from implementation of remote service disconnection capabilities of AMI

- Penalties to residential consumers most vulnerable to adverse impacts of service reduction or curtailment

It is important to keep in mind that while an AMI system may more readily enable the implementation of TOU rates, AMI is not required for TOU rates since the periods and pricing are fixed up-front. Meters with multiple registers can be read with conventional meter reading equipment. In this way, the use of TOU rates is fundamentally different from the use of CPP or RTP rates.

A review of the relative upfront capital costs and the benefits of the infrastructure investments said to be required by the implementation of new rate structures must be carefully considered before reconfiguring existing meter infrastructure or installing new or additional metering technologies.[25] Critically, many of the grid operational benefits, aside from reduced meter reading costs, may not materialize at all if the billing system data is not integrated into the grid operations software system in a manner that allows the distribution engineers to actually use the data for planning and/or operations. At least one study by the Division of Ratepayer Advocates in California found that the costs of AMI metering for one California utility significantly exceeded the forecast of $1.6 billion, and the benefits did not materialize to the extent forecasted.[26]

Impacts on Customer Bills Due to Reduced Generation Costs

A primary potential benefit of TOU rates is a reduction in customer bills resulting from shifting load from high-priced peak periods to lower-priced periods. Such load shifting could reduce total generation energy costs due to a shift in the wholesale price curve, and can also reduce generation and transmission capacity costs by reducing the need for more expensive peaker plants and related transmission investments. These changes could in theory benefit residential customers through lower total revenue requirements and better cost allocation of generation capacity costs.

In evaluating this potential benefit, commissions should carefully consider 1) the potential for load shifting in the relevant jurisdiction; 2) the relative costs of alternatives to reduce peak demand; and 3) whether system-wide peak load reduction will impact the need for new generation and transmission capacity required in the jurisdiction.

[25] P. Alvarez. 2014. Smart Grid Hype and Reality: A Systems Approach to Maximizing Customer Return on Utility Investment.
[26] California Division of Ratepayer Advocates. Hieta, K., Kao, V., and Roberts, T. Case Study of Smart Meter System Deployment: Recommendations for Ensuring Ratepayer Benefits. March 2012.

The potential to reduce generation capacity depends on whether the changes in residential load profiles impact the need for new generation capacity to meet resource requirements. While reducing peak load would initially seem to reduce the need for peaker plants, TOU rates may be too blunt an instrument, as they may not capture the actual system peak load hour in any particular year, which could then be used for peak demand forecasting. CPP rates are more targeted towards the actual peak hours, but such rates may be difficult for residential customers to respond to, since they are not known until as late as one day in advance. Moreover, response to CPP rates may provide a near-term benefit for those customers able to respond but may not significantly reduce the allocation of costs to the residential class as a whole. A commission should carefully consider the drivers of new generation and transmission capacity in its jurisdiction and study the degree to which a change in overall residential load profile would impact those drivers and cost allocation to the class.

Equity and Distributional Bill Impacts

Residential rate design impacts the allocation of costs within the customer class. For example, a tariff using only flat volumetric pricing (price per kilowatt-hour) allocates costs proportionately to electricity consumption, so all customers whose total consumption is less than that of the average customer will pay lower than average monthly bills. On the other hand, a hypothetical tariff that charges every customer a flat fee (aka, a large fixed charge) would cause all customers to pay virtually the same amount per monthly bill, regardless of how much it costs to serve their needs, how much capacity they require, how much electricity or distribution service they consume, or when they use it. A two-part rate with a fixed customer charge and a flat volumetric rate distributes costs between these two extremes. The higher the fixed charge, the less differentiated the monthly bills will be among customers with different consumption totals.[27]

Inclining block rates (aka, tiered rates) favor customers who use less than the average amount of electricity during a billing cycle by charging less for some "baseline quantity" of electricity. In other words, if rates change from a flat rate to an inclining block rate, some of the revenue requirement collected during the billing period will shift from customers consuming less than average to customers consuming more than average. In many cases, this is cost-based, reflecting higher costs for incremental resources, more peak-orientation of larger users, or a simple per-customer allocation of a limited low-cost resource. The baseline amount can be uniform for all customers, or can be differentiated based on housing type and climate zone.

Similarly, TOU rates favor customers whose load profile is better than the average, meaning those customers whose proportion of monthly consumption during the on-peak period is less

[27] Extensive litigation in every state concerns the question of whether "cost causation" due to the nature of utility costs justifies fixed charges on residential customers. This paper does not concern itself with the issue of fixed charges, though as environmental and consumer advocates we favor lower fixed charges based both on cost causation and on other rate design principles.

than the average proportion of on-peak consumption. TOU rates increase the bills of customers who use more energy on-peak, meaning they have a worse than average load profile.

On most systems with summer peaks, TOU rates could thus increase the cost of air-conditioning service, and reduce the cost of lights, appliances, and other non-peak oriented uses. If customers can control loads, like water heating, laundry, or dishwashing by the use of technology or changed behavior, or choose to do without some level of peak-oriented consumption, they can reduce their usage during the pre-set and known on-peak periods and their monthly bills under TOU rates.

Research in most jurisdictions has shown that on average lower income customers use less electricity,[28] and use proportionately less electricity during peak periods. Such lower usage customers would thus benefit from a change in rate design from a flat rate to either an inverted tier rate or a TOU rate. On the other hand, there is evidence[29] that lower-income customers have less discretionary load to shift than higher-income customers (e.g., they have lower elasticities of demand), and lower-income customers have less discretionary income to spend on automation and enabling technologies, especially if those technologies (for example, smart thermostats) are fixtures that would not be cost-effective for a renter with a short time horizon. It is important that deployment of TOU rates include programmatic assistance to low- and moderate-income customers to adapt to the changes.

Bill Volatility Impacts

TOU rates and inclining block rates have one shared trait that is a potentially negative impact for customers: bill volatility. Unexpected changes in consumption due to weather variability can disproportionately amplify customer bills. For tiered rates this might occur because a larger percentage of consumption than normal would be billed at a higher tiered rate, so that the monthly bill would increase by proportionately more than just the increase in consumption. For TOU rates this might occur because a larger percentage of consumption occurs during the on-peak period, again amplifying the bill increase by a larger percentage than just the increase in consumption.

Customers value bill stability, and tend to become confused and irritated when bill increases do not appear to be linked to increases in consumption that the customer has consciously caused. These impacts depend on the details of the rate design. Bill volatility is exacerbated by larger tier differentials for inclining block rates, or by large on/off peak ratios for TOU rates. A commission

[28] National Consumer Law Center, Median 2009 Household Electricity Usage (KWH) by Poverty 150% Status, 2014.
[29] There are various studies showing differential responses by low-income customers. See, for example, Nexant, California Statewide Opt-In Time-of-Use Pricing Pilot: Interim Evaluation. April 11, 2017.

must evaluate the relative benefits of either inclining block or TOU rates against the potential harms of volatile bills in determining the exact design of the rate. In this regard, historical consumption variability in the utility service territory should also be considered.

Consumer Protection for Residential Customers

There are features that can be incorporated into proposals to implement TOU rates to help mitigate many of the potential harms to the most vulnerable residential consumers. As indicated above, an opt-in structure, particularly for LMI customers, can protect customer choice and ensure that those customers who can most benefit from the rate will participate. Additional consumer protections include the following:

- Implementation of meaningful pilot programs to determine how different groups of consumers respond to the proposed TOU rate and the extent to which the rate option results in financial benefits or harms among segmented groups of residential consumers, and the impacts on consumption levels and system peak loads;
- "Shadow billing" where consumers receive full information about what billing under the full range of rate options would have been given existing usage level and timing of consumption;
- Increased distribution through utility programs of smart appliances (refrigerators, water and space heating equipment, cooling equipment) and advanced energy management equipment (smart thermostats, internet and cell phone controls) in low- and moderate-income households;
- Enhanced low- and moderate-income energy efficiency programs, featuring whole-house, deep retrofit design and zero upfront contribution or financing from income-eligible program participants;
- Improved opportunities for low- and moderate-income customer access to distributed solar resources, including community solar projects; and
- Simple and clear consumer education.

4.0 Alternative Means of Achieving TOU Pricing Goals

It should be recognized that adjusting prices and rate structures is but one method to promote peak load reduction and its attendant benefits. There are other options. For example, direct load control of customer air conditioners has been utilized by many summer-peaking utilities to reduce air conditioner load, with neither TOU rates nor AMI systems. Such programs allow the utilities to remotely cycle air conditioner compressors with very rapid response times. The utilities have to install a communications network and install a device on the external compressor of a central air conditioning system. Utility direct load is also accomplished with timers or active controls of electric water heaters.

Peak-time rebates (PTR) which provide a credit for reducing load during critical periods, without a surcharge for increasing load, has been effective in Maryland and other states. The peak load reductions, as shown in Figure 5, are nearly as impressive as for critical peak pricing, without the customer impacts of other forms of TVR.

A reasonable question for commissions is whether other means of accomplishing peak load reduction may be either more cost effective, or have fewer negative consequences, than adjusting prices through TOU or CPP rates. For example, if additional metering is required to implement TOU rates, such an investment could be compared to the investment in a direct load control program.

5.0 Guiding Resources

The authors believe it is useful for regulators to have goals, principles and objectives in mind when evaluating significant changes to rate structure and design. The need to take into consideration State and local policy goals and objectives has been noted above. Sources of guiding principles for ratemaking more generally, and for addressing the growth of DER on utility systems are discussed below.

Lessons from Bonbright: The Bonbright Criteria

Professor Bonbright's famous 1961 work, "Principles of Public Utility Rates," outlined eight criteria of a sound rate structure. It is useful to consider how TVR, and in particular TOU rates, fare under these criteria. The following summary addresses each criterion.

1. The related, "practical" attributes of simplicity, understandability, public acceptability, and feasibility of application.

Simplicity: TOU rates may not be viewed as simple by some, especially in comparison to widely used pure volumetric energy rates. While the time periods can change over time, the concept of volumetric charges tied to specific, predefined high and low use time periods is a natural extension of current rate designs.

Understandability: The peak time pricing concept will also be familiar to those who have experienced higher highway toll prices during peak periods, or paid for parking during baseball games or other events, and should facilitate customer education.

Public acceptability: TOU rates may not be readily accepted by portions of the residential customer base, such as those who may find it difficult to adjust the timing of their energy use due to work structures, medical devices, or other reasons. But those who see the opportunity to reduce utility bills by responding to the clear price signals included in TOU rates will likely be willing to try them. As such, these charges should be piloted first and then rolled out more broadly as an alternative rate option before mandatory imposition is considered.

2. Freedom from controversies as to proper interpretation.

Proper interpretation of TOU charges should be clear for customers who can prepare for and manage appliance use and electricity consumption in advance. Regulators should assure that various stakeholders representing different interests would interpret the TOU rate in the same way.

3. Effectiveness in yielding total revenue requirements under the fair-return standard.

Rate structures that establish an effective relationship between billing parameters and cost causation are reasonably likely to yield total revenue requirements following implementation. TOU rate structures are designed to encourage reduced consumption during peak use periods which also drive utility costs to a large degree. To the extent customers respond to the peak time price signal, utility costs should be reduced. Thus the link with cost causation is strong, and achieving total revenue requirements is more assured. It is equally important to note, however, that there may be a significant lag between avoided consumption and avoided capital investment costs.

4. Revenue stability from year to year.

If utility short-run costs vary consistently with their TOU rates, then TOU rates will stabilize utility revenues relative to costs. However, a pre-set TOU rate that recovers a large share of revenues during temperature-sensitive periods will actually reduce utility revenues significantly in a mild year. If most system capacity costs are fixed, it will not track costs as well as a non-TOU rate. This is becoming a larger challenge with the introduction of capital-intensive renewable and storage resources, where fewer and fewer costs vary in the short-run, but many of these (fixed) costs are incurred to meet peak period needs.

5. Stability of the rates themselves, with a minimum of unexpected changes seriously adverse to existing customers. (Compare: "The best tax is an old tax.")

If small customers use technologies or behavioral changes to reduce consumption during peak hours, utility revenue will decrease and over time utility costs will also decrease, potentially avoiding the need for new investments. This more closely correlated revenue/cost relationship inherent in TOU rates should result in a diminished need for rate proceedings. A more dynamic rate design (CPP or RTP) leads to less rate and bill stability for customers.

6. Fairness of the specific rates in the apportionment of total costs of service among the different customers.

In theory, rates that are more closely tied to cost causation will be more fair to customers and result in better apportionment of cost responsibility among customers. Those that consume more, especially during high cost hours, will pay more. Apartment dwellers use less than suburban homeowners and will pay less (if individually metered).

7. Avoidance of "undue discrimination" in rate relationships.

As for the previous criterion, the improved cost causation relationship should minimize the potential for undue discrimination.

8. Efficiency of the rate classes and rate blocks in discouraging wasteful use of service while promoting all justified types and amounts of use:

(a) in the control of the total amounts of service supplied by the company;

(b) in the control of the relative uses of alternative types of service (on-peak vs. off-peak electricity, Pullman travel vs. coach travel, single party telephone service vs. service from a multi party line, etc.).

In comparison to price signals associated with conventional volumetric energy charges, volumetric TOU rates with higher peak prices further the discouragement of wasteful uses of service during periods when reductions in consumption can reduce utility costs. In addition, the hybrid approach of incorporating an inverted block structure into each time period can both protect vulnerable customers while further enhancing the price signal to reduce consumption.

Finally, the authors of this paper support the concept of **customer agency.** In other words, customers should have increased energy choice and control, to facilitate the basic right of energy self-determination. As part of this evolution, utilities should be required to educate consumers as to which available rate design will provide them with the lowest energy bills.

NARUC DER Manual Guidance

Unlike with flat rates, customers need to be aware of usage throughout the day and the month to respond to the price signals in a time variant rate (NARUC Manual, p. 26). A customer may increase savings, if that customer uses energy in response to the price signal (NARUC Manual, p. 26).

The NARUC Manual, referenced throughout this paper, does not make recommendations or reach conclusions as to appropriate rate designs to be utilized by its members in different jurisdictions. Instead it lays out a background on the principles of rate design to provide the regulator with the pros and cons of different designs and compensation methods. It outlines questions to support an investigation and how to use some of the details to support a decision-making process. It expressly advises regulators to look closely at data, analyses and studies from its particular service area before any actions are taken. The section entitled 'A Path Forward for Regulators' offers a decision framework for change (NARUC Manual, pp. 143-148). This paper endorses such an approach and endeavors to augment the thinking on TOU rates so that all involved understand the options and inherent trade-offs in its implementation. Further, the authors endorse a deliberative, collaborative process to understand the impacts of decisions made or to be made. "Reforms that are rushed and not well thought out could set policies and implement rate design mechanisms that have unintended consequences..." (NARUC Manual, p. 62).

6.0 Conclusions

There are several basic forms of TVR rates, with TOU rates being the most well-known and commonly practiced today. The broad range of prospective TOU rate design options provide flexibility in achieving stated policy goals and objectives, while carrying the potential to address the overall cost levels and causative factors of the utility. Important questions remain as to the degree to which residential customers at all socio-economic levels are able to respond to the new price signals.

Some residential loads can be controlled more easily than others. For example, electric water heaters and electric vehicle charging are relatively large loads that can be easily controlled. Offering TOU rates only to customers with these types of loads, together with education and technology to take advantage of TVR rates, may be a reasonable first step in TOU deployment.

Customers should have 1) the information to determine which utility rates are best for them; and 2) the opportunity to easily choose those optimal rates. This suggests more than just a superficial "customer choice," and the ability to make a meaningful choice among viable alternatives, with easy-to-use tools to help them determine the best option. Until there is more data concerning bill impacts and distributional effects, commissions are encouraged to evaluate TOU rates as compared to other alternatives, including flat rates and inclining block rates, and consider the relative costs and benefits of alternative mechanisms for peak load reduction.

Following are key recommendations and points for regulators considering residential TOU rate proposals:

- Require explicit up-front identification of the utility system and policy objectives to be achieved with a TOU rate, such as economic efficiency, deployment of DER technologies, peak load reduction, emissions reduction, and/or more equitable cost/benefit allocation.
- Rather than confining evaluation to TOU rates alone, identify and evaluate the costs and benefits associated with the full range of alternatives to achieving identified goals, such as tiered rates, utility direct load control programs, peak time rebates, or greater efficiency spending.
- In evaluating impacts on customer bills, carefully consider the drivers of new generation as well as new transmission and distribution capacity in the relevant jurisdiction and study the degree to which a change in overall residential load profile may occur and impact those drivers and cost allocation to the customer class.
- To help make TOU rates both effective and understandable, keep the rate design to a relatively few time periods (e.g. 2-3) that are well-synced with underlying system costs;

ensure the pricing differences are appropriate; and consider closely the length of the on-peak price period to facilitate customer adoption and load response.

- Ensure customers have the advance education and technology they need to respond. Use the following types of programs to achieve this: pilots such as implementing TOU rates with segments of customers with larger loads that are easier to control, like electric water heaters or electric vehicle charging; shadow billing for a year to give customers a chance to understand how they will be affected; and distribution of smart appliances such as timer controls or grid-integration for electric water heaters, or smart thermostats for space conditioning, if such distribution is found to be cost-effective based on incremental demand response benefits.
- If emissions reductions are a stated goal, carefully study what resources will run more as a result of load shifts – such as gas vs. coal vs. hydro or solar or wind – to inform structuring of periods that will result in maximum potential emissions cuts.
- TOU rate design is generally consistent with customer-sited solar deployment, but the extent to which they are compatible for the residential consumer is highly dependent on the rate design that applies to the self-generation. While TOU peak pricing periods often coincide with solar photovoltaic (PV) peak production periods, this will vary from utility to utility, state to state and region to region.
- TOU rates can easily be combined with inclining block rates to provide a more powerful price signal, as has been done in several states including California and Washington.

Appendix A: Price Elasticity and Load Shifting

Elasticity of demand refers to the inverse relationship between electricity consumption and its price. Substitution elasticity measures the relative change in electricity consumption in the two periods (e.g., the ratio of the peak to off-peak consumption) for one percent change in the relative prices in those periods (the ratio of the off-peak to peak price). Substitution elasticities are generally small in the short run but may be greater in the long run for those customers who can afford to invest in technology enablement to respond to relative price changes. An increase in substitution elasticity or an increase in the peak-to-off peak ratio leads to greater load shifting impacts.

Resource Insights reviewed more than ten different studies of price elasticity, and found that all but one of these found that consumer price elasticity is higher for the upper blocks of tiered rates.[30] Most found that long-run elasticity would be expected to be in the -0.3 to -0.7 range, meaning a 1% higher price would result in a decrease in consumption of 0.3% to 0.7%.

The Brattle Group has provided a review of empirical evidence from 34 studies in 7 different countries showing the relationship between price ratio and demand reductions during the peak price window.[31] They find "that customers respond to rising prices by lowering their peak demand in a fairly consistent fashion," and that enabling technologies improve load reductions. As well, they developed a generalizable equation to reflect this relationship that is shown in figure 1, below. The black line shows a predictable "arc" of response, whereas the blue line shows how response is improved with enabling technologies. The blue and black dots show empirical findings from real-world studies.

[30] Testimony of Paul Chernick, California PUC Docket No. 12-06-013, pages 13-24. Available at www.resourceinsights.com

[31] Ahmad Faruqui and Sanem Sergici, *Arcturus: International Evidence on Dynamic Pricing* (July 1, 2013).

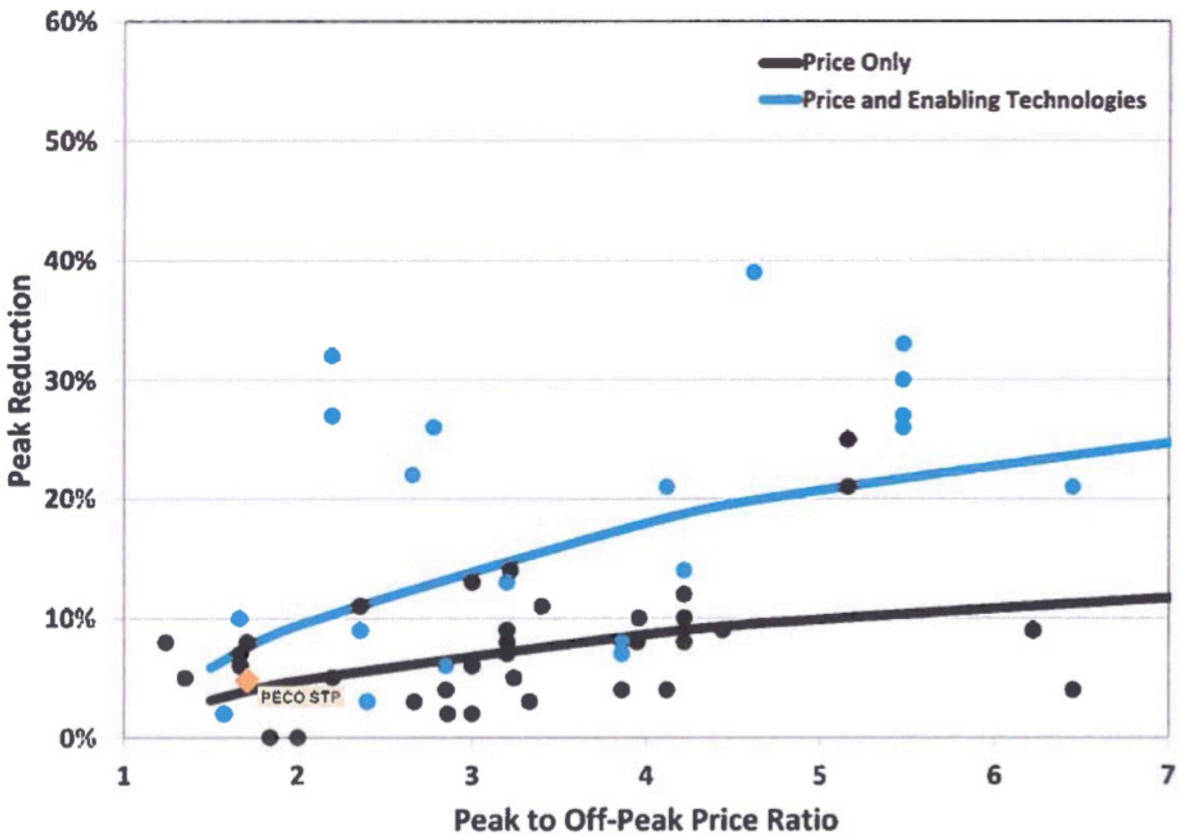

Figure 1: Relationship Between Price Differential and Peak Load Reduction[32]

Numerous pilot studies have demonstrated that residential customers exhibit a small but consistent elasticity of demand in response to price signals, with peak load reductions generally in the range of 3%-10% without additional technologies. However, commissions should be cautious in interpreting the results of these pilots. There are several features that make it difficult to extrapolate with certainty how short-lived opt-in pilot results will translate to longer-term default rate responses. There is significant evidence that opt-in customers perform better than the average customer.[33]

In summer peaking service territories, the peak load may occur during the second or third day of a prolonged heat wave. Little data exists to demonstrate whether residential customers will continue to shift their air conditioning load during each and every day of a heat wave. For load shifting to actually impact the construction of peaker plants (thus lowering generation capacity costs), the load shift must reliably occur during the annual coincident peak.

[32] Source: Ahmad Faruqui and Sanem Sergici, Arcturus: International Evidence on Dynamic Pricing (July 1, 2013).

[33] SmartPricing Options: Final Evaluation. Prepared For: U.S. Department of Energy by Potter, J., George, S., and Jimenez, L. September 2014.