STATE OF NEW JERSEY

BOARD OF PUBLIC UTILITIES

In the Matter of the Petition of Public Service Electric and Gas Company for Approval of an Increase in Electric and Gas Rates and for Changes in the Tariffs for Electric and Gas Service, B.P.U.N.J. No. 17 Electric and B.P.U.N.J. No. 17 Gas, and for Changes in Depreciation Rates, Pursuant to N.J.S.A. 48:2-18, N.J.S.A. 48:2-21 and N.J.S.A. 48:2-21.1, and for Other Appropriate Relief

BPU Docket Nos. _______________

DIRECT TESTIMONY

OF

AHMAD FARUQUI

PRINCIPAL EMERITUS

THE BRATTLE GROUP

December 29, 2023

P-10

PUBLIC SERVICE ELECTRIC AND GAS COMPANY
DIRECT TESTIMONY
OF
AHMAD FARUQUI
PRINCIPAL EMERITUS - THE BRATTLE GROUP

Q. What is your name?

A. Ahmad Faruqui.

Q. What is your affiliation?

A. I am a Principal Emeritus with The Brattle Group.

Q. What are your qualifications?

A. I am an economist by training and have advised utilities, regulatory bodies, governments and legislative councils on all six continents. My CV is appended as Schedule AF-1.

Q. What is the topic of your testimony?

A. I am testifying in support of PSE&G's application for developing new time-of-use (TOU) rates for residential customers.

Q. What issues will you address in your testimony?

A. In my testimony, I provide the rationale for why TOU rates are more desirable than flat or inclining block rates, followed by a national overview of the state of TOU deployment. Then, I explain how PSE&G developed its TOU rates and discuss how it intends to deploy them.

Q. Why should rates be aligned with cost causation?

A. Cost causation is one of the fundamental tenets of rate design. It helps to promote economic efficiency and also promotes equity. It's mentioned in Professor Bonbright's widely cited text on public utility regulation.

Q. Why are TOU rates better aligned with cost causation than flat rates or inclining block rates?

A. Consumers don't consume the same amount of electricity around the clock. Electricity consumption varies by day, by month, and by season. In summer peaking utilities, air conditioning load creates a pattern of use that rises with temperature. Often, loads begin to rise in the afternoon and linger on into the evening hours. Load shapes are also driven by customer lifestyles. Since electricity cannot yet be stored in sufficient quantities, extra generation capacity has to be kept in reserve to meet peak loads. It stays idle most of the time and is expensive to install and operate. With flat rates, consumers have no incentive to conserve electricity during peak hours and to use more during off-peak hours. TOU rates provide customers an incentive to reduce peak load and to shift it to off-peak hours.

Q. What is the status of TOU rates in the US?

A. According to the US Energy Information Administration (EIA)[1], as of the year 2022, 380 utilities were offering time-varying rates including TOU rates and dynamic pricing rates to their residential customers. There were 13.1 million customers on these rates, representing 9% of all customers in the nation. However, it's worth noting that the average participant rate is skewed upwards by a few utilities. Nearly 60% of investor-owned utilities offering TOU rates have enrollment rates of less than 1% while some 15% of utilities have participation rates that exceed

[1] Annual Electric Power Industry Report, Form EIA-861, accessed at https://www.eia.gov/electricity/data/eia861/.

15%. Reasons for low enrollment at utilities include poor marketing of the TOU rate, inconvenient design (i.e., long peak period), and/or additional charges to cover the cost of an interval meter (where smart metering has not been deployed).

One of the primary reasons why TOU rate offerings are going up is the widespread deployment of smart meters. According to EIA[2], U.S. electric utilities had about 111 million advanced smart metering infrastructure (AMI) installations, representing 80% of all residential electric customers in 2021.

Q. How many pricing periods are typically to be found in a TOU rate?

A. About two-thirds of the utilities offer TOU rates with two periods and the remaining one-third offer TOU rates with three or more periods.

Q. What is the ratio of peak to off-peak prices in TOU rates?

A. According to the OpenEI database,[3] 85% of TOU rates have a price ratio greater than 2-to-1, with the mean value being 3-to-1. The mean differential between peak and off-peak rates is 12 cents/kWh. TOU rates with three periods have a similar price ratio as those with two period TOU rates and a similar differential.

Q. Based on your experience working with a wide range of utilities in the US and abroad and your review of the literature, why do utilities offer TOU rates?

A. In my view, the foremost reason why utilities offer TOU rates is to help customers manage their energy bills. Customers want choice and offering a TOU rate to them in addition to the existing rate (which could be flat or have an inclining block structure) accommodates that desire.

[2] US Energy Information Administration, accessed at https://www.eia.gov/tools/faqs/faq.php?id=108&t=3#:~:text=In%202021%2C%20U.S.%20electric%20utilities,electric%20meters%20were%20AMI%20meters.

[3] Utility Rate Database, accessed at https://openei.org/wiki/Utility_Rate_Database.

TOU rates encourage customers to shift their load away from the peak period and helps reduce costs for all customers over the long run. They also encourage off-peak usage which enhances the affordability of newly emerging, climate-friendly technologies, such as electric vehicles (EVs). Well-designed TOU rates represent a win-win situation for customers and their utilities.

Q. What is the typical duration of the peak period?

A. For a long time, utilities developed the duration of the peak period based on a review of prices in the wholesale market. The peak hours used to be 16 hours long and did not appeal to customers. Newer TOU rates, primarily designed to appeal to EV drivers, have much shorter peak periods, typically ranging from 4 to 6 hours. Peak periods used to cover the early afternoon hours, such as noon to 6 pm. Now they occur much later in the afternoon, and often range from 4 pm to 9 pm.

Q. How are the pricing periods developed?

A. Utilities typically develop pricing periods by reviewing recent data on annual hourly load shapes for system marginal costs and annual hourly load shapes for the system as a whole. Sometimes, they also review annual hourly load shapes for the residential class.

Q. How are prices developed by period?

A. Utilities typically develop them by reviewing hourly marginal energy costs and capacity costs for supply (capacity, energy, transmission and distribution). In this proceeding, PSE&G is only proposing changes in the distribution portion of rates. Since customers pay a single amount that includes generation, transmission and distribution, we have developed illustrative rates that include all these components. It’s my understanding that the final version of TOU rates will be developed in future Basic Generation Service (“BGS”) proceedings.

Q. Are system costs based on embedded or marginal costs?

A. In nearly every case that I am aware of, utilities base their rates on an embedded cost of service study. TOU rates are designed to be revenue-neutral for the class as a whole. Thus, a customer whose load shape resembles that of the class as a whole will see no change in their bill unless they change their load shape. If they lower their peak load and/or shift it to the off-peak period, they will realize bill savings. Peakier-than-average customers will see higher bills unless they reduce their peak load. Customers who are less peaky than the class average will realize immediate savings by choosing a TOU rate and if they lower their peak load, will realize even higher savings.

In a few cases, utilities also review a marginal cost of service study. However, these are only used to determine the ratio between peak and off-peak period charges. The absolute values are still based on an embedded cost of service study.[4]

Q. What are the different ways in which utilities deploy TOU rates to customers?

A. There are three modes of deployment: opt-in, opt-out and mandatory. Opt-in means the rate is offered to all customers. Any customer who wants to take it can sign up for it. Those customers who don't take the optional rate stay on their existing rate. Opt-out means that all customers are rolled over to the rate but any customer who does not want to stay on it can opt-out to another rate, which may be the prior rate or a new rate. Mandatory means that all customers are rolled over to the TOU rate and they have no choice. In Michigan, which has moved all customers to a default TOU rate, customers do have a choice to switch to other rates but they are also TOU rates.

[4] This method of developing rate is also called the equiproportional marginal cost method.

Q. How many TOU rates are deployed on an opt-in basis?

A. Most TOU deployments are on an opt-in basis.

Q. How many TOU rates are deployed on an opt-out basis?

A. In the US, California and Colorado have rolled out TOU rates as the default rate. In California, this was first done by a municipal utility, SMUD, which serves more than half a million customers in Sacramento and surrounding areas. It was then followed by all three large investor-owned utilities which serve 12 million customers. In Canada, the province of Ontario with some four million customers has rolled out TOU rates but they only apply to the energy portion of the rate.

Q. How many TOU rates are deployed on a mandatory basis?

A. The first utility to deploy TOU rates on a mandatory basis was Fort Collins, which serves nearly 69,000 customers. In Michigan, the two large investor-owned utilities, Consumers Energy and DTE, have deployed a TOU rate as the default and given customers a choice to opt-out to other TOU rates.

Q. Are pilots a pre-requisite for deploying TOU rates?

A. No. There have been scores of pilots around the US and many others around the globe. Utilities can safely proceed with offering opt-in TOU rates based on the experiences of other utilities, supplemented with insights gathered by conducting focus groups with their own customers. However, default and mandatory deployments should ideally be preceded by pilots. That has been the case in California, Colorado and Michigan.

Q. Is seasonal variation often found in TOU rates?

A. Yes, it's quite common, particularly in utilities where system load shapes vary across the seasons because of climatic factors, and this causes variation in the cost of service across seasons.

Q. What are the main features of well-designed TOU rates?

A. Well-designed TOU rates are customer-friendly and have short peak periods. They provide customers with an opportunity to save money by shifting their usage during the peak period to off-peak periods. Utilities provide videos on their web portal to educate customers on how they benefit by reducing peak loads and shifting energy consumption to the off-peak period. They often provide a bill calculator that allows customers to find the lowest cost rate that is consistent with their lifestyle. A single individual may have a different lifestyle than a young couple with no children or a family with young children or empty nesters.

Q. How can customers take advantage of TOU rates?

A. The penetration of EVs is growing fast. EVs are often the biggest load in a customer's house. Customers with EVs can set them to charge after midnight, when electricity costs are lowest. Customers with central air conditioning can precool their homes during the off-peak period by lowering their thermostat by a couple of degrees and raising it by a couple of degrees during the peak period. These days, most homes have programmable thermostats that make this a relatively easy task. Since central air conditioning is a big load in the house, this can yield substantial savings by itself. They can do their laundry during the off-peak hours. In addition, they can set the delay button on their dishwasher so it runs after midnight, which usually falls within the off-peak period.

Q. What utilities have successfully deployed opt-in TOU rates?

A. OGE in Oklahoma and APS and SRP in Arizona have successfully recruited large numbers of customers to TOU rates for years. They offer a choice of several TOU rates to their customers. In the past few years, utilities in Georgia, Missouri and New York have begun offering similarly well-designed rates to their customers on an opt-in basis. For additional details on the status of TOU rates in the US, please consult Schedule AF-2.

Q. Why is PSE&G planning to deploy TOU rates?

A. The primary purpose is to better reflect the cost of service. As noted earlier, this will promote economic efficiency and equity. There is a national trend toward TOU rates. This is being driven by a desire to combat climate change via electrification of buildings and transportation, and to manage the cost and operational challenges of that transition. EV deployment is rising fast. It's going to be potentially the biggest user of electricity in homes. Unless customers charge their EVs during off-peak and night time periods, they will end up creating a serious challenge to the grid. With TOU rates, they will be able to lower their charging costs and also reduce the strain on the grid. Of course, as noted earlier, smart meters are a pre-requisite to the widespread deployment of TOU rates.

Additionally, the Residential TOU Program meets PSE&G's commitment set forth in the BPU's CEF-EV Order to address rates for residential EV charging.[5]

Q. What specific TOU rates is PSE&G planning to deploy?

A. PSE&G is planning to offer two TOU rates to its residential customers. One TOU rate is going to be a two-period rate that modifies the existing Residential Load Management ("RLM")

[5] CEF-EV Order at 13 (Stipulation of Settlement, paragraph 33).

rate by shortening the peak period and enhancing the discount during the off-peak period. The other TOU rate will be a three-period TOU rate with a specially discounted night time rate to encourage night-time charging of EVs.

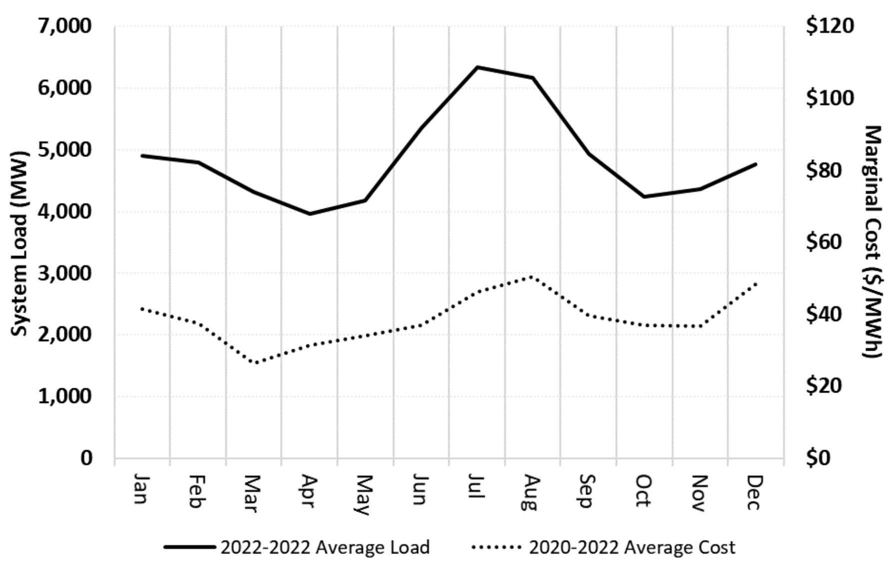
Q. Why is more than one TOU rate being offered?

A. To give customers choice, especially to those who drive EVs.

Q. How were they developed?

A. PSE&G is proposing to develop TOU rates focused on distribution costs in this proceeding. In a later filing, it will develop TOU rates focused on generation energy and capacity costs, transmission costs and all other costs. However, since customers pay a total bill, and not a separate distribution bill, in this testimony I have developed all-in TOU rates. We developed TOU pricing periods by reviewing data on hourly system load shapes, and hourly system marginal costs (equal to Day Ahead Locational Marginal Pricing ("LMPs")). These are summarized in Figure 1. System loads are shown on the vertical axis on the left and marginal costs on the vertical axis on the right.

Figure 1 Average System Load and Marginal Cost by Month (2020-2022)



The figure shows two distinct patterns across the year: winter and summer. Winter has eight months, which goes from October through December and January through May. Summer has four months, from June through September. This also aligns with PSE&G's gas season definition.

Figure 2 Typical Summer Weekday Profile (2020-2022)

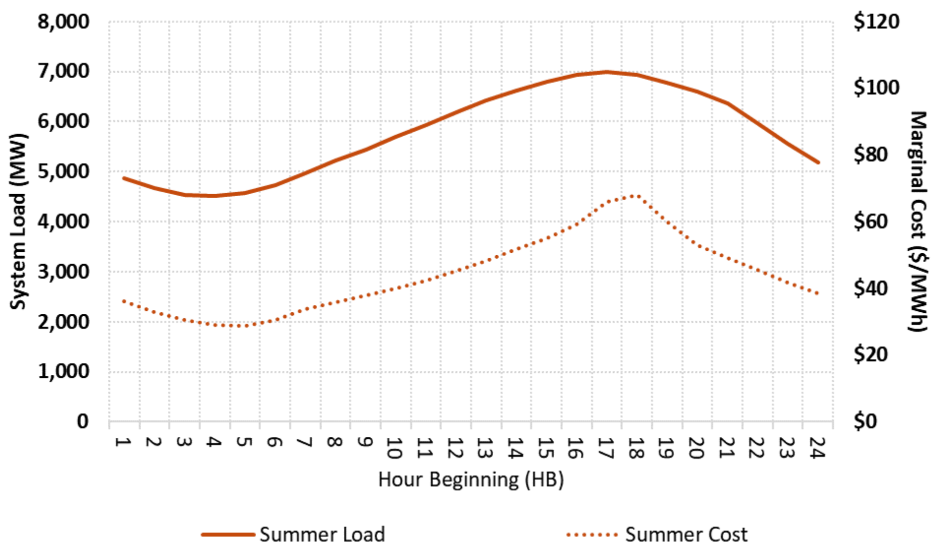
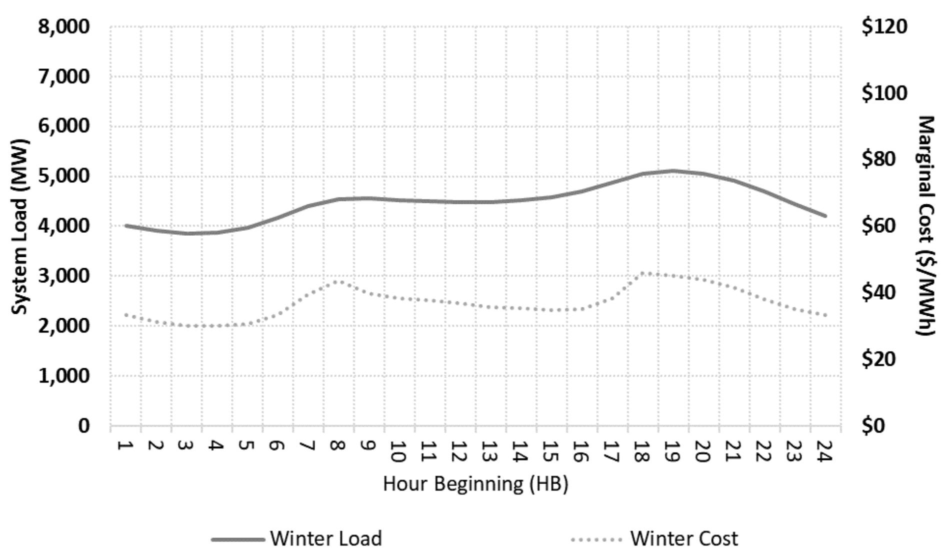


Figure 3 Typical Winter Weekday Profile (2020-2022)



Winter features bimodal peaks with pronounced evening peak while summer features one pronounced evening peak. For simplicity and better customer experience, we propose adopting the same pricing period definitions for all seasons. The two-period TOU rate will have an on-peak time period that runs from 4 P.M. to 9 P.M. (EST) Monday through Friday, which is significantly shorter than the peak period in the existing TOU rate, and very much in line with the newer generation of TOU rates that are being offered in the US.[6] The three-period TOU rate will have the same on-peak period as the two-period TOU rate and will run from 4 P.M. to 9 P.M. (EST) Monday through Friday. In addition, it will have an off-peak period from 12 A.M. to 6 A.M. (EST) in all days that should appeal to EV drivers. All other hours shall constitute the Mid-Peak period.

Q. How did you design the two-period TOU rate?

A. The TOU rates were developed in close concert with Stephen Swetz of PSE&G and were designed to be revenue neutral with the RS rate class. As a starting point, Witness Swetz used PSE&G's embedded cost study for the Residential ("RS"), to develop TOU distribution rates. We designed generation rates to be revenue neutral to current the current RS default generation rates or Basic Generation Service ("BGS") RS rates. We used the Day-Ahead LMPs from PJM as a proxy for the marginal energy cost of generation. For other generation costs, we used costs that were used to develop BGS rates, then adjusted the results to ensure revenue neutrality. We designed transmission rates to be revenue neutral to the RS transmission rates but set rates to recover costs via certain TOU rate periods to better align with cost causation.

For the two-period TOU rate, we first calculated the summer and non-summer peak rates to reflect the generation, transmission, and distribution capacity and the generation energy costs. We allocated the remaining costs (net of revenue from peak hours and revenue from fixed

[6] The definition of current RLM on-peak period is 7 A.M. to 9 P.M. (EST) Monday through Friday during Daylight Savings Time. All other hours are considered as off-peak period.

charges) equally across the off-peak periods, solving for the corresponding rates to ensure revenue neutrality.

The current RS rate varies by season. It also has two tiers in it. Under PSE&G's rate proposal, the average residential customer on the RS rate would pay 22 cents/kWh in the summer and 17 cents/kWh in the winter months. This reflects an increase of 18% in summer and an increase of 7% in winter compared to the current RS rate. Both rates are shown in the figure below.

Figure 4 Summary of Current and Proposed RS Rate

		Current RS Rate		**Proposed RS Rate**	
		Summer	**Winter**	**Summer**	**Winter**
Generation ($/kWh)	0-600	$0.077023	$0.080531	$0.077023	$0.080531
	Over 600	$0.086772		$0.086772	
Distribution ($/kWh)	0-600	$0.047449	$0.035553	$0.081585	$0.047785
	Over 600	$0.051523		$0.085659	
Transmission ($k/kWh)		$0.061233	$0.061233	$0.061233	$0.061233
Average Total Rate ($/kWh)		**$0.187680**	**$0.160734**	**$0.221816**	**$0.171218**
Monthly Charge ($/Month)		$4.95		$8.05	

Figure 5 Summary of Proposed Two-Period TOU Rate

	Two Period TOU			
	Summer		**Winter**	
	On Peak	**Off Peak**	**On Peak**	**Off Peak**
Generation ($/kWh)	$0.127337	$0.065788	$0.131136	$0.072600
Transmission ($/kWh)	$0.139700	$0.052704	$0.069850	$0.052704
Distribution ($/kWh)	$0.209513	$0.037114	$0.153778	$0.037114
Final Rate ($/kWh)	**$0.476551**	**$0.155605**	**$0.354764**	**$0.162418**
Monthly Charge ($/Month)	$8.05			

Under PSE&G's rate proposal, under the two-period rate, the average residential customer would pay a rate of 48 cents/kWh during the peak period and a rate of 16 cents/kWh during the off-peak period in the summer; in the winter, the corresponding values would be 35 cents/kWh during the peak period and a rate of 16 cents/kWh during the off-peak period.

Q. Why did you design a three-period TOU rate in addition to a two-period TOU rate?

A. The three-period TOU rate is primarily designed to appeal to PSE&G's customers that drive EVs but all residential customers would be eligible to sign up for it.

Q. How did you design the three-period TOU rates?

A. Our methodology is similar to that of the two-period TOU rate. Like the two-period TOU rate, the three-period TOU rate is also revenue neutral, meaning that it collects the same amount of revenue for the class, before any load shifting.

Figure 6 Summary of Proposed Three-Period TOU Rate

	Three Period TOU					
	Summer			Winter		
	On Peak	**Mid Peak**	**Off Peak**	**On Peak**	**Mid Peak**	**Off Peak**
Generation ($/kWh)	$0.127337	$0.070636	$0.048759	$0.131136	$0.075768	$0.063677
Transmission ($/kWh)	$0.139700	$0.069850	-	$0.069850	$0.069850	-
Distribution ($/kWh)	$0.209513	$0.042307	$0.021153	$0.153778	$0.042307	$0.021153
Final Rate ($/kWh)	**$0.476551**	**$0.182794**	**$0.069912**	**$0.354764**	**$0.187925**	**$0.084830**
Monthly Charge ($/Month)	$8.05					

Under the three-period rate, the average residential customer would pay a rate of 48 cents/kWh during the peak period, which is the same as the peak period price in the two-period TOU rate; a rate of 18 cents/kWh during the mid-peak period, and a rate of 7 cents/kWh during the off-peak period in the summer. In the winter, the corresponding values would be 35 cents/kWh during the peak period, 19 cents/kWh during the mid-peak period and 8 cents/kWh during the off-peak period. The figures below provide graphical illustrations of the rate.

Figure 7 Graphic Illustration of Two-Period TOU Rates (Summer)

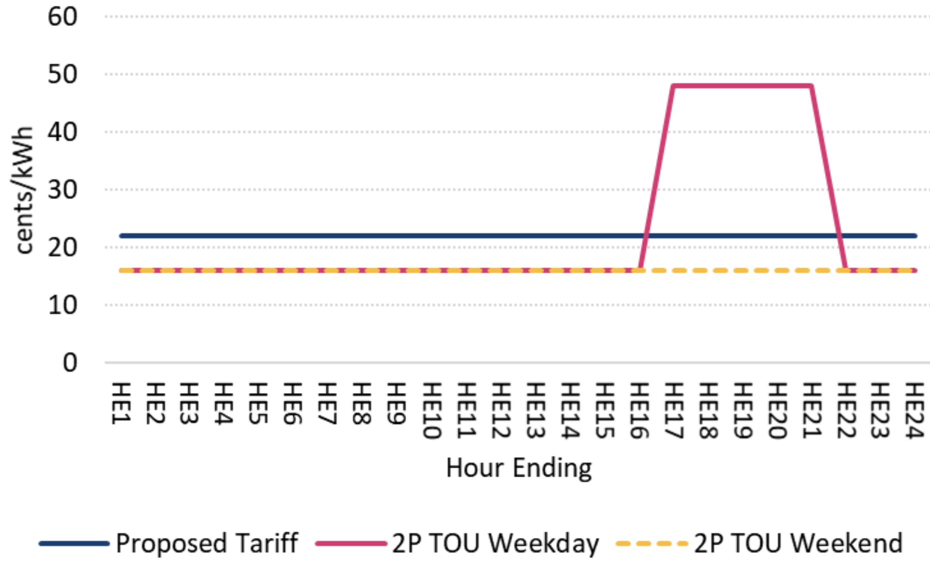
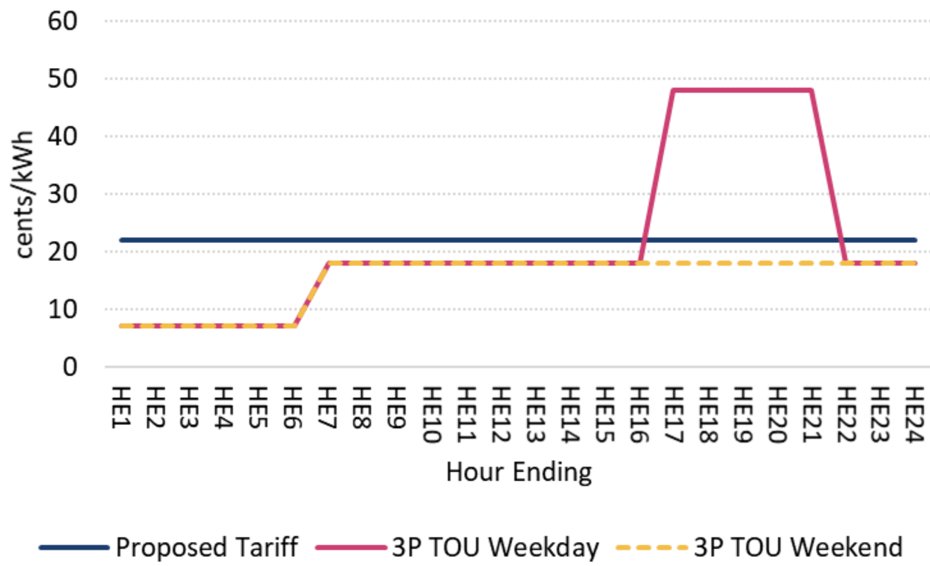


Figure 8 Graphic Illustration of Three-Period TOU Rates (Summer)



Q. How do the proposed TOU rates compare with those being offered by other utilities?

A. Structurally, they are quite similar. Since California has the largest number of customers on TOU rates, and since it also has the largest number of customers with EVs, I have compared PSE&G's rates with those being offered by PG&E, one of the two largest investor-owned utilities in the state. It serves some 5 million electric customers in northern California and has a long history of offering TOU rates. It is also the utility which serves my personal residence.

Figure 9 shows the two-period TOU rates for the utilities and Figure 10 shows the three-period TOU rates. Structurally, the TOU rates are similar but since the average rate levels differ significantly for the two utilities (approximately 22 cents/kWh for PSE&G and approximately 38 cents/kWh for PG&E), PSE&G's customers are always going to be paying less per kWh than PG&E's customers.

Figure 9: Comparison of PSE&G's Two-Period TOU rate with PG&E's

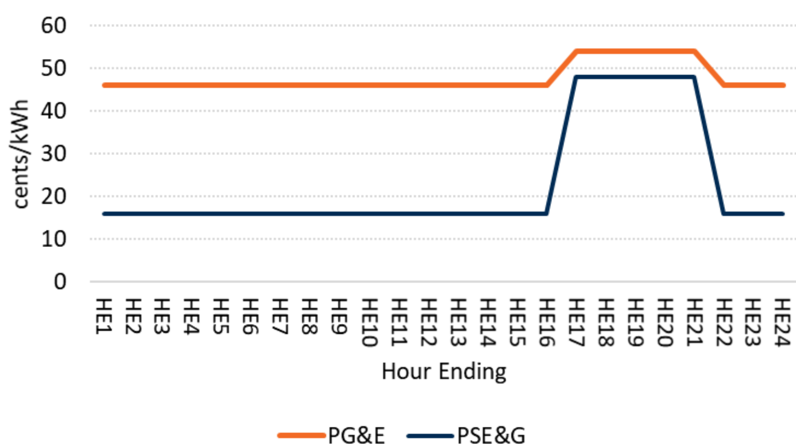
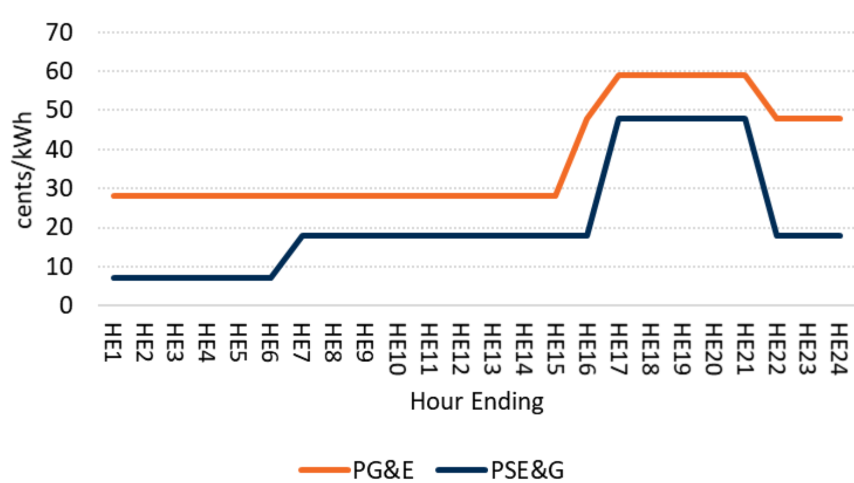


Figure 10: Comparison of PSE&G's Three-Period TOU rate with PG&E's



Q. Will the pricing periods in the TOU rates change at some point in the future?

A. Yes, they may change in the future if significant changes take place in the time pattern of system loads and system marginal energy and capacity costs. Such changes have occurred in utilities that have had TOU rates in place for decades. I have been on PG&E's TOU rates since the early 1990's. Back then, the on-peak period ran from noon to 6 pm. A decade or two later, it was changed and ran from 2 pm to 7 pm. Now it runs from 4 pm to 9 pm.

Q. Will the levels of the TOU rates change over time?

A. Yes, they may also change over time as significant changes take place in energy and capacity costs by time period.

Q. Are the rates designed to be revenue-neutral for the residential class?

A. Yes, they are. I have estimated the impact of the TOU rates on the average customer in a sample of 170 customers that was provided to me by PSE&G. The results are shown below in Figures 11 and 12, first for the two-period TOU rate, then for the three-period TOU rate. In the figures, positive numbers indicate bill savings and negative numbers indicate bill increases.

Figure 11 Average Bill Impact – Two-Period TOU

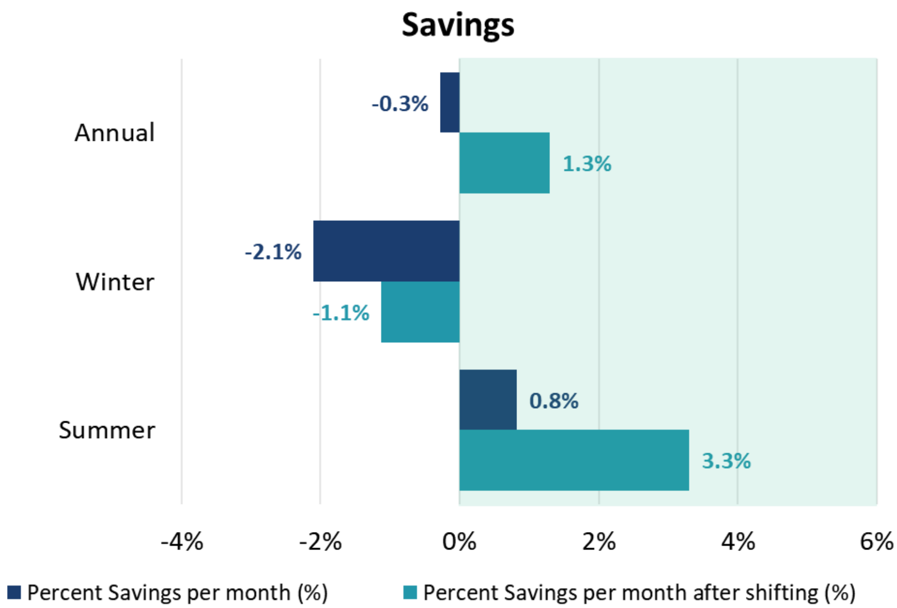
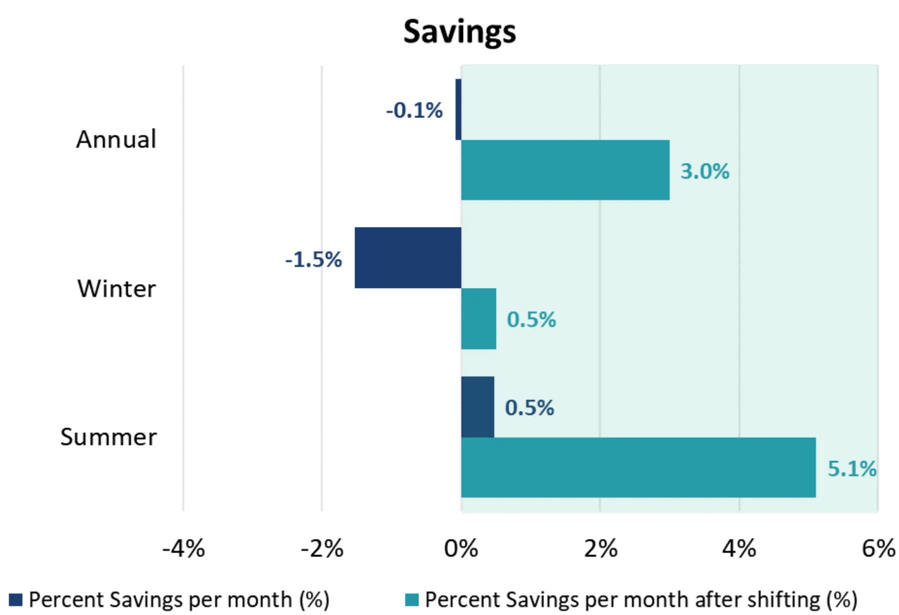


Figure 12 Average Bill Impact – Three-Period TOU



Q. What will be the likely impact of the TOU rates on customer bills?

A. Working with the sample of 170 customers, I estimated how each customer's bill will change if they were to move from the RS to each of the two TOU rates. For each rate, I rank ordered the bill impacts by customer so that the biggest drop in bills occur to the left of the chart and the highest rise in bills occur to the right of the chart. This creates the "propeller charts" that are shown below in Figures 13 and 14. These charts show how the two TOU rates will affect customer bills before they engage in any load shifting. Approximately half of the customers save money simply by switching to the TOU rates, even in the absence of load shifting: 49% in the case of the two-period rate and 48% in the case of the three-period rate.

Figure 13 Monthly Bill Impact on Sample Customers (Two Period TOU, without load shifting)

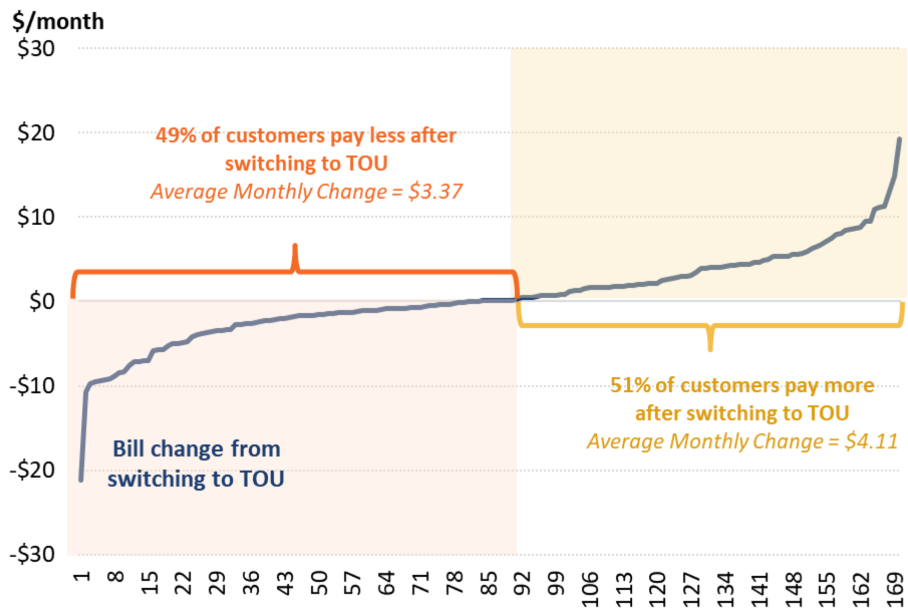
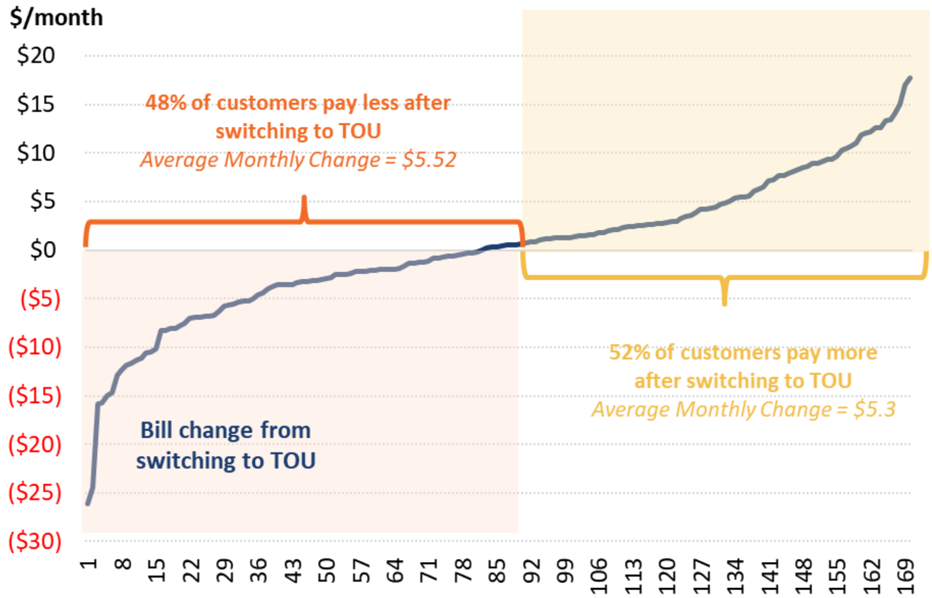


Figure 14 Monthly Bill Impact on Sample Customers (Three Period TOU, without load shifting)



Q. How strong is the incentive to shift loads away from the peak period?

A. Strong price signals exist for shifting load away from the peak period in both the two-period and the three-period TOU rates. For the two-period TOU rate, the peak to off-peak price ratio is about 3.1:1 to one in summer months, and 2.2:1 for non-summer months. The three-period TOU rate has an even stronger price signal, with a 6.8:1 price ratio during the summer months between on-peak and off-peak period.

Figure 15 Summary of the On-Peak to Off-Peak Ratio

		Residential 2P TOU	Residential 3P TOU
Summer			
On-Peak	$/kWh	$0.476551	$0.476551
Mid-Peak	$/kWh	-	$0.182794
Off-Peak	$/kWh	$0.155605	$0.069912
Winter			
On-Peak	$/kWh	$0.354764	$0.354764
Mid-Peak	$/kWh	-	$0.187925
Off-Peak	$/kWh	$0.162418	$0.084830
On-Peak : (Mid-Peak): Off-Peak Ratios			
Summer		3.1 :1	6.8 :2.6 :1
Winter		2.2 :1	4.2 :2.2 :1

Q. As a result of the price incentives offered by these two TOU rates, how much will customers lower their peak demand?

A. Customers will have a strong incentive to reduce their peak loads in response to these two TOU rates and to shift that load to the non-peak periods. Using the analytical charts in Arcturus, a Brattle database that contains a meta-analysis of results from more than 400 deployments of time-varying rates around the globe, I would expect to see the following pattern of results for the two TOU rates.[7] In the summer, the two-period TOU rate would induce a drop of 10% in peak load and a drop of 7% in the winter. As for the three-period TOU rate, in the summer it would induce a drop of 16% in peak load and a drop of 12% in the winter.

[7] For the purposes of this analysis, the model is developed based on 127 observations that are Time-of-Use rate and opt-in deployment from the Arcturus database. For background on Arcturus, please consult: https://www.brattle.com/wp-content/uploads/2023/02/Do-Customers-Respond-to-Time-Varying-Rates-A-Preview-of-Arcturus-3.0.pdf.

Figure 16 The Arc of Price Responsiveness – Two-Period TOU

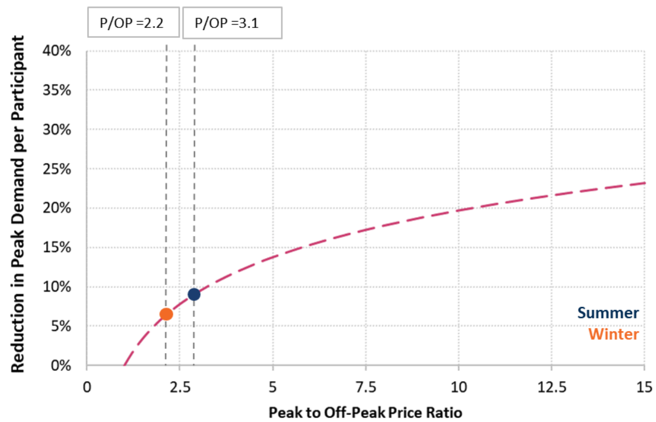
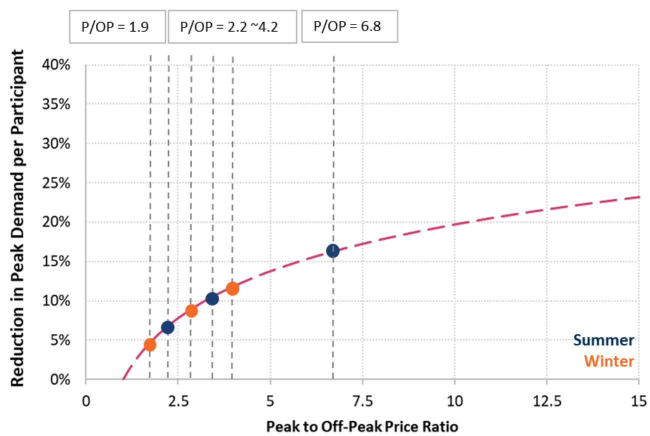


Figure 17 The Arc of Price Responsiveness – Three-Period TOU



Q. When customers respond to TOU rates by reducing their peak loads, will their bills go down?

A. Yes, I would expect them to go down as they shift their usage from a costlier period to the less costly off-peak period in the case of the two-period TOU rate and to the less-costlier mid-peak and off-peak periods in the case of the three-period TOU rate. The propeller charts which include the effect of load shifting away from the peak period are shown below. They show that a greater percentage of customers will see lower bills than the results shown in the previous figures which assumed no load shifting. For the two-period rate, 69% of customers save money, compared to

49% in the absence of load shifting. For the three-period rate, 80% save money, compared to 48% in the absence of load shifting.

Figure 18 Monthly Bill Impact on Sample Customers (Two Period TOU, with load shifting)

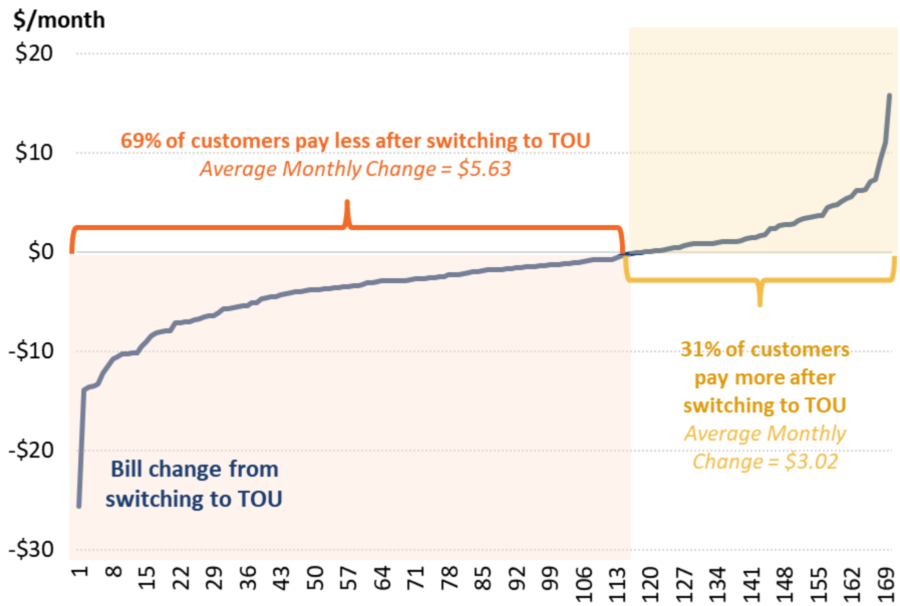
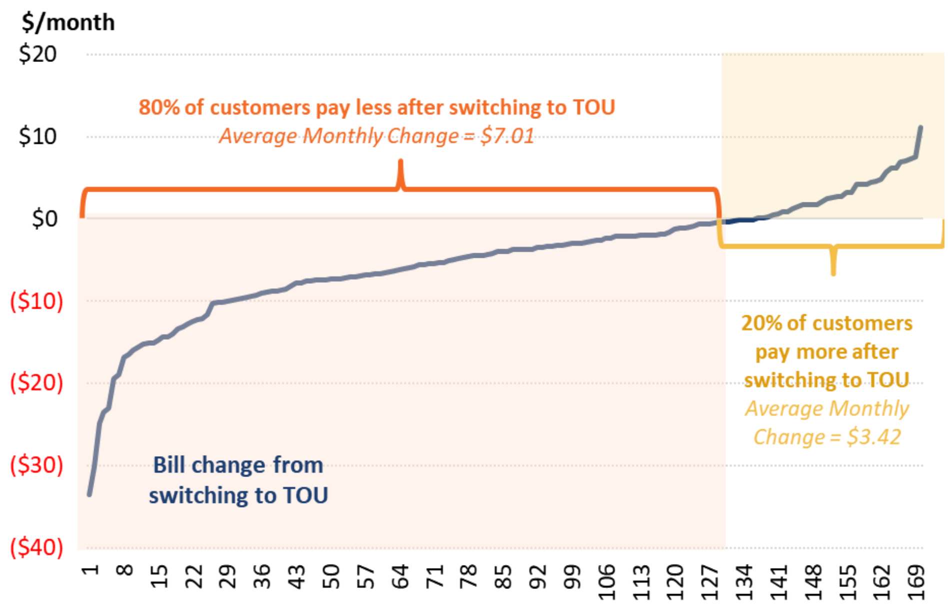


Figure 19 Monthly Bill Impact on Sample Customers (Three Period TOU, with load shifting)



Q. Will any customer be harmed by switching to TOU rates?

A. No. PSE&G will provide bill protection for the first year that a customer is on a TOU rate. They will not see a bill increase. If their bill goes down, they will get to keep the savings. Also, if they don't like the TOU rate for any reason, they will be able to opt-out of it. Additionally, PSE&G will provide ideas on its web portal to help customers modify their pattern of consuming energy to maximize their bill savings.

Q. What is your general assessment of the two TOU rates that PSE&G is proposing to offer its residential customers?

A. PSE&G's TOU rates recognize that customers have diverse tastes and preferences. Some customers want simplicity in their tariffs, others value comfort, while others want to closely monitor their usage and lower their bills by changing the way they consume energy. PSE&G will continue to offer its existing RS Rate Schedule as the default residential rate. The two TOU tariffs will be complementary to the RS Rate Schedule. They will appeal to customers who want to lower their bills by reducing their usage during the peak period and shifting it to the off-peak period.

Q. What is your opinion of the two-period TOU rate?

A. The rate features a discount of 17% compared to the existing tariff in the off-peak period, and a premium of 155% compared to the price in the on-peak period in summer. Customers who are able to shift energy consumption from the on-peak period (which is 5 hours long) to the off-period (which is 19 hours long) in the summer will save 67% on each kWh that is shifted in summer and 54% on each kWh in winter. In my opinion, this rate will appeal to those customers who are able to shift significant end use loads from the on-peak to the off-peak period. For example, they could load their dishes in the dishwasher and set its timer to start operating at 9 p.m. They could program their thermostat so it's a few degrees lower during the off-peak hours in the summer months. If their normal setting is 74 degrees, they could raise it to 75 degrees during the on-peak hours and lower it to 73 degrees during the off-peak hours. The greater the differential in the temperature setting between the off-peak and on-peak periods, the more they will save.

Q. What is your opinion of the three-period TOU rate?

A. This rate features three pricing periods to provide a greater discount during the night time. Based on what I have observed in other jurisdictions where three-period TOU rates are being offered, it should appeal to customers who drive electric vehicles (EVs). They can simply set the timer in their cars to charge the battery during the off-peak hours. Most EVs can be fully charged in six hours and most drivers don't always fully charge their EVs. For each summer kWh shifted from the on-peak to the off-peak period, they will save 85%. For each summer kWh they shift from the on-peak to the mid-peak period, they will save 62%. For winter, the percentage savings are 76% and 47% from the on-peak to the off-peak and mid-peak period, respectively. In my opinion, this rate will appeal to customers who are seriously interested in saving money by moving significant portions of their load out of the on-peak period to the mid-peak and off-peak periods. This rate exemplifies the trends in modern rate designs: allowing customers to create significant savings opportunities by lowering demand when the grid is stressed. This would help PSE&G keep rates lower for customers in the long run by avoiding the need to invest in distribution infrastructure upgrades to meet higher peak demands.

Q. Is a shorter peak period likely to attract more customers than a longer peak period?

A. Yes. A shorter peak period is easier for customers to cope with than a longer peak period. Another advantage of the shorter peak period is that the price differential between on-peak and off-peak hours can be higher than with a longer peak period. Customers would save more for each kWh that is reduced and/or shifted to the off-peak period. In sum, a shorter on-peak period is easier for customers to cope with and also more rewarding. Thus, I would expect it to attract more customers.

Q. Should the TOU rate structure stay constant or change over time?

A. Over time, I would expect system load shapes and costs to change, due to changes in the mix of generation resources and in the manner that customers use electricity, driven by the increasing penetration of EVs and distributed energy resources, such as solar panels and battery storage. As such changes occur, the rate structure should change which may involve changing the duration of the pricing periods as well as the prices within the periods. However, the rates should not be changed every year.

Q. What is the optimal frequency for changing rates?

A. In my view, rate structures and parameters should not be changed too frequently to prevent customer confusion and frustration. Ideally, the structure of the rates and its key parameters should be kept constant over a five-year period. Of course, the price levels in each period may change during this period to reflect changes in the cost of service, market prices and other factors. But the price ratios and period definitions should not be changed too frequently.

Q. Would you expect the proposed TOU rates to be well received by customers?

A. Yes, I would. Customers are likely to appreciate being given more choices to lower their bills by making slight modifications in their lifestyle. All of them will have an opportunity to try out the new TOU rates and see if they can lower their bills. They will have bill protection for the first year, and will only pay the lower of the TOU bill or the bill they would have paid with the standard rate. If are not able to lower their bill, they will have the option to get off the TOU rate at the end of their initial 12 month period.

Q. Does that conclude your testimony?

A. Yes.

Ahmad Faruqui

PRINCIPAL EMERITUS

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Dr. Faruqui is an energy economist whose consulting practice encompasses rate design, demand response, distributed energy resources, demand forecasting, decarbonization, electrification and energy efficiency and load flexibility.

In his career, Dr. Faruqui has advised some 150 clients in 12 countries on 5 continents and appeared before regulatory bodies, governments, and legislative councils in Alberta (Canada), Arizona, Arkansas, California, Colorado, Connecticut, Delaware, District of Columbia, Egypt, FERC, Georgia, Illinois, Indiana, Iowa, Jamaica, Kansas, Kentucky, Michigan, Maryland, Minnesota, Missouri, Nevada, New Brunswick (Canada), Nova Scotia (Canada), Ohio, Oklahoma, Ontario (Canada), Pennsylvania, the Philippines, Saudi Arabia (ECRA), Texas, and Washington.

He has authored or coauthored more than 150 papers in peer-reviewed and trade journals and co-edited 5 books on industrial structural change, customer choice, and electricity pricing. His innovations have been cited in *Bloomberg*, *Businessweek*, *The Economist*, *Forbes*, and *National Geographic*, in addition to news outlets including the *Los Angeles Times*, *The New York Times*, *San Francisco Chronicle*, *San Jose Mercury News*, and *The Washington Post*. He has also appeared on Fox Business News and NPR.

He has taught economics at San Jose State University, the University of California, Davis, and the University of Karachi and delivered guest lectures at Carnegie Mellon, Harvard, Idaho, MIT, New York University, Northwestern, Rutgers, Stanford, UC Berkeley, and UC Davis. He has also given seminars on energy issues on 20 countries on 6 continents.

AREAS OF EXPERTISE

- Regulatory Economics, Finance, & Rates
- Electricity Wholesale Markets & Planning

EDUCATION

- **University of California, Davis**
  PhD in Economics
  MA in Agricultural Economics
- **University of Karachi (Karachi, Pakistan)**
  MA in Economics (Highest Honors)
  BA in Economics, with minors in Mathematics, & Statistics (Highest Honors)

PROFESSIONAL EXPERIENCE

- **The Brattle Group (2006–Present)**
  Principal Emeritus (2021–Present)
  Principal (2006–2021)

EXPERT TESTIMONY

UNITED STATES

Arizona

- Rebuttal Testimony before the Arizona Corporation Commission on behalf of Arizona Public Service Company, in the matter of Stacey Champion, et al., v Arizona Public Service Corporation, Docket No. E-01345A-18-0002, August 17, 2018.
- Direct Testimony before the Arizona Corporation Commission on behalf of Arizona Public Service Company, in the matter of Stacey Champion, et al., v Arizona Public Service Corporation, Docket No. E-01345A-18-0002, July 31, 2018.
- Direct Testimony before the Arizona Corporation Commission on behalf of Arizona Public Service Company, in the matter of the Application of Arizona Public Service Company for a Hearing to Determine the Fair Value of the Utility Property of the Company for Ratemaking Purposes, to Fix a Just and Reasonable Rate of Return Thereon, to Approve Rate Schedules Designed To Develop Such Return, Docket No. E-01345A-16-0036, June 1, 2016.
- Direct Testimony before the Arizona Corporation Commission on behalf of Arizona Public Service Company, in the matter of the Application for UNS Electric, Inc. for the Establishment of Just and Reasonable Rates and Charges Designed to Realize a Reasonable Rate of Return on the Fair Value of the Properties of UNS Electric, Inc. Devoted to the its

Operations Throughout the State of Arizona, and for Related Approvals, Docket No. E-04204A-15-0142, December 9, 2015.

- Testimony before the Board of Directors on behalf of Salt River Project, in the matter of "An Evaluation of SRP's Electric Rate Proposal for Residential Customers with Distributed Generation," December 31, 2014.

Arkansas

- Direct Testimony before the Arkansas Public Service Commission on behalf of Entergy Arkansas, Inc., in the matter of Entergy Arkansas, Inc.'s Application for an Order Finding the Deployment of Advanced Metering Infrastructure to be in the Public Interest and Exemption from Certain Applicable Rules, Docket No. 16-060-U, September 19, 2016.

California

- Prepared testimony before the California Public Utilities Commission on behalf of Bloom Energy Corporation, Application R.20-11-003, September 10, 2021.
- Testimony before the Board of Directors on behalf of SMUD, in the matter of "Encouraging Rooftop Solar without Creating Cross-subsidies," April 30, 2019.
- Rebuttal Testimony before the Public Utilities Commission of the State of California, Pacific Gas and Electric Company Joint Utility on Demand Elasticity and Conservation Impacts of Investor-Owned Utility Proposals, in the Matter of Rulemaking 12-06-013, October 17, 2014.
- Prepared testimony before the Public Utilities Commission of the State of California on behalf of Pacific Gas and Electric Company on rate relief, Docket No. A.10-03-014, Summer 2010.
- Qualifications and prepared testimony before the Public Utilities Commission of the State of California, on behalf of Southern California Edison, Edison SmartConnect™ Deployment Funding and Cost Recovery, exhibit SCE-4, July 31, 2007.
- Testimony on behalf of the Pacific Gas & Electric Company, in its application for Automated Metering Infrastructure with the California Public Utilities Commission. Docket No. 05-06-028, 2006.

Colorado

- Rebuttal testimony before the Public Utilities Commission of the State of Colorado in the Matter of Advice Letter No. 1535 by Public Service Company of Colorado to Revise its

Colorado PUC No.7 Electric Tariff to Reflect Revised Rates and Rate Schedules to be Effective on June 5, 2009. Docket No. 09al-299e, November 25, 2009.

- Direct testimony before the Public Utilities Commission of the State of Colorado, on behalf of Public Service Company of Colorado, on the tariff sheets filed by Public Service Company of Colorado with advice letter No. 1535 – Electric. Docket No. 09S-__E, May 1, 2009.

Connecticut

- Testimony before the Department of Public Utility Control, on behalf of the Connecticut Light and Power Company, in its application to implement Time-of-Use, Interruptible Load Response, and Seasonal Rates- Submittal of Metering and Rate Pilot Results- Compliance Order No. 4, Docket no. 05-10-03RE01, 2007.

District of Columbia

- Direct testimony before the Public Service Commission of the District of Columbia on behalf of Potomac Electric Power Company in the matter of the Application of Potomac Electric Power Company for Authorization to Establish a Demand Side Management Surcharge and an Advance Metering Infrastructure Surcharge and to Establish a DSM Collaborative and an AMI Advisory Group, case no. 1056, May 2009.

Georgia

- Direct testimony before the State of Georgia Public Service Commission on behalf of Georgia Power Company, in the matter of Georgia Power Company's 2019 Base Rate Case, Docket No. 42516, June 28, 2019.

Idaho

- Rebuttal Testimony before the Idaho Public Utilities Commission on behalf of Idaho Power Company (Idaho Power), in the matter of the Application of Idaho Power Company for Authority to Establish New Schedules for Residential and Small General Service Customers with On-Site Generation, Case No. IPC-E-17-13, January 26, 2018.

Illinois

- Direct testimony on rehearing before the Illinois Commerce Commission on behalf of Ameren Illinois Company, on the Smart Grid Advanced Metering Infrastructure Deployment Plan, Docket No. 12-0244, June 28, 2012.

- Testimony before the Illinois Commerce Commission on behalf of Commonwealth Edison Company regarding the evaluation of experimental residential real-time pricing program, 11-0546, April 2012.
- Rebuttal Testimony before the Illinois Commerce Commission on behalf of Commonwealth Edison Company in the matter of the Petition to Approve an Advanced Metering Infrastructure Pilot Program and Associated Tariffs, No. 09-0263, August 14, 2009.
- Prepared rebuttal testimony before the Illinois Commerce Commission on behalf of Commonwealth Edison, on the Advanced Metering Infrastructure Pilot Program, ICC Docket No. 06-0617, October 30, 2006.

Indiana

- Direct testimony before the State of Indiana, Indiana Utility Regulatory Commission, on behalf of Vectren South, on the smart grid. Cause no. 43810, 2009.

Kansas

- Rebuttal testimony before the State Corporation Commission of the State of Kansas on behalf of Evergy Kansas Central, Inc. and Evergy Kansas South, Inc. in the matter of the Joint Application of Westar Energy, Inc. and Kansas Gas and Electric Company to Make Certain Changes in Their Charges for Electric Services, Docket No. 18-WSEE-328-RTS, December 04, 2020.
- Direct testimony before the State Corporation Commission of the State of Kansas on behalf of Evergy Kansas Central, Inc. and Evergy Kansas South, Inc. in the matter of the Joint Application of Westar Energy, Inc. and Kansas Gas and Electric Company to Make Certain Changes in Their Charges for Electric Services, Docket No. 18-WSEE-328-RTS, October 13, 2020.
- Rebuttal testimony before the State Corporation Commission of the State of Kansas, on behalf of Westar Energy, in the matter of the Joint Application of Westar Energy, Inc. and Kansas Gas and Electric Company for Approval to Make Certain Changes in their Charges for Electric Services, Docket No. 18-WSEE-328-RTS, July 3, 2018.
- Direct testimony before the State Corporation Commission of the State of Kansas, on behalf of Westar Energy, in the matter of the Joint Application of Westar Energy, Inc. and Kansas Gas and Electric Company for Approval to Make Certain Changes in their Charges for Electric Services, Docket No. 18-WSEE-328-RTS, February 1, 2018.

- Reply affidavit before the State Corporation Commission of the State of Kansas, on behalf of Westar Energy, in the matter of the General Investigation to Examine Issues Surrounding Rate Design for Distributed Generation Customers, Docket No. 16-GIME-403-GIE, May 5, 2017.
- Direct testimony before the State Corporation Commission of the State of Kansas, on behalf of Westar Energy, in the matter of the Application of Westar Energy, Inc. and Kansas Gas and Electric Company to Make Certain Changes in Their Charges for Electric Service, Docket No. 15-WSEE-115-RTS, March 2, 2015.

Louisiana

- Rebuttal testimony before the Council of the City of New Orleans on behalf of Entergy New Orleans, LLC, in the matter of Application of Entergy New Orleans, LLC for a Change in Electric and Gas Rates Pursuant to Council Resolutions R-15-194 and R-17-504 and for Related Relief, Docket No. UD-18-07, March 2019.
- Direct testimony before the Council for the City of New Orleans on behalf of Entergy New Orleans, LLC, in the matter of Application of Entergy New Orleans, LLC for a Change in Electric and Gas Rates Pursuant to Council Resolutions R-15-194 and R-17-504 and for Related Relief, Docket No. UD-18-07, July 2018.
- Direct testimony before the Louisiana Public Service Commission on behalf of Entergy Louisiana, LLC, in the matter of Approval to Implement a Permanent Advanced Metering System and Request for Cost Recovery and Related Relief in accordance with Louisiana Public Service Commission General Order dated September 22, 2009, R-29213, November 2016.
- Direct testimony before the Council of the City of New Orleans, on behalf of Entergy New Orleans, Inc., in the matter of the Application of Energy New Orleans, Inc. for Approval to Deploy Advanced Metering Infrastructure, and Request for Cost Recovery and Related Relief, October 2016.

Maryland

- Direct Testimony before the Maryland Public Service Commission, on behalf of Potomac Electric Power Company in the matter of the Application of Potomac Electric Power Company for Adjustments to its Retail Rates for the Distribution of Electric Energy, April 19, 2016.

- Rebuttal Testimony before the Maryland Public Service Commission on behalf of Baltimore Gas and Electric Company in the matter of the Application of Baltimore Gas and Electric Company for Adjustments to its Electric and Gas Base Rates, Case No. 9406, March 4, 2016.
- Direct testimony before the Public Service Commission of Maryland, on behalf of Potomac Electric Power Company and Delmarva Power and Light Company, on the deployment of Advanced Meter Infrastructure. Case no. 9207, September 2009.
- Prepared direct testimony before the Maryland Public Service Commission, on behalf of Baltimore Gas and Electric Company, on the findings of BGE's Smart Energy Pricing ("SEP") Pilot program. Case No. 9208, July 10, 2009.

Minnesota

- Rebuttal testimony before the Minnesota Public Utilities Commission State of Minnesota on behalf of Northern States Power Company, doing business as Xcel Energy, in the matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in Minnesota, Docket No. E002/GR-12-961, March 25, 2013.
- Direct testimony before the Minnesota Public Utilities Commission State of Minnesota on behalf of Northern States Power Company, doing business as Xcel Energy, in the matter of the Application of Northern States Power Company for Authority to Increase Rates for Electric Service in Minnesota, Docket No. E002/GR-12-961, November 2, 2012.

Mississippi

- Direct testimony before the Mississippi Public Service Commission, on behalf of Entergy Mississippi, Inc., in the matter of Application for Approval of Advanced Metering Infrastructure and Related Modernization Improvements, EC-123-0082-00, November 2016.

Missouri

- Direct testimony before the Missouri Public Service Commission, on behalf of Union Electric Company d/b/a Ameren Missouri, in the matter of Union Electric Company d/b/a Ameren Missouri's Tariffs to Increase Its Revenues for Electric Service, ER-2019-0335, July 3, 2019.

Montana

- Rebuttal testimony before the Public Service Commission of the State of Montana on behalf of NorthWestern Energy, in the matter of NorthWestern Energy's Application for Authority to Increase Retail Electric Utility Service Rates and for Approval of Electric Service Schedules and Rules and Allocated Cost of Service and Rate Design, Docket No. D2018.2.12, April 2019.

- Prefiled direct testimony before the Public Service Commission of the State of Montana on behalf of NorthWestern Energy, in the matter of NorthWestern Energy's Application for Authority to Increase its Retail Electric Utility Service Rates and for Approval of its Electric Service Schedules and Rules, Docket No. D2018.2.12, September 28, 2018.

Nevada

- Prepared rebuttal testimony before the Public Utilities Commission of Nevada on behalf of Nevada Power Company and Sierra Pacific Power Company d/b/a NV Energy, in the matter of net metering and distributed generation cost of service and tariff design, Docket Nos. 15-07041 and 15-07042, November 3, 2015.
- Prepared direct testimony before the Public Utilities Commission of Nevada on behalf of Nevada Power Company d/b/a NV Energy, in the matter of the application for approval of a cost of service study and net metering tariffs, Docket No. 15-07, July 31, 2015.

New Mexico

- Direct testimony before the New Mexico Regulation Commission on behalf of Public Service Company of New Mexico in the matter of the Application of Public Service Company of New Mexico for Revision of its Retail Electric Rates Pursuant to Advice Notice No. 507, Case No. 14-00332-UT, December 11, 2014.

Oklahoma

- Rebuttal Testimony before the Corporation Commission of Oklahoma on behalf of Oklahoma Gas and Electric Company in the matter of the Application of Oklahoma Gas and Electric Company for an Order of the Commission Authorizing Applicant to modify its Rates, Charges and Tariffs for Retail Electric Service in Oklahoma, Cause No. PUD 201500273, April 11, 2016.
- Direct Testimony before the Corporation Commission of Oklahoma on behalf of Oklahoma Gas and Electric Company in the matter of the Oklahoma Gas and Electric Company for an Order of the Commission Authorizing Applicant to modify its Rates, Charges and Tariffs for Retail Electric Service in Oklahoma, Cause No. PUD 201500273, December 18, 2015.
- Responsive Testimony before the Corporation Commission of Oklahoma on behalf of Oklahoma Gas and Electric Company in the matter of the Application of Brandy L. Wreath, Director of the Public Utility Division, for Determination of the Calculation of Lost Net Revenues and Shared Savings Pursuant to the Demand Program Rider of Oklahoma Gas and Electric Company, Cause No. PUD 201500153, May 13, 2015.

Pennsylvania

- Direct testimony before the Pennsylvania Public Utility Commission, on behalf of PECO on the Methodology Used to Derive Dynamic Pricing Rate Designs, Case no. M-2009-2123944, January 11, 2011.

South Carolina

- Rebuttal Testimony before the Public Service Commission of South Carolina on behalf Duke Energy Carolinas, LLC and Duke Energy Progress, LLC in the matter Duke Energy Carolinas, LLC's Establishment of Solar Choice Metering Tariffs Pursuant to S.C. Code Ann. Section 58-40-20, Febrauray 23, 2021.

Washington

- Pre-filed Direct Testimony before the Washington Utilities and Transportation Commission on Behalf of Puget Sound Energy, Dockets UE-22 and UG-22, January 31, 2022.
- Pre-filed Direct Testimony before the Washington Utilities and Transportation Commission on Behalf of Puget Sound Energy, Dockets UE-151871 and UG-151872, February 25, 2016.

CANADA

Alberta

- Virtual proceedings in front of the Alberta Utilities Commission, Application No. 24116-A001, Proceeding ID No. 24116. June 24, 2020.
- Information Response to Alberta Utilities Commission in Electric Distribution System Inquiry - Combined Module Proceedings ID 24116. June 17, 2020.

British Columbia

- Filed expert report, "Capacity Savings Estimates in BC Hydro's 2021 IRP: An Independent Review" with the British Columbia Utilities Commission (BCUC). February 22, 2022.

New Brunswick

- Presented before the New Brunswick Energy and Utilities Board in the Matter of the Stakeholder recommendations on rate design reform: Matter 357. May 12, 2020.

Nova Scotia

- Presented before the Nova Scotia Utility and Review Board in the Matter of The Public Utlities Act, R. S. N. S. 1989, c380, as amended. Time-Varying Pricing Tariff Application No. M09777. November 20, 2020.
- Presented before the Nova Scotia Utility and Review Board to provide an assessment of Nova Scotia Power, Inc.'s proposed Extra Large Industrial Active Demand Control (ELIADC) tariff for Port Hawkesbury Paper (PHP). February 2020.

REGULATORY APPEARANCES

Arkansas

- Presented before the Arkansas Public Service Commission, "The Emergence of Dynamic Pricing," at the workshop on the Smart Grid, Demand Response, and Automated Metering Infrastructure, Little Rock, Arkansas, September 30, 2009.

Delaware

- Presented before the Delaware Public Service Commission, "The Demand Response Impacts of PHI's Dynamic Pricing Program," Delaware, September 5, 2007.

Kansas

- Presented before the State Corporation Commission of the State of Kansas, "The Impact of Dynamic Pricing on Westar Energy," at the Smart Grid and Energy Storage Roundtable, Topeka, Kansas, September 18, 2009.

Ohio

- Presented before the Ohio Public Utilities Commission, "Dynamic Pricing for Residential and Small C&I Customers," at the Technical Workshop, Columbus, Ohio, March 28, 2012.

Texas

- Presented before the Public Utility Commission of Texas, "Direct Load Control of Residential Air Conditioners in Texas," at the PUCT Open Meeting, Austin, Texas, October 25, 2012.

SELECTED CONSULTING EXPERIENCE

INNOVATIVE PRICING

- **Cost of service and tariff design study**. For a large electric utility in South-East Asia, Brattle provided consulting services for their cost of service and tariff design studies for incentive-based regulation, covering regulatory period 2 (2018–2020). Our work focused on understanding the cost drivers, reviewing the extent to which the current tariffs reflect the cost drivers, and developing new tariffs that better align with current and projected costs.
- **Impact analysis for TOU rates in Ontario.** Measured the impacts of a system-wide Time of Use (TOU) deployment in the province of Ontario, Canada, on behalf of the Ontario Power Authority. To account for the lack of a designated control group, Brattle created a quasi-experimental design that took advantage of differences in the timing of the TOU rollout.
- **Measurement and evaluation for in-home displays, home energy controllers, smart appliances, and alternative rates for Florida Power & Light (FPL).** Carried out a 2-year impact evaluation of a dynamic and enabling technology pilot program. Used econometric methods to estimate the changes in load shapes, changes in peak demand, and changes in energy consumption for three different treatments. The results of this study were shared with Department of Energy to fulfil the data reporting requirements of FPL's Smart Grid Investment Grant.
- **Report examining the costs and benefits of dynamic pricing in the Australian energy market.** For the Australian Energy Market Commission (AEMC), developed a report that reviewed the various forms of dynamic pricing, such as time-of-use pricing, critical peak pricing, peak time rebates, and real-time pricing, for a variety of performance metrics including economic efficiency, equity, bill risk, revenue risk, and risk to vulnerable customers. It also discussed ways in which dynamic pricing could be rolled out in Australia to raise load factors and lower average energy costs for all consumers without harming vulnerable consumers, such as those with low incomes or medical conditions requiring the use of electricity.
- **Whitepaper on emerging issues in innovative pricing.** For the Regulatory Assistance Project (RAP), developed a whitepaper on emerging issues and best practices in innovative rate design and deployment. The paper included an overview of AMI-enabled electricity pricing options, recommendations for designing the rates and conducting experimental pilots, an overview of recent pilots, full-deployment case studies, and a blueprint for rolling out innovative rate designs. The paper's audience was international regulators in regions that were exploring the potential benefits of smart metering and innovative pricing.

- **Assessing the full benefits of real-time pricing.** For two large Midwestern utilities, assessed and, where possible, quantified the potential benefits of the existing residential real-time pricing (RTP) rate offering. The analysis included not only "conventional" benefits such as avoided resource costs, but under the direction of the state regulator, was expanded to include harder-to-quantify benefits such as improvements to national security and customer service.
- **Pricing and technology pilot design and impact evaluation for Connecticut Light & Power (CL&P).** Designed the Plan-It Wise Energy pilot for all classes of customers and subsequently evaluated the Plan-It Wise Energy program (PWEP). PWEP tested the impacts of CPP, PTR, and time of use (TOU) rates on the consumption behaviors of residential and small commercial and industrial customers.
- **Dynamic pricing pilot design and impact evaluation: Baltimore Gas & Electric.** Designed and evaluated the Smart Energy Pricing (SEP) pilot, which ran for four years. The pilot tested a variety of rate designs including critical peak pricing and peak time rebates on residential customer consumption patterns. In addition, the pilot tested the impacts of smart thermostats and the Energy Orb.
- **Impact evaluation of a residential dynamic pricing experiment: Consumers Energy (Michigan).** Designed the pilot and carried out an impact evaluation with the purpose of measuring the impact of critical peak pricing (CPP) and peak time rebates (PTR) on residential customer consumption patterns. The pilot also tested the influence of switches that remotely adjust the duty cycle of central air conditioners.
- **Impact simulation of Ameren Illinois utilities' power smart pricing program.** Simulated the potential demand response of residential customers enrolled in real-time prices. The results of this simulation were presented to the Midwest ISO's Supply Adequacy Working Group (SAWG) to explore alternative ways of introducing price responsive demand in the region.
- **The case for dynamic pricing: Demand Response Research Center.** Led a project involving the California Public Utilities Commission, the California Energy Commission, the state's three investor-owned utilities, and other stakeholders in the rate design process. Identified key issues and barriers associated with the development of time-based rates. Revisited the fundamental objectives of rate design, including efficiency and equity, with a special emphasis on meeting the state's strongly-articulated needs for demand response and energy efficiency. Developed a score-card for evaluating competing rate designs and applied it to a set of illustrative rates that were created for four customer classes using actual utility data. The work was reviewed by a national peer-review panel.

- **Analyzed the economics of self-generation of steam.** Specified, estimated, tested, and validated a large-scale model that analyzes the response of some 2,000 large commercial customers to rising steam prices. The model includes a module for analyzing conservation behavior, another module for the probability of self-generation switching behavior, and a module for forecasting sales and peak demand.
- **Design and impact evaluation of the statewide pricing pilot: Three California utilities.** Working with a consortium of California's three investor-owned utilities to design a statewide pricing pilot to test the efficacy of dynamic pricing options for mass-market customers. The pilot was designed using scientific principles of experimental design and measured changes in usage induced by dynamic pricing for over 2,500 residential and small commercial and industrial customers. The impact evaluation was carried out using state-of-the-art econometric models. Information from the pilot was used by all three utilities in their business cases for advanced metering infrastructure (AMI). The project was conducted through a public process involving the state's two regulatory commissions, the power agency, and several other parties.
- **Economics of dynamic pricing: Two California utilities.** Reviewed a wide range of dynamic pricing options for mass-market customers. Conducted an initial cost-effectiveness analysis and updated the analysis with new estimates of avoided costs and results from a survey of customers that yielded estimates of likely participation rates.
- **Economics of time-of-use pricing: A Pacific Northwest utility.** This utility ran the nation's largest time-of-use pricing pilot program. Assessed the cost-effectiveness of alternative pricing options from a variety of different perspectives. Options included a standard three-part time-of-use rate and a quasi-real time variant where the prices vary by day. Worked with the client in developing a regulatory strategy. Worked later with a collaborative to analyze the program's economics under a variety of scenarios of the market environment.
- **Economics of dynamic pricing options for mass-market customers - Client: A multi-state utility.** Identified a variety of pricing options suited to meet the needs of mass-market customers, and assessed their cost-effectiveness. Options included standard three-part time-of-use rates, critical peak pricing, and extreme-day pricing. Developed plans for implementing a pilot program to obtain primary data on customer acceptance and load shifting potential. Worked with the client in developing a regulatory strategy.
- **Real-time pricing in California - Client: California Energy Commission.** Surveyed the national experience with real-time pricing of electricity, directed at large power customers. Identified lessons learned and reviewed the reasons why California was unable to implement real-time pricing. Cataloged the barriers to implementing real-time pricing in

California, and developed a program of research for mitigating the impacts of these barriers.

- **Market-based pricing of electricity - Client: A large Southern utility.** Reviewed pricing methodologies in a variety of competitive industries including airlines, beverages, and automobiles. Recommended a path that could be used to transition from a regulated utility environment to an open market environment featuring customer choice in both wholesale and retail markets. Held a series of seminars for senior management and their staff on the new methodologies.
- **Tools for electricity pricing - Client: Consortium of several U.S. and foreign utilities.** Developed Product Mix, a software package that uses modern finance theory and econometrics to establish a profit-maximizing menu of pricing products. The products range from the traditional fixed-price product to time-of-use prices to hourly real-time prices, and also include products that can hedge customers' risks based on financial derivatives. Outputs include market share, gross revenues, and profits by product and provider. The calculations are performed using probabilistic simulation, and results are provided as means and standard deviations. Additional results include delta and gamma parameters that can be used for corporate risk management. The software relies on a database of customer load response to various pricing options called StatsBank. This database was created by metering the hourly loads of about one thousand commercial and industrial customers in the United States and the United Kingdom.
- **Risk-based pricing - Client: Midwestern utility.** Developed and tested new pricing products for this utility that allowed it to offer risk management services to its customers. One of the products dealt with weather risk; another one dealt with the risk that real-time prices might peak on a day when the customer does not find it economically viable to cut back operations.

DEMAND RESPONSE

- **Combined heat and power generation study.** Investigated the economic potential for combined heat and power and regulatory policies to unlock that potential in a Middle Eastern country.
- **National action plan for demand response: Federal Energy Regulatory Commission.** Led a consulting team developing a national action plan for demand response (DR). The national action plan outlined the steps that need to be taken in order to maximize the amount of cost-effective DR that can be implemented. The final document was filed with U.S. Congress.

- **National assessment of demand response potential: Federal Energy Regulatory Commission.** Led a team of consultants to assess the economic and achievable potential for demand response programs on a state-by-state basis. The assessment was filed with the U.S. Congress, as required by the Energy Independence and Security Act.
- **Demand response program review for Integrated Resource Plan development.** In response to legislation requiring the Connecticut utilities to jointly prepare a 10-year integrated resource plan, we conducted the analysis and helped prepare the plan. In coordination with the two leading utilities in the state, we conducted a detailed analysis of alternative resource solutions (both supply- and demand-side), drafted the report, and presented it to the Connecticut Energy Advisory Board. The analysis involved a detailed review and critique of the companies' proposed DR programs.
- **Integration of DR into wholesale energy markets.** Developed a whitepaper, "Fostering Economic Demand Response in the Midwest ISO," evaluating alternative approaches to efficiently integrating DR into its energy markets while encouraging increased participation. This work involved interviewing market participants and analyzing several approaches to economic DR regarding economic efficiency, participation rates, operational fit with other ISO rules, and susceptibility to state-level and ISO-level implementation barriers. This work involved an extensive survey of DR programs (qualification criteria, bidding rules, incorporation into market clearing software, measurement and verification, and settlement) in ISO/ Regional Transmission Organization (RTO) markets around the country. The project also required a detailed review of existing DR program tariffs for utilities in the RTO's service territory and development of a matrix for summarizing the various characteristics of these programs.
- **Integration of DR into resource adequacy constructs.** For the Midwest ISO, assisted in developing qualification criteria for DR as a capacity resource (we also developed estimates of likely future contributions of DR to resource adequacy, for use by their transmission planning group). For PJM, as part of our review of its capacity market, we developed recommendations on how to treat DR comparably to generation resources while accounting for the special attributes of DR. Our recommendations addressed product definition, auction rules, and penalty provisions. For the Connecticut utilities in their integrated resource planning, we evaluated future resource needs given various levels of demand response programs.
- **Evaluation of the demand response benefits of advanced metering infrastructure: Mid-Atlantic utility.** Conducted a comprehensive assessment of the benefits of advanced metering infrastructure (AMI) by developing dynamic pricing rates that are enabled by AMI.

The analysis focused on customers in the residential class and commercial and industrial customers under 600 kW load.

- **Estimation of demand response impacts: Major California utility.** Worked with the staff of this electric utility in designing dynamic pricing options for residential and small commercial and industrial customers. These options were designed to promote demand response during critical peak days. The analysis supported the utility's advanced metering infrastructure (AMI) filing with the California Public Utilities Commission. Subsequently, the commission unanimously approved a $1.7 billion plan for rolling out nine million electric and gas meters based in part on this project work.

SMART GRID STRATEGY

- **Development of a smart grid investment roadmap for Vietnamese utilities.** For the five Vietnamese power corporations, developed a roadmap to guide future smart grid investment decisions. The report identified and described the various smart grid investment options, established objectives for smart grid deployment, presented a multi-phase approach to deploying the smart grid, and provided preliminary recommendations regarding the best investment opportunities. Also presented relevant case studies and an assessment of the current state of the Vietnamese power grid. The project involved in-country meetings as well as a stakeholder workshop that was conducted by Brattle staff.
- **Cost-benefit analysis of the smart grid: Rocky mountain utility.** Reviewed the leading studies on the economics of the smart grid and used the findings to assess the likely cost-effectiveness of deploying the smart grid in one geographical location.
- **Modeling benefits of smart grid deployment strategies.** Developed a model for assessing the benefits of smart grid deployment strategies over a long-term (e.g., 20-year) forecast horizon. The model, called iGrid, is used to evaluate seven distinct smart grid programs and technologies (e.g., dynamic pricing, energy storage, PHEVs) against seven key metrics of value (e.g., avoided resource costs, improved reliability).
- **Smart grid strategy in Canada.** The Alberta Utilities Commission (AUC) was charged with responding to a Smart Grid Inquiry issued by the provincial government. Advised the AUC on the smart grid, and what impacts it might have in Alberta.
- **Smart grid deployment analysis for collaborative of utilities.** Adapted the iGrid modeling tool to meet the needs of a collaborative of utilities in the southern U.S. In addition to quantifying the benefits of smart grid programs and technologies (e.g., advanced metering infrastructure deployment and direct load control), the model was used to estimate the costs of installing and implementing each of the smart grid programs and technologies.

- **Development of a smart grid cost-benefit analysis framework.** For the Electric Power Research Institute (EPRI) and the U.S. DOE, contributed to the development of an approach for assessing the costs and benefits of the DOE's smart grid demonstration programs.
- **Analysis of the benefits of increased access to energy consumption information.** For a large technology firm, assessed market opportunities for providing customers with increased access to real-time information regarding their energy consumption patterns. The analysis includes an assessment of deployments of information display technologies and analysis of the potential benefits that are created by deploying these technologies.
- **Developing a plan for integrated smart grid systems.** For a large California utility, helped to develop applications for funding for a project to demonstrate how an integrated smart grid system (including customer-facing technologies) would operate and provide benefits.

DEMAND FORECASTING

- **Electricity sales and peak demand forecasting study.** For a large electric utility in South-East Asia, Brattle provided consulting services that involved assessing the performance of their load forecasting methodology and developing new models that provided more accurate forecasts.
- **Electricity consumption and maximum demand forecasting.** For a medium-sized utility in Asia-Pacific, Brattle provided consulting services on forecasting electricity consumption and maximum demand. Our work focused on analyzing drivers of growth in electricity sales, reviewed model performance, identified best practices and provided recommended approaches for analyzing trends in electricity sales and load forecasting.
- **Forecasting review.** Evaluated and critiqued the process conducted by an Australian utility company's electricity market forecasting, including the forecasting of electricity demand, supply, and price.
- **Comprehensive review of load forecasting methodology.** PJM Interconnection. Conducted a comprehensive review of models for forecasting peak demand and re-estimated new models to validate recommendations. Individual models were developed for 18 transmission zones as well as a model for the RTO system.
- **Analyzed downward trend: Western utility.** Conducted a strategic review of why sales had been lower than forecast in a year when economic activity had been brisk. Developed a forecasting model for identifying what had caused the drop in sales and its results were used in an executive presentation to the utility's board of directors. Also developed a time

series model for more accurately forecasting sales in the near term and this model is now being used for revenue forecasting and budgetary planning.

- **Analyzed why models are under-forecasting: Southwestern utility.** Reviewed the entire suite of load forecasting models, including models for forecasting aggregate system peak demand, electricity consumption per customer by sector and the number of customers by sector. Ran a variety of forecasting experiments to assess both the ex-ante and ex-post accuracy of the models and made several recommendations to senior management.
- **U.S. demand forecast: Edison Electric Institute.** For the U.S. as a whole, developed a base case forecast and several alternative case forecasts of electric energy consumption by end use and sector. Subsequently developed forecasts that were based on EPRI's system of end-use forecasting models. The project was done in close coordination with several utilities and some of the results were published in book form.
- **Developed models for forecasting hourly loads: Merchant generation and trading company.** Using primary data on customer loads, weather conditions, and economic activity, developed models for forecasting hourly loads for residential, commercial, and industrial customers for three utilities in a Midwestern state. The information was used to develop bids into an auction for supplying basic generation services.
- **Gas demand forecasting system - Client: A leading gas marketing and trading company, Texas.** Developed a system for gas nominations for a leading gas marketing company that operated in 23 local distribution company service areas. The system made week-ahead and month-ahead forecasts using advanced forecasting methods. Its objective was to improve the marketing company's profitability by minimizing penalties associated with forecasting errors.

DEMAND-SIDE MANAGEMENT

- **The economics of biofuels.** For a western utility that is facing stringent renewable portfolio standards and that is heavily dependent on imported fossil fuels, carried out a systematic assessment of the technical and economic ability of biofuels to replace fossil fuels.
- **Assessment of demand-side management and rate design options: Large Middle Eastern electric utility.** Prepared an assessment of demand-side management and rate design options for the four operating areas and six market segments. Quantified the potential gains in economic efficiency that would result from such options and identified high priority programs for pilot testing and implementation. Held workshops and seminars for senior management, managers, and staff to explain the methodology, data, results, and policy implications.

- **Likely future impact of demand-side programs on carbon emissions - Client: The Keystone Center.** As part of the Keystone Dialogue on Climate Change, developed scenarios of future demand-side program impacts, and assessed the impact of these programs on carbon emissions. The analysis was carried out at the national level for the U.S. economy, and involved a bottom-up approach involving many different types of programs including dynamic pricing, energy efficiency, and traditional load management.
- **Sustaining energy efficiency services in a restructured market - Client: Southern California Edison.** Helped in the development of a regulatory strategy for implementing energy efficiency strategies in a restructured marketplace. Identified the various players that were likely to operate in a competitive market, such as third-party energy service companies (ESCO's) and utility affiliates. Assessed their objectives, strengths, and weaknesses and recommended a strategy for the client's adoption. This strategy allowed the client to participate in the new market place, contribute to public policy objectives, and not lose market share to new entrants. This strategy has been embraced by a coalition of several organizations involved in the California PUC's working group on public purpose programs.
- **Organizational assessments of capability for energy efficiency - Client: U.S. Agency for International Development, Cairo, Egypt.** Conducted in-depth interviews with senior executives of several energy organizations, including utilities, government agencies, and ministries to determine their goals and capabilities for implementing programs to improve energy end-use efficiency in Egypt. The interviews probed the likely future role of these organizations in a privatized energy market, and were designed to help develop U.S. AID's future funding agenda.
- **Enhancing profitability through energy efficiency services - Client: Jamaica Public Service Company.** Developed a plan for enhancing utility profitability by providing financial incentives to the client utility, and presented it for review and discussion to the utility's senior management and Jamaica's new Office of Utility Regulation. Developed regulatory procedures and legislative language to support the implementation of the plan. Conducted training sessions for the staff of the utility and the regulatory body.

ADVANCED TECHNOLOGY ASSESSMENT

- **Competitive energy and environmental technologies - Clients: Consortium of clients, led by Southern California Edison, included the Los Angeles Department of Water and Power and the California Energy Commission.** Developed a new approach to segmenting the market for electrotechnologies, relying on factors such as type of industry, type of process and end-use application, and product size. Developed a user-friendly system for assessing the competitiveness of a wide range of electric and gas-fired technologies in more than 100 four-digit SIC code manufacturing industries and 20 commercial businesses. The system includes a database of more than 200 end-use technologies and a model of customer decision making.

- **Market infrastructure of energy-efficient technologies - Client: EPRI**. Reviewed the market infrastructure of five key end-use technologies, and identified ways in which the infrastructure could be improved to increase the penetration of these technologies. Data was obtained through telephone interviews with equipment manufacturers, engineering firms, contractors, and end-use customers

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PRESENTATIONS & SPEAKING ENGAGEMENTS

- “Utilities Need to Modernize their Tariffs to Enhance the Customer Experience: A National Perspective,” presented to the 21st Century Energy Policy Task Force, Indiana, October 1, 2020.
- “Are Consumers Upending the Utility Business Model?” presented at the Florence School of Regulation, September 9, 2020.
- “Designing Tariffs for Tomorrow’s Customer: The Innovation Imperative,” presented to the Electricity Authority, September 2, 2020.
- “Designing Pilots and Proceeding with Full Scale Deployment,” presented at the Washington Utilities and Transportation Commission, June 8, 2020.
- “The Five "Immortal Objections" to Time-of-Use Rates,” presented at the PLMA Load Management Dialogue, May 28, 2020.
- “ Stakeholder recommendations on rate design reform: Matter 357,” with Cecile Bourbonnais, presented at the New Brunswick Energy and Utilities Board, May 12, 2020.
- “Moving Ahead with Time-Varying Rates (TVR): US and Global Perspectives,” presented at the MI Power Grid: Energy Programs and Technology Pilots Stakeholder Meeting, April 16, 2020.
- “Moving Ahead with Time-Varying Rates (TVR): US and Global Perspective,” presented to the NARUC Staff Subcommittee on Rate Design, April 6, 2020.

- "Demand on Demand," presented at the AESP Annual Conference, February 20, 2020.
- "Empirical Assessment of the Demand for Residential Solar Distributed Generation and the Impact of Electricity Rate Design Reform," with Agustin J. Ros and Cecile Bourbonnais, presented at the Rutgers University Center for Research in Regulated Industries, January 17, 2020.
- "Assessment of APS's Bill Comparison Web Tool: Methodology and Findings," with Ryan Hledik and Cecile Bourbonnais, December 10, 2019.
- "A Survey of Residential Time-of-Use (TOU) Rates," with Ryan Hledik and Sanem Sergici, November 12, 2019.
- "Advancing the Practice of Rate Design," presented at the 40th PLMA Conference, November 6, 2019.
- "The Total Value Test (TVT) for Assessing Electrification Programs," with Ryan Hledik and Omar Siddiqui, presented at the California Efficiency + Demand Management Council (CEDMC), October 24, 2019.
- "A Conversation about Customer Centricity," presented at Virtual Speaker Forum, October 21, 2019.
- "Encouraging Rooftop Solar without Creating Cross-Subsidies," presented to SMUD, April 30, 2019.
- "Post-Modern Rate Design: The 'Secret Sauce' in Customer Engagement," presented at the Entergy Regulatory Conference, April 9, 2019.
- "Valuing and Compensating Distributed Energy Resources in ERCOT," with Ira Shavel and Yingxia Yang, prepared for the Texas Clean Energy Coalition, March 28, 2019.
- "2040: A Pricing Odyssey," presented at the EEI Spring Rates and Regulatory Affairs Committee Meeting, March 25, 2019.
- "Reinventing Demand Response for the Age of Renewable Energy," with Ryan Hledik, December 14, 2018.
- "Enabling Grid Modernization through Alternative Rates and Alternative Regulation," with Sanem Sergici and William P. Zarakas, presented at the Energy Policy Roundtable in the PJM Footprint, November 29, 2018.
- "Modernizing Distribution Tariffs for Households," presented to the Energy Consumers Association in Sydney, Australia, November 9, 2018.

- "The State of Electric Vehicle Home Charging Rates," with Ryan Hledik and John Higham, presented to Colorado PUC, October 2018.
- "Rate Design to Enable Flexible Loads," with Mariko Geronimo Aydin, presented at APPA Business & Financial Conference 2018, September 18, 2018.
- "Customer-driven Rate Design is the Wave of the Future," presented at the Colorado Rural Electric Association Managers Association Meeting, September 10, 2018.
- "Understanding the Costs and Benefits of Electrification: Electrification Cost-Benefit Case Studies," presented at the Electric Power Research Institute (EPRI) Electrification 2018 International Conference & Exposition, August 23, 2018.
- "Do Load Shapes of PV Customers Differ From Other Customers?" with Walter Graf, Presented at the Center for Research in Regulated Industries (CRRI) 31st Annual Western Conference, June 28, 2018.
- "Tariffs of the Future for Gas Utilities," with Léa Grausz, Henna Trewn, and Cecile Bourbonnais, presented at the Center for Research in Regulated Industries (CRRI) 31st Annual Western Conference, June 28, 2018.
- "Collecting Allowed Revenues When Demand is Declining," with Henna Trewn and Léa Grausz, presented at the Center for Research in Regulated Industries (CRRI) 31st Annual Western Conference, June 28, 2018.
- "Incentivizing the Adoption of Gas-Fueled Emerging Technologies with Pricing Tools," with Léa Grausz, presented at the 27th World Gas Conference, June 25, 2018.
- "Estimating the Impact of Innovative Rate Designs," presented to Southern California Edison, June 7, 2018.
- "Rate Design 3.0 and The Efficient Pricing Frontier," presented at the EUCI 2018 Residential Demand Charges Conference, Nashville, TN, May 15, 2018.
- "Does Dynamic Pricing of Electricity Eliminate the Need for Demand Charges?" presented at the Harvard Electricity Policy Group's (HEPG) 89th Plenary Session, January 25, 2018.
- "Dynamic Pricing: What Can We Learn from Other Jurisdictions?" presented at the California Public Utilities Commission's (CPUC) Electric Rate Forum, December 12, 2017.
- "Demand Charges and Dynamic Pricing Are Complements, Not Substitutes," presented at the California Public Utilities Commission's (CPUC) Electric Rate Forum, December 11, 2017.

- "Dynamic Pricing Works in a Hot and Humid Climate: Evidence from Florida," with Sanem Sergici and Neil Lessem, presented at the International Energy Policy & Programme Evaluation Conference, November 2, 2017.
- "A Hybrid Model for Forecasting Electricity Sales and Peak Demand: A Case Study of TNB in Malaysia," with Sanem Sergici and Neil Lessem, presented at the International Energy Policy & Programme Evaluation Conference, November 2, 2017.
- "Workshop on Pricing Reforms," with Neil Lessem, Presented to Energy Networks Association (ENA), October 17, 2017.
- "A Walk on the Frontier of Rate Design," with Cody Warner, presented to the Western Farmers Electric Cooperative's Residential Demand Workshop, October 5, 2017.
- "The Future of Tariff Reform: A Global Survey," with Léa Grausz and Hallie Cramer, presented to the Indiana Energy Association's (IEA) Annual Energy Conference, September 28, 2017.
- "Forecasting the Impact of DSM on Energy Sales," with Zhen Wang, presented to the Edison Electric Institute (EEI), September 14, 2017.
- "A Global Survey of Customer-centric Tariff Reforms," with Neil Lessem, presented to the Commerce Commission, Wellington, New Zealand, August 24, 2017.
- "The Public Benefits of Leasing Energy Efficient Equipment: A Utility Case Study," with Henna Trewn and Neil Lessem, presented at the Center for Research in Regulated Industries' (CRRI) 30th Annual Western Conference, June 30, 2017.
- "Estimating the Impact of DSM on Energy Sales Forecasts: A Survey of Utility Practices," with James Hall and Zhen Wang, presented at the Center for Research in Regulated Industries' (CRRI) 30th Annual Western Conference, June 29, 2017.
- "Moving Forward with Tariff Reform," presented during the EEI Webinar on Rate Design, April 6, 2017.
- "An Irreverent Take on Customer Research in Our Industry," presented at the EPRI Workshop: Understanding Customer Preferences for and Adoption of New Services and Technology, April 4, 2017.
- "The Tariffs of Tomorrow," presented at the University of California, Davis Energy Efficiency Center Seminar, January 11, 2017.

- “Residential Demand Charges, Distributional Effects and Energy Storage,” with contributions from Ryan Hledik, presented during the Edison Electric Institute (EEI) Grid Talk Webinar, November 17, 2016.
- “Curating the Future of Rate Design,” presented at the EUCI’s Residential Demand Charges Conference, October 20, 2016.
- “Understanding Residential Customer Response to Demand Charges: Present and Future,” with Sanem Sergici and Ryan Hledik, presented at EUCI’s Residential Demand Charges Conference, October 20, 2016.
- “Technology's Role, Rates and Customers, 1985-2016,” presented at the Wisconsin Public Utility Institute, August 16, 2016.
- “Dynamic Pricing & Demand Response,” with Sanem Sergici, presented at IPU's 58th Annual Regulatory Studies Program: The Fundamentals Course, August 11, 2016.
- “Retail Costing and Pricing for Electricity,” with Philip Q Hanser and Sanem Sergici, presented at IPU's 58th Annual Regulatory Studies Program: The Fundamentals Course, August 11, 2016.
- “Emerging Issues in Forecasting Energy Consumption,” with Josephine Duh and Zhen Wang, Presented at the CRRI Western Conference 2016, June 24, 2016.
- “A Three-Year Impact Evaluation of TOU Rates in Ontario, Canada,” with Neil Lessem, presented at the Center for Research in Regulated Industries (CRRI) 29th Annual Western Conference, June 23, 2016.
- “Capturing Smart Meter Enabled Benefits in System Wide Rollouts: June 23, 2016,” presented at the Center for Research in Regulated Industries (CRRI) 29th Annual Western Conference, June 23, 2016.
- “Residential Rates for the Utility of the Future,” presented at Grid Edge World Forum 2016, June 22, 2016.
- “Residential Rates for the Utility of the Future,” presented to the Alternative Rate Design Stakeholder Process for Xcel Energy, May 13, 2016.
- “Modeling Customer Response to Xcel Energy's RD-TOU Rate,” with Ryan Hledik, presented to Xcel Energy, April 21, 2016.
- “Residential Demand Charges: An Overview,” presented at the EEI Rate Committee Meeting, March 15, 2016.

- "A Conversation about Standby Rates," presented to Standby Rate Working Group Michigan Public Service Commission, January 20, 2016.
- "Competitive Electricity Pricing Strategies: A California Perspective," with J. Robert Malko, and Philip R. Swensen, presented at the Fourteenth Annual Rate Symposium, sponsored by the Missouri Public Service Commission, the University of Missouri-Columbia and Utah Sate University, held in Kansas City, Missouri, February 1988.
- "Response of Residential Electric Loads to Time-of-Use Rates: Evidence from Eleven Pricing Experiments," with J. Robert Malko, presented at Midwest Economics Association Annual Meeting, Louisville, Kentucky, April 1981.

SELECTED HONORS & AWARDS

2023	ESIG Excellence Award
2020	*Who's Who Legal*: Energy Experts
1990–2020	Association of Energy Services Professionals (AESP): Recognized as one of seven individuals who was a game changer in the profession during the past 30 years
1976–77	Regents' Fellowship, The University of California at Davis
1977–78	Dissertation Grant, Kellogg Foundation
1973	Overseas Doctoral Scholarship, Government of Pakistan
1973	Rashid Minhas Gold Medal in Economics, University of Karachi

*Forthcoming chapter, **Handbook on Electricity Regulation,** edited by Jean-Michel Glachant, Paul Joskow and Michael Pollitt.*

Time Varying Rates (TVRs) are moving from the periphery to the mainstream of electricity pricing for residential customers in the United States

Ahmad Faruqui and Ziyi Tang[1]

"There's 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 an argument among those who levy them… 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."

D. J. Bolton[2]

Electric tariffs for residential customers[3] through the 1960's were almost entirely volumetric rate designs expressed in cents per kWh. Often, the energy charge dropped with usage, making it a declining block rate.

In those days, the provision of electricity followed a declining cost curve and rates reflected that phenomenon. In the early 1950's, Lewis Strauss, chair of the US Atomic Energy Commission, had famously said the day would come when electricity would be too cheap to meter.[4]

That day never came. Instead, rate shock arrived when OPEC imposed an oil embargo which followed the Yom Kippur War of 1973. It was further amplified when the Iranian Revolution occurred in 1979. In November 1978, the Public Utilities Regulatory Policies Act (PURPA) was passed.[5] It made energy conservation a priority. Load management of electric loads was expanded to include time-of-use (TOU) pricing. A few states in the Mid-Atlantic region decided to make these rates mandatory for very large customers. One state provided incentives for customers to install thermal energy storage equipment and to pair it with a TOU rate.[6] In addition, 16 pilots with TOU rates were launched by the Federal Energy Administration (FEA). They were dispersed throughout the US and included the territory of Puerto Rico.

These pilots received widespread attention. Their results were evaluated by the Research Triangle Institute in North Carolina. At the behest of the National Association of Regulatory Utility Commissioners (NARUC), the Electric Power Research Institute (EPRI) launched the Electric Utility Rate Design Study (EURDS) in 1976. Among other topics, it reviewed and summarized the results of the FEA pilots.[7] Later, EPRI combined the data from the five best pilots and published a meta-analysis.[8]

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[1] The authors are Principal Emeritus and Electricity Modeling Specialist respectively with The Brattle Group. This chapter reflects their views and not those of Brattle. They have benefited from comments by Steve Barrager, John Chamberlin, Soren Christian, Chris King, Mark Kolesar, Stephen Littlechild, Bruce Mountain, Bruce Nordman, Mike Oldak, Hethie Parmesano, Branko Terzic and Bill Uhr.
[2] Bolton (1938).
[3] Unless otherwise qualified, in the rest of this chapter the term "customer" refers to residential customers.
[4] https://www.nrc.gov/reading-rm/basic-ref/students/history-101/too-cheap-to-meter.html.
[5] 16 USC Ch. 46: PUBLIC UTILITY REGULATORY POLICIES (house.gov)
[6] "How to level the load," *The Energy Daily*, December 5, 1985.
[7] For the early history of the EURDS, see Robert G. Uhler (1976). He was the first Executive Director and was succeeded by Rene Males.
[8] Douglas W. Caves, Laurits R. Christensen, and Joseph A. Herriges (1984).

Lack of interval metering posed a major barrier to TOU pricing. So did the consistent opposition of consumer advocates. They favored flat volumetric rates. As an in-between measure, inclining block rates were introduced.

In the 1980's, Demand-Side Management (DSM) was spread throughout the US.[9] DSM included utility energy efficiency programs and government codes and standards to promote energy efficiency and load management. Tariff reform took a back seat.[10]

To offset rising bills, retail choice became a priority in the 1990s. It succeeded with large commercial and industrial customers but made little headway with households.

TOU rates languished in the US until California's energy crisis of 2000-01. Soon thereafter, TVR including TOU rates and newly introduced dynamic pricing garnered interest. Dynamic pricing included critical-peak pricing (CPP) and real-time pricing (RTP). In this chapter, TOU rates and dynamic pricing rates are called time-varying rates (TVR).

A second generation of TOU pilots was carried out, initially in California[11], and later in Connecticut, Florida, Illinois Maryland and Michigan.[12] Simultaneously, smart meters began to be rolled out.

Today, 104 million smart meters are deployed at US households, representing 73 % of all residential meters. TVR are finally getting significant attention. In 2022, 9.4% of households were on TOU rates, more than double the percentage in 2018, which had not changed much since 2013. If the trend continues, some 25-35% of households may be on TOU rates by 2030.

This chapter is organized as follows:

Section 1: Evolution of TVR

Section 2: Lessons Learned from Four Decades of Deploying TVR

Section 3: Strategies for Rate Modernization

Section 4: What's Likely to Happen in the Future?

Section 5: Conclusions

Section 1: The Evolution of TVR

With rare exceptions, electric rates for households in the US did not feature time variation until the 1960's.[13] The preferred medium for managing peak loads was direct load control of water heaters and central air conditioners.

[9] Clark W. Gellings and John H. Chamberlin (1993).
[10] Academics and researchers continued to publish articles, such as Chao (1983).
[11] Ahmad Faruqui and Stephen S. George (2005).

[12] Ahmad Faruqui and Sanem Sergici (2011); Ahmad Faruqui, Sanem Sergici and Lamine Akaba (2013); Ahmad Faruqui, Sanem Sergici and Lamine Akaba (2014); and Ahmad Faruqui, Neil Lessem, and Sanem Sergici (2017).

[13] European countries were ahead of the US. See, e.g., Christophe Aubin, Denis Fougère, Emmanuel Husson, and Marc Ivaldi (1995) and F. M. Westfield (1980) and Valerie Lesgards et Edouard Rossat (2022).

Since the conclusion of the landmark Madison Gas and Electric Company case of August 1974, commissions, utilities, and intervenors began studying the desirability and feasibility of implementing TOU rates. In 1978, PURPA required commissions to consider and make a determination regarding the cost-effectiveness of TOU rates, which were accorded the status of a federal rate-making standard.

To address these issues, the FEA, a precursor to the Department of Energy, worked with several states and Puerto Rico to conduct pilots with TOU rates. The pilots represented the first of many waves that would follow and their designs were of uneven quality.[14] Even then, they showed that customers lowered their on-peak usage by curtailing it and/or shifting it to off-peak periods, thereby improving load factor and lowering costs.

Between the late seventies and the mid-eighties, EURDS went through four phases and published nearly a hundred reports. In its second phase, EURDS was directed by a Project Committee comprised of commissioners and utility vice presidents. At one point, it was headed by Professor Alfred Kahn, who chaired the New York Public Service Commission while on leave from Cornell University.[15]

In an interview with the EPRI Journal, he was quite vocal about the merits of TVR: “Never mind whether you want to go to incremental-cost pricing or stick with historical-average pricing. You should at least have time-of-consumption rates; rates that differ, reflecting the fact that, even historically, the costs of installing more capacity should not be put on people who consume off peak. They are not responsible for construction of that capacity. It is indisputable that the costs imposed on a system, if only the generating costs are different when you consume at peak on a hot summer day or you consume in the middle of the night-so that truly cost-based rates cannot avoid varying consumption, logically.”[16]

J. Robert Malko, an economist from the Wisconsin Commission, managed EURDS.[17] Several advisory committees drawn from commissions and utilities guided the work of the EURDS. The utility staff were drawn from investor-owned utilities, municipal utilities and cooperatives.

The EURDS advisers agreed that TOU rates should be cost reflective, in accordance with the widely accepted Bonbright principles.[18] However, there was little agreement on whether they should be based on marginal or embedded costs. The majority supported basing rates on embedded costs, a practice that continues to this day.[19]

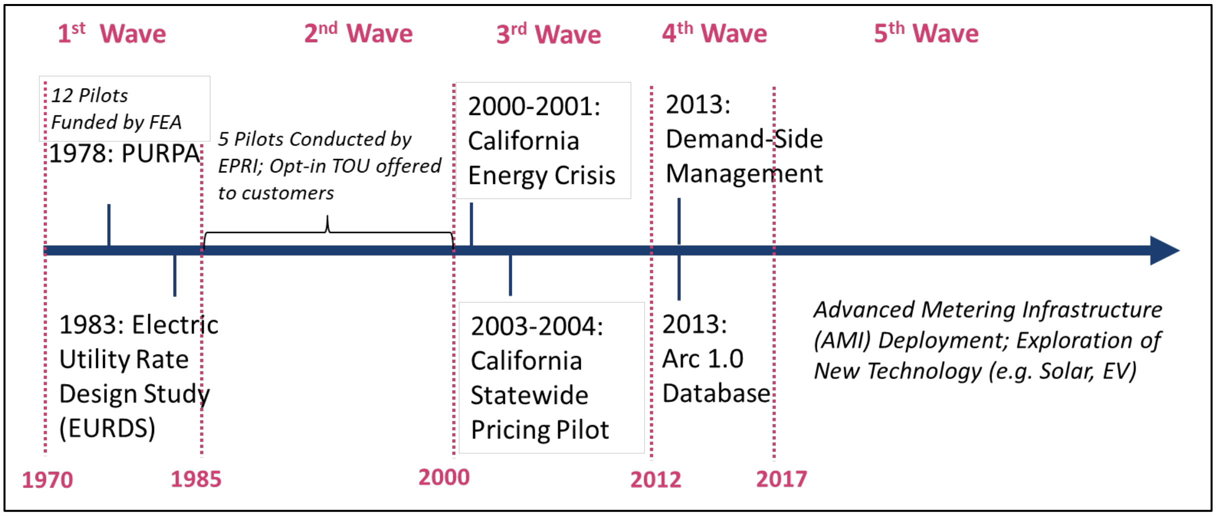
In the eighties, there was universal agreement that a big barrier to implementing TOU rates was the absence of interval metering. In the years that followed, a few utilities went ahead and installed interval meters. A few, especially in California, deployed TOU rates on a mandatory basis for their large commercial and industrial customers.

Figure 1 shows the evolution of TVR and how it interacted with other driving factors.

FIGURE 1 THE EVOLUTION OF TVR

[14] See Aigner (1985).
[15] “Alfred E. Kahn,” *Wikipedia*, last modified February 5, 2023, https://en.wikipedia.org/wiki/Alfred_E._Kahn.
[16] “Alfred Kahn breaks tradition,” *EPRI Journal*, December 1976, 42-45.
[17] Faruqui worked for him in the EURDS.
[18] James C. Bonbright (1961).

[19] Hethie S. Parmesano and Catherine S. Martin (1983).



First wave

Across the 16 pilots that were implemented, the short-run effects of TOU rates on customer electricity usage were encouraging but inconsistent. In most cases, customers materially reduced peak consumption in response to the TOU rates, with very little (if any) load-shifting to shoulder or off-peak periods. The reduction in peak consumption was statistically significant in many pilots.[20] The FEA found that higher peak-to-off-peak price ratios and shorter on-peak periods generally led to stronger customer response. However, these experiments did not test customer responses in the long run.

The industry mostly put the idea of TOU implementation on hold.

Second wave

The second wave began in the mid-1980s, when EPRI examined the results from five of the best designed FEA pilots and found consistent evidence of consumer behavior.[21] Unfortunately, not much came of this discovery because of the lack of smart metering infrastructure and because of the industry's focus on retail restructuring and the expansion of wholesale electricity markets. However, a few utilities did move ahead with mandatory TOU rates for large residential customers. Virtually all utilities moved ahead with opt-in TOU rates, but few customers took those rates.

In a related development, also in the 1980s, Bob Noyce, founder of Intel, and Mike Markkula, founder of Apple Computer invested in a startup company founded by Bill Uhr. These technology investors saw a major market opportunity in Uhr's microprocessor-based integrated thermal storage system that provided cooling, heating, and hot water for a 2500 square-foot home. Twelve pilots monitored by Virgina Power demonstrated that the systems could reduce the winter peak total house load by up to 90% and summer peak by up to 70%. Using TOU rates, the homeowners could save 25% to 35% on their annual electric bill. Notwithstanding the pilot success and serious interest by home builders, the company was unable to move into production due to the lack of utility support.

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[20] Ahmad Faruqui and J. Robert Malko (1983).

[21] Douglas W. Caves, Laurits R. Christensen, and Joseph A. Herriges (1984).

Third wave

The 2000–01 California energy crisis gave impetus to the next wave of pilots with TVR. In addition to TOU rates, they featured dynamic pricing designs.[22] Unlike TOU, where the time periods and the prices for each period are known in advance, dynamic prices may or may not be known in advance and the time period over which the prices are invoked may or may not be fixed in advance. In the third wave, dynamic pricing pilots included studies of TOU pricing as well as other types of dynamic pricing. Some of these pilots featured enabling technologies such as in-home displays and smart thermostats.

In California, a statewide pricing pilot involving all three investor-owned utilities was conducted in 2003–04. It showed that customers reduced peak-period energy use in response to time-varying prices.[23] This pilot was a game changer. Since 2013, many more pilots have been conducted around the globe, bringing the total worldwide experience to almost 80 pilots featuring over 400 energy-only pricing treatments.[24] Figure 1 summarizes peak reduction effects from these pilots conducted through 2021, with each data point representing a single pricing treatment.

The figure shows that as customers' peak-to-off-peak price ratio increases, customers reduce their peak consumption more, although at a declining rate. The solid curve in Figure 2 show effects in response to prices only and without enabling technologies. Enabling technologies, such as smart thermostats, were shown to enhance customer responsiveness, as demonstrated by the dotted curve.[25] These results reinforce previous findings that customers do respond to price signals and that enabling technologies significantly enhance that responsiveness.

FIGURE 2 THE ARC OF PRICE RESPONSIVENESS BY TECHNOLOGY

[22] Ahmad Faruqui et al. (2001).
[23] "Impact Evaluation of the California Statewide Pricing Pilot," Charles River Associates, March 16, 2005, accessed at http://www.calmac.org/publications/2005-03-24_SPP_FINAL_REP.pdf.
[24] Ahmad Faruqui, Sanem Sergici and Cody Warner (2017); Ahmad Faruqui, Sanem Sergici and Ziyi Tang, "Do Customers Respond to TVR: A Preview of Arcturus 3.0" (2023).
[25] The difference between the curves is statistically significant and each of the curves by itself is also statistically significant.

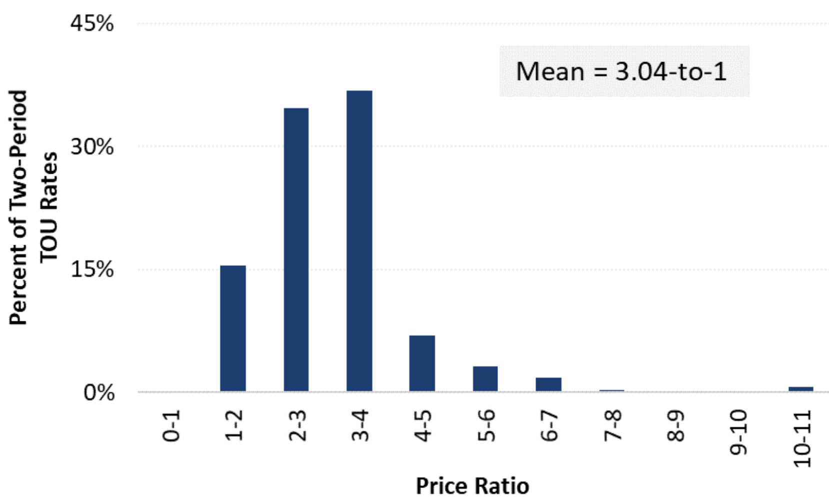
In the third wave of pilots, observers also discovered that low income customers can be price-responsive, although not to the same degree as the average residential customer. A 2012 study summarized the insights gained from these pilots.[26]

Overall, the third wave of pilots yielded rich information on customer responsiveness to time-varying pricing. Pilots in the third wave provided the impetus and scientific evidence for widespread investment in advanced metering infrastructure.

Fourth wave

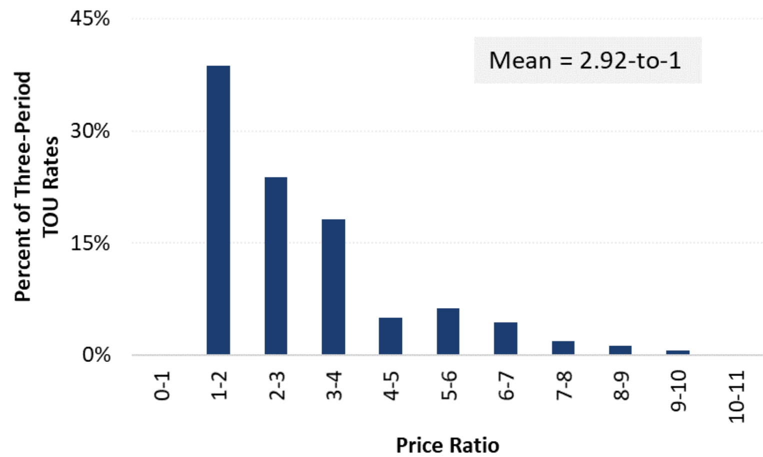
The fourth wave involved the large-scale rollout of TVR. Some featured two pricing periods and others featured three pricing periods. Today, the ratio of peak to off-peak prices in 85% of the two-period TOU rates is at least 2:1 while the mean price ratio is 3:1. TOU rates with three periods have a similar price ratio as those with two periods.[27]

FIGURE 3 PRICE RATIO IN TWO-PERIOD TIME-OF-USE RATES



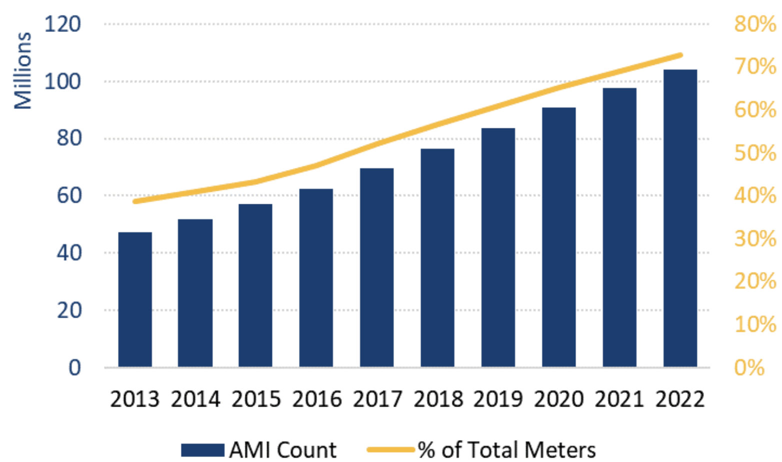
[26] Ahmad Faruqui, Ryan Hledik, and Jennifer Palmer (2012).
[27] US Department of Energy, Utility Rate Database, OpenEI, last modified February 2023, accessed at https://openei.org/wiki/Utility_Rate_Database.

FIGURE 4 PRICE RATIO IN THREE-PERIOD TIME-OF-USE RATES



In the fourth wave, the implementation of TVR did not keep pace with the installation of advanced metering infrastructure. According to EIA-861 Survey, 104.2 million households have advanced metering infrastructure, which is about 73% of total residential electric meters in 2022.[28]

FIGURE 5 SMART METER INSTALLATION (2013-2022)



But only 13.1 million households are enrolled on a TVR, which is about 9.4% of total number of residential customers. The barriers to large-scale implementation of TVR include:

- Insufficient evidence of benefits: Stakeholders are still not convinced benefits would be realized through full-scale deployment. Unless evidence of benefits is compelling, regulators, utilities, and customers will fear that a broader group of customers will be harmed by the new rates and that they will fail to promote economic efficiency or equity.
- Customer dissatisfaction and backlash: The move from flat rates to TVR will more efficiently and fairly allocate costs among individual customers but it will definitely raise bills for customers whose load factors

[28] "Annual Electric Power Industry Report", Form EIA-861, U.S. Energy Information Administration, Oct 5, 2023, accessed at https://www.eia.gov/electricity/data/eia861/.

are lower than the average load factor for the residential class. It may take time for those customers experiencing bill increases to understand how to manage their electricity consumption relative to the new rate structure. Additional investment in customer education and outreach will be needed to help customers fully understand the new rates, how to choose among their rate options, and how to adjust their usage patterns to lower their bills. It would be useful to give customers a choice of several rates, including flat rates, TOU rates with different price differentials across periods, and dynamic pricing rates.

- Effects on sensitive or disadvantaged customers: Special attention has to be paid to the needs of customers with medical disabilities, customers who are unemployed and low income customers in general.

Some questions remain about how customers will react with full-scale deployment, even though study after study has shown that such rates will yield real and quantifiable efficiency benefits to customers. Despite this evidence, there are persistent fears about a customer backlash or a failure to realize expected benefits. There are ways to overcome these fears, including:

- Customer bill effect studies: Utilities and regulators can conduct studies to understand how customer bills will be affected.
- Customer behavior studies: There are models available today for carrying out simulations to determine the likely customer response. These models draw from findings in prior pilot studies.
- Customer outreach and education: Utilities can engage in customer outreach programs to explain why tariffs are being changed and how the new tariffs will work. It will be important to ensure the new rates use clear and understandable language. Utilities can enlist neutral parties to endorse the change and they can use modern social media to spread the word.

Tapping into the newer generations of technology-savvy customers will be crucial. Utilities can develop new and more efficient ways to communicate with their customers, help to develop apps and smart energy tools, and otherwise explore methods to enhance the customer experience with technology. Here are some options for easing the transition:

- Transition rates: Utilities and regulators can design transition schemes that change the rates gradually over three to five years.
- Bill protection: Alternatively, bill protections can be provided to customers, ensuring that customer bills will not go up but they will be able to keep the savings, with those protections being phased out gradually over time.
- Add protections for sensitive customers: For the first five years, rates could be optional for sensitive or disadvantaged customers, such as low-income customers, small users, and disabled customers. Or these customers could be provided financial assistance for a limited period of time.
- Provide additional information and options to customers: There may be ways to provide additional options for customer participation. For example, consider a subscription concept in which customers “buy” their historical usage at the historical price, and buy or sell deviations from that usage at the new tariffs. This option would also help to transition into the fifth wave of tariff reform involving transactive energy.

Fifth Wave

We have now entered the fifth wave. Enabling residential customer responsiveness under TVR should be a priority. Once cost-reflective tariffs are in place, technological barriers will have to be overcome to achieve customer engagement. Better tools will have to be provided to customers to help them lower their bills.

New technology is already beginning to reveal to customers the extent to which electricity cost can vary depending on usage patterns over time. Public policies and initiatives are opening the door for households to have more control over the source of their electricity—beyond retail choice—through distributed generation. Smart appliances, thermostats, and apps are giving residential customers more tools to control and customize usage patterns. Customers will still have the right to access reliable power supply, but these changes will continue to give households more power to optimize their individual electricity use, their cost of electricity, and their environmental footprint.

We also expect continued improvements in data exchanges from and to smart houses to give residential customers opportunities to capture value directly from wholesale electricity markets. This means that customers will not only react to wholesale market and system conditions, but they will actively participate in wholesale markets through agents or technologies that allow customers to communicate and coordinate directly with market administrators and system operators. Not all customers will have the appetite for engaging in power supply decisions to this degree, but the newer generations of customers who are used to social media, fast-paced and complex communications, and a suite of apps to manage their lives will not find this foreign. Some customers will install solar panels, battery storage, and load flexible HVAC systems and appliances to lower their bills and take advantage of TVR.

In one vision of how this could evolve, customers would subscribe to a "baseline" load shape based on their typical usage patterns. They could buy or sell deviations from the baseline on the wholesale market through sophisticated energy management systems or agents. This was originally called "demand subscription," but the idea has morphed into "transactive energy".[29] This vision has gained some traction with millennials through Wi-Fi thermostats, digital appliances, and first-generation home energy management systems. Regardless of the specific method, we believe that in the future the gaps among customers, retail markets, and wholesale markets will be significantly reduced.

But this future cannot be realized if customers do not have even the basic information on how their usage patterns relate to the real cost structure of electricity. Customers cannot react to the high production and investment costs of electricity during peak demand periods if they are shielded from observing these costs at the point of consumption. Customers who are charged the traditional and mostly flat volumetric rate for electricity will be immobilized in the transactive energy future. They will not have the incentives or information necessary to lower their bills in an efficient manner, participate in valuable demand-side services in wholesale markets, or actively contribute to more efficient electricity production and investments in the future.

Household electricity historically has been mostly a uniform commodity for consumers, indistinguishable by source or time of use. For the most part, utilities could price electricity as if it were a uniform commodity without harming their bottom line. But in recent years a number of industry shocks and changes have made it clear that this pricing scheme is not always best for customers or utilities. The first four waves of tariff reform have gauged consumer response and enabled utilities to price electricity more efficiently as the diverse product it is. At the same time,

[29] Stephen Barrager and Edward Cazalet (2014).

customers are awakening to the diversity of electricity supply depending on location, time of day, and environmental attributes.

Driven by the need to reduce carbon emissions and to promote load flexibility, the California Public Utilities Commission (CPUC) is evaluating a rate design concept called CalFUSE in to enable widespread adoption of demand flexibility solutions.[30] The opt-in CalFUSE frameworks include a broad spectrum of six elements to: develop standardized, universal access to current electricity price, introduce dynamic prices based on real-time, wholesale energy cost, incorporate dynamic capacity charges based on real-time grid utilization, transition to bidirectional prices, offer subscription option, and introduce transactive features. The tariff separates the collection of energy and distribution costs and introduces the notion of scarcity pricing to allocate capacity charges to time periods.

Section 2: Lessons Learned from Deploying TVR

Several lessons can be gleaned from the past four decades which would help in designing better rates in the future.

1. Don't oversell the benefits of TVR

In the early 2000s, Puget Sound Energy in the Pacific Northwest rolled out what its CEO termed a "dynamic pricing" rate. But the new rate was simply a TOU rate with three pricing period. Notably, the price differential between the peak and off-peak periods was only 30%. Customers were informed they would save money on the rate. Some customers shifted nearly half their loads from peak to off-peak periods only to discover a year later that they had only saved 50 cents to a dollar per month. Customers felt cheated. Ten percent dropped out. Local and national media outlets reported on the story. The backlash was severe. The utility ended the program, giving TOU rates a bad rap.

Lesson: Don't oversell the savings from TVR.

2. Pilots are not Always Needed

After witnessing the California energy crisis, the Ontario Energy Board decided to move all customers in the province to TOU rates once smart meters had been deployed. No pilot preceded the TOU deployment. The TOU program succeeded because the Premier was a visionary.

Lesson: A pilot is not always necessary.

3. Embrace Gradualism

[30] California Public Utilities Commission (2022).

One of the most successful TOU programs in the U.S. was launched by SMUD in California. It conducted pilots with CPP and TOU rates. Results were positive and the utility decided to introduce them to its customers. The success of the roll-out campaign can be attributed to a smooth transition plan which spanned three years.

Another example is provided by the Australia Energy Market Commission. To accelerate the deployment of TOU rates, it suggested that they be made mandatory for the largest customers, opt-in for vulnerable customers and be the default for everyone else. However, advocates of the vulnerable customer group thought the design was "a trap" and vehemently opposed it. In the end, the plan did not win the government's approval and was scuttled.

Lesson: Coordinate the design and rollout of TVRs with all stakeholder.

4. Think Outside the (Service Territory) Box

Until 1990, RTP was an academic concept in the US[31] until Georgia Power introduced it to its large commercial and industrial customers. The utility hired a pricing manager from ESKOM in South Africa who had implemented a successful RTP program for large mining customers. Because mining uses electricity heavily and because mining operations can be disrupted, RTP was the perfect rate option for this sector. The pricing manager brought the practice with him to the U.S.

The RTP rate had a two-stage structure. In the first stage, customers paid what they had paid historically by holding their load profile constant. In the second stage, they paid for changes in the load profile on an hourly basis. The first stage bill included a fixed charge, a demand charge and a flat energy charge. In the second stage, the hourly prices were based on marginal energy costs. Customers were notified of the prices on an hour-ahead basis.

The utility recruited customers from inside and outside of the U.S. to relocate to the utility's service territory and participate in the RTP program. The program was designed for customers with maximum demands higher than 1 MW. Load dropped 17 percent on average whenever wholesale price exceeded $1/kWh. Initially offered to industrial customers, the program was later extended to commercial customers. Years later, a day-ahead version was made available to C&I customers with less than 1 MW demand.

Lesson learned: Persistence and perseverance pay off.

5. Key Decision Makers Need to be On Board

TVA, a federal agency, serves power to more than 150 publicly owned utilities in the southeastern US and also designs their rates. TVA wished to modernize its rate designs. However, smart metering was not available. To brainstorm solutions, the agency organized a workshop with its distribution utilities. After considering all the options, seasonal rates were proposed and everyone was on board with them. However, TVA's board rejected the idea. The board members were concerned that customers with central air conditioning systems would see higher bills.

Lesson: Anticipate adverse reaction from those who are going to see higher bills.

[31] It had been discussed elsewhere. See, e.g., Littlechild (2003).

6. Mind the Transition Costs

In Oklahoma, OGE's CEO asked his leadership team to explore demand-side solutions instead of building a 600-MW power plant. After doing comprehensive market research, the utility reached the conclusion that there was enough appetite for the utility to pilot a sophisticated variable-peak pricing (VPP) rate with four levels of critical-peak pricing. It also installed smart thermostats on customer premises. Instead of the utility controlling the thermostat, customers had their own control and could pre-set it to their comfort level in advance.

The pilot was successful and the utility offered VPP to all its customers on an opt-in basis. In five years, the participation rate reached nearly 15 percent. On average, the program reduced the peak demand of participating customers by 40 percent, lowering customer bills by 20 percent. The program's success was attributed to word-of-mouth marketing. The VPP prices were sent directly to the thermostat, where the customer had programmed the temperature settings by price.

Lesson: Customer centricity is vital to the success of innovative rates.

7. When There's a Will, there's a Way.

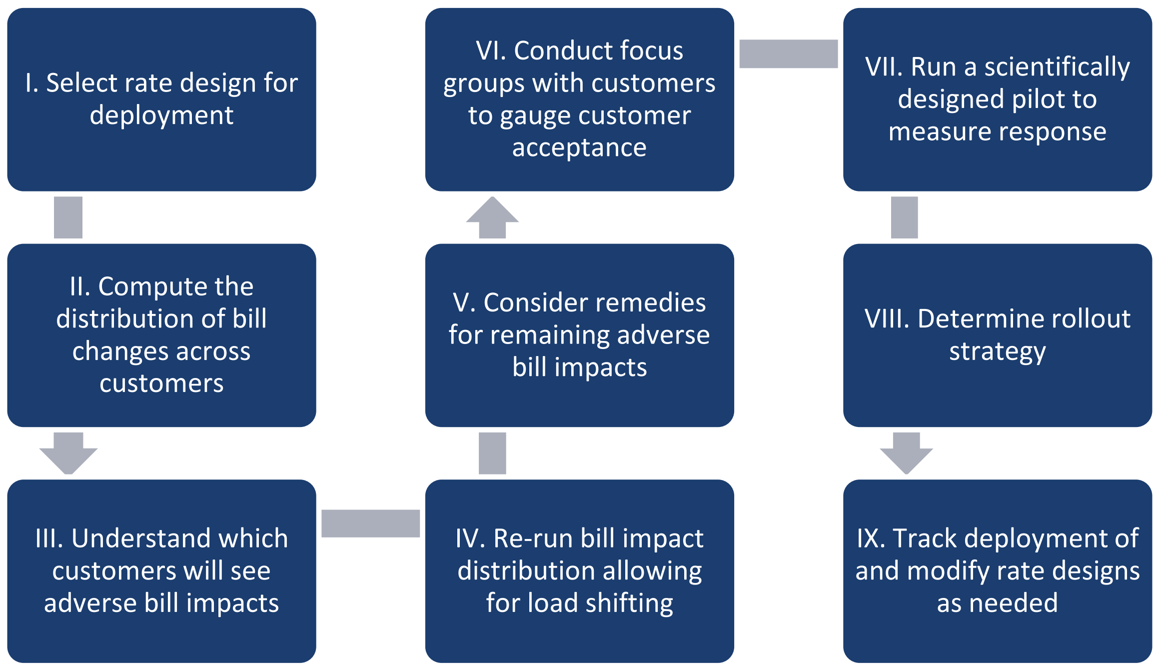
In the course of exploring rate design reforms in the late 2000s, BGE in Maryland became interested in applying the lessons learned from California's pricing pilots involving TOU rates and CPP rates which involved all three investor-owned utilities and ran for two years. The utility decided to launch a CPP pilot of its own and also pair it with a peak-time rebate (PTR) pilot. The pilot ran for four years. The results showed that the peak reduction from CPP and PTR were about the same. The utility decided to proceed with PTR since it believed that there were no losers under this design. PTR was offered to all customers as a default option. Analysis showed that some 88% of customers participated in it and peak demand during critical hours dropped by 15-20%.

Lesson: A PTR may be more palatable than a CPP rate.

Section 3: Strategies for Rate Modernization

Each utility follows its own pathway, depending on its particular circumstances. In general, most utilities follow this pathway.

FIGURE 6 A NINE-STEP PATHWAY FOR TRANSITIONING TO MODERN RATE DESIGN



I. Select Rate Design for Deployment

Select the specific rate design for deployment. In some case, more than one rate design may be picked for deployment. Utilities should evaluate each of these options and offer choices to customers along an efficient pricing frontier. Some of the choices being considered or offered by utilities to their customers are listed in the Table 1.[32] When these rate design options are offered to customers, they will be able to pick the one that represents the best combination of risk and reward.

FIGURE 7 THE EFFICIENT PRICING FRONTIER

[32] Ahmad Faruqui and Cecile Bourbonnais (2020).

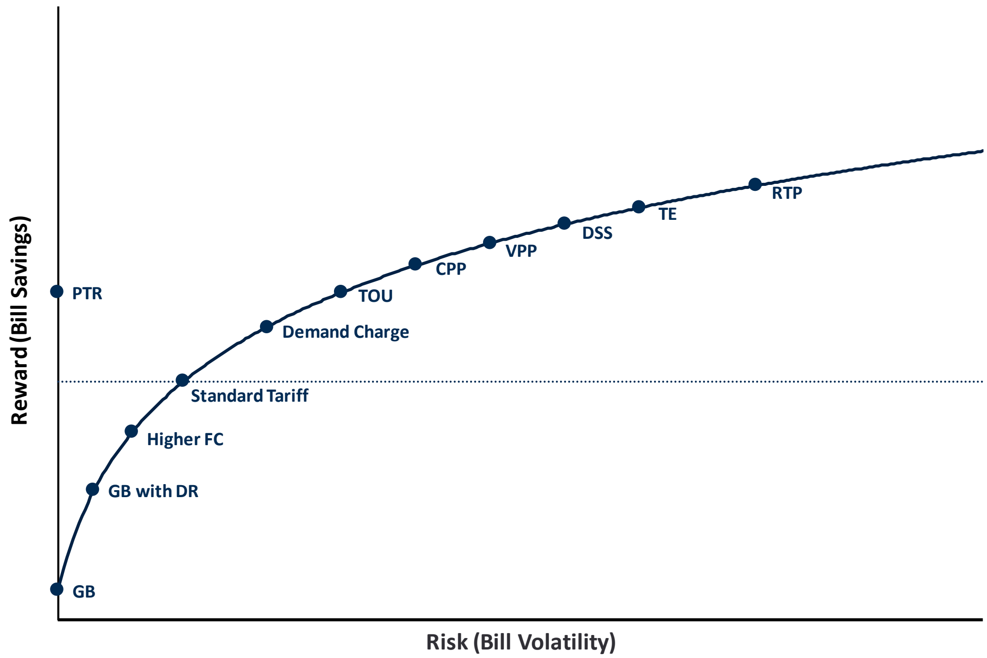
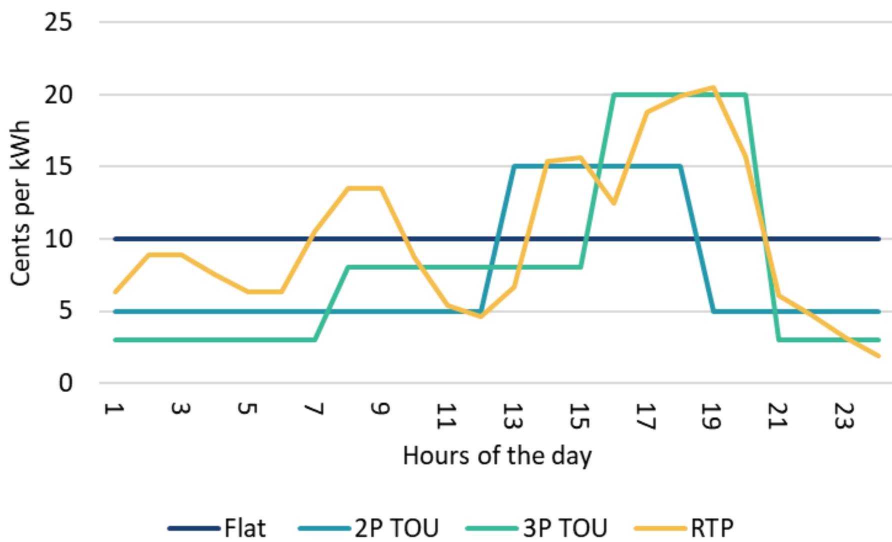
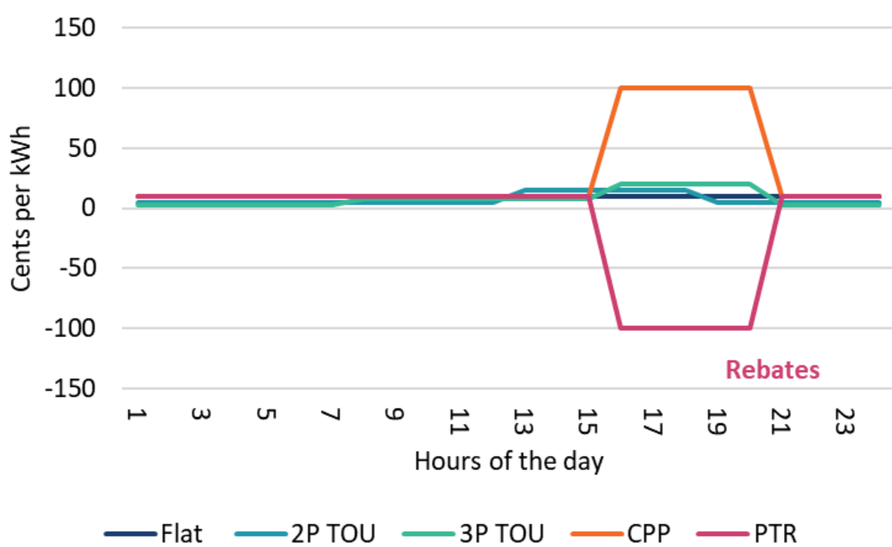


TABLE 1 RATE DESIGN OPTIONS

Rate Design	Definition
Guaranteed Bill (GB)	Customers pay the same bill every month, regardless of usage.
Flat Rate	A uniform $/kWh rate is applied to all usage.
Demand Charge	Customers are charged based on peak electricity consumption, typically over a span of 15, 30, or 60 minutes.
Time-of-Use (TOU)	The day is divided into time periods which define peak and off-peak hours. Prices are higher during the peak period hours to reflect the higher cost of supplying energy during that period.
Critical Peak Pricing (CPP)	Customers pay higher prices during critical events when system costs are highest or when the power grid is severely stressed.
Inclining Block Rates (IBR)	Customers are charged a higher rate for each incremental block of consumption.
Peak Time Rebates (PTR)	Customers are paid for load reductions on critical days, estimated relative to a forecast of what the customer would have otherwise consumed (their "baseline").
Variable Peak Pricing (VPP)	During pre-defined peak periods, customers pay a rate that varies by utility to reflect the actual cost of electricity.
Demand Subscription Service (DSS)	Customers subscribe to a kW demand level based on the size of their connected load. If they exceed their subscribed level, they must reduce their demand to restore electrical service.
Transactive Energy (TE)	Customers subscribe to a "baseline" load shape based on their typical usage patterns, and then buy or sell deviations from their baseline.
Real-Time Pricing (RTP)	Customers pay prices that vary by the hour to reflect the actual cost of electricity.

FIGURE 8 STYLIZED TIME-VARYING RATES

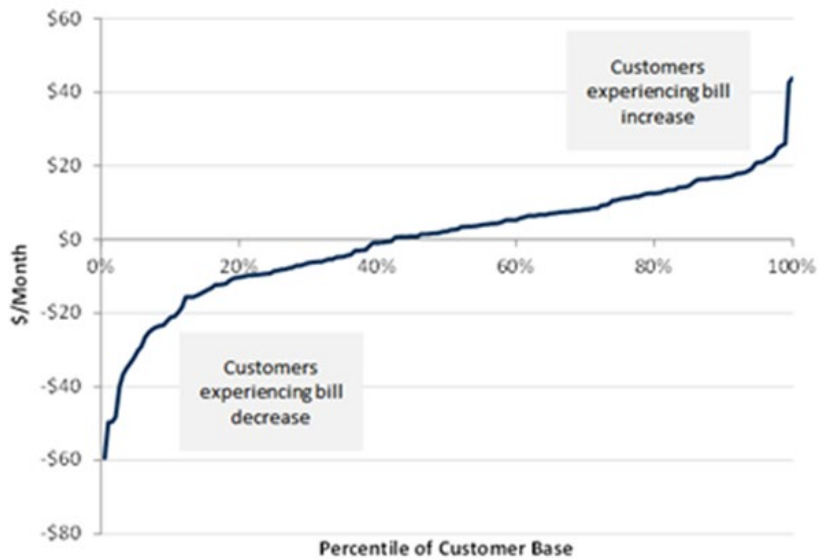




II. Estimate the distribution of bill changes across customers

For the chosen rate design(s), compute the impact of the rate design on a representative sample of customers. Plot the results in the form of a "propeller" chart, such as Figure 8, identifying those who are going to see higher bills and those who will see lower bills under the assumption that customers will not change their load shape.

FIGURE 9 DISTRIBUTION OF BILL IMPACTS



III. Understand which customers will see adverse bill impacts

Try to understand the sociodemographic and regional characteristics of those customers who are going to experience significantly higher bills. Identify policies that can be used to mitigate the adverse impacts. Examples include the offering the rebates to low-income customers and carrying out energy efficiency improvements in their facilities. If the rates would be offered to them on an opt-in basis, they could be given bill protection for the first year or two as they try them out. If the rates would be offered to them on an opt-out basis, such customers could be excluded from the default provisions altogether.

IV. Re-run bill impact distribution allowing for load shifting

Re-run the bill impact analysis by allowing for changes in load shapes that would occur as customers respond to the price signals. For example, lower off-peak rates would encourage them to raise off-peak usage and higher on-peak rates would encourage them to lower peak usage. Databases and models exist to simulate changes in customer load shapes. Changes in load shapes will mitigate the adverse bill impacts.

V. Consider remedies for remaining adverse bill impacts

If the adverse bill impacts are still significant for certain groups of customers, consider instituting one of these remedies shown in Table 2.

TABLE 2 REMEDIES FOR ADVERSE BILL IMPACT

Remedy	Implementation
Gradualism	Roll out the new rates gradually for each rate design element. For example, to introduce a TOU rate, if the peak price will be 25 ¢/kWh and the current tariff is 15 ¢/kWh, implement a peak price of 17 ¢/kWh in the first year and increase it annually by 2 ¢/kWh until it reaches 25 ¢/kWh.
Bill Protection	Provide customers with bill protection for a limited period so that they pay the lower of their old and new bill.
Optional Rates	Make the new rate design optional for vulnerable customers, mandatory for the largest customers, and the default for all other customers.

Financial Assistance	Provide customers with adverse bill impacts financial assistance for a limited period.
Enabling Technologies	Install enabling technologies such as smart thermostats on customer premises.
Two-staged Rollout	Structure the rate into two stages, where the first stage charges customers the current rate if their usage resembles a historical reference period, and the second stage exposes them to the new rate.

VI. Conduct focus groups with customers to gauge customer acceptance

These will help determine how best to communicate the rationale behind the selected rates and to see if they would be comfortable with the modern rate designs. Make appropriate modifications in language to make the modern rate designs understandable to customers.

VII. Run a scientifically-designed pilot to measure response

The pilot should be designed on scientific principles that would preserve the internal and external validity of the results, allowing them to be extrapolated to the population of customers. There are three ways of ensuring that pilots will yield results that are statistically valid and generalizable to the population at large. These include randomized control trials, randomized encouragement designs, and matching controls. Analysis of before-and-after data on the "treatment" customers who are on modern rates, and side-by-side data on treatment group and control group customers can then be carried out using econometric methods to yield a difference-in-differences estimate of the impact of the new rates on customer load shapes. Price elasticities can also be derived, allowing results to be predicted for a wide range of rates, not just those that are included in the pilot.

VIII. Determine rollout strategy

Decide on the rollout strategy. It could be opt-in, opt-out or mandatory. Examples of each are presented below.

- In Arizona, a variety of TOU rates are offered on an opt-in basis by two utilities, Arizona Public Service (APS) and the Salt River Project (SRP). About 61 percent of APS' customers and 35 percent of SRP's residential customers take service on a TOU rate. Analyses from a sample of customer numbers show that TOU rates with a shorter peak period yields an average reduction of 17% of on-peak kWh and TOU rates with a longer peak period have an average of 8% reduction.
- In Colorado, Fort Collins, a small utility, moved all its customers from volumetric rates to TOU rates in October 2018. The deployment was mandatory and it was preceded by a one-year pilot. The residential opt-out pilot showed a 2.5% reduction in energy consumption. Xcel Energy, a much bigger utility, began rolling out a default TOU rate in 2022 to all customers with smart meters. It was preceded by a pilot.
- In Michigan, Consumers Energy rolled out TOU rates as the default tariff to all its residential customers in 2021. The deployment was preceded by a pilot program that saw a general reduction in peak energy of between 3% and 4%. DTE Energy has recently rolled out TOU rates as the default tariff. Customers can opt-out to other rates but all of them are TOU rates. Both utilities offer choices but they are all TOU rates.
- In Illinois, Commonwealth Edison and Ameren offer RTP to their customers but only 2% have taken it.
- Georgia Power is rolling a few TOU rates to its residential customers, including a rate with a significantly lower off-peak rate designed specifically for EV owners.

- In Missouri, regulators have ordered Ameren and Evergy to roll out default TOU rates in October with peak to off-peak price ratio that range from 4:1 to 5:1. These are the highest such ratios in default TOU rates in the US.[33]

IX. Modify rate designs as needed

Finally, track the deployment of the modern rate design(s) and survey the customers for feedback. The utility can set up social media sites and monitor the conversation, and make necessary modifications in the rate design on a regular basis.

Section 4: What's Likely to Happen in the Future?

As utilities begin the transition to net zero, they will incentivize customers to install new technologies that promote electrification through rebates and low interest financing programs. Additional incentives will come from governments at the federal, state and local levels.

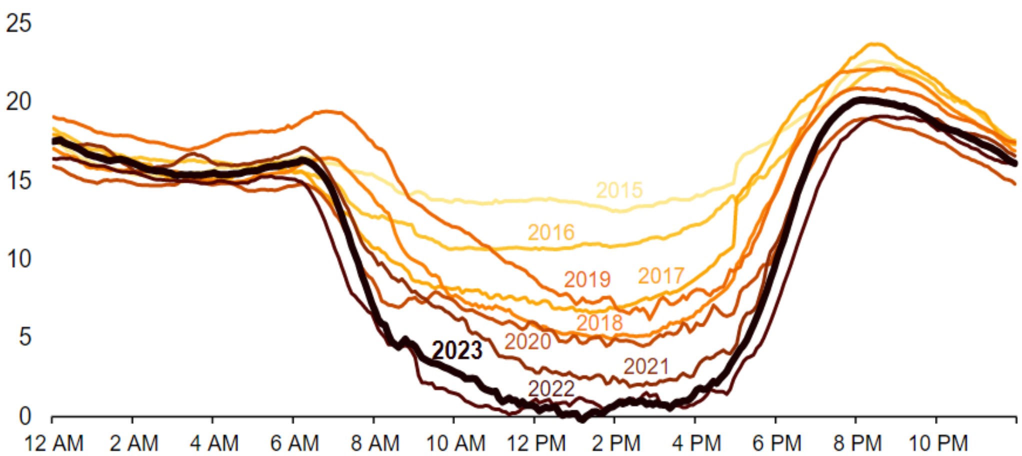
The most prominent technologies that are receiving incentives today are electric vehicles (EVs) and heat pumps. Also, faced with rising bills, and seeking to move toward an organic lifestyle, customers are moving forward by installing photovoltaic (PV) panels on their roofs. An increasing number of new PV installations are integrated with battery energy storage systems. They are receiving significant incentives from the federal government. Many of these customers also drive EVs.

As EVs and heat pumps are widely deployed, utilities will need to find a way for managing the growth in peak loads that will follow their deployment. As the share of large scale solar grows on the supply side, utilities will see that their net peak load will shift from the early afternoon hours to the late afternoon an early evening hours. This phenomenon, knowns as the duck curve (Figure 9), has already begun to happen in California.[34] The peak period used to run from noon to 6 pm about two decades ago. A decade ago, it shifted to the 2 pm to 7 pm window. Now it runs from 4 pm to 9 pm.

[33] Jeffrey Tomich, "Missouri overhauls electric rates, raising rewards – and risks – for customers", *EnergyWire*, July 12,2023, https://www.eenews.net/articles/missouri-overhauls-electric-rates-raising-rewards-and-risks-for-customers/.

[34] "As solar capacity grows, duck curves are getting deeper in California", U.S. Energy Information Administration, June 21, 2023, accessed at https://www.eia.gov/todayinenergy/detail.php?id=56880.

Figure 10 California's Duck Curve (CAISO Lowest Net Load Day Each Spring, 2015-2023, GW)



In Hawaii, the off-peak period now lies in the afternoon hours and the same is evident in Australia, where a "sponge tariff" is offered to encourage additional energy use in the afternoon hours.

In all of these cases, a TOU tariff will prove to be an indispensable resource to encourage off-peak charging. That's already the case in California where the off-peak period now begins at midnight, to encourage the nighttime charging of EVs.

More and more utilities are beginning to offer TOU rates with exceptionally low off-peak rates. These are often three-period rates where the off-peak period begins at midnight.

As for dynamic pricing, despite the substantial benefits that economists have pointed out,[35] the future remains uncertain:

- In Illinois, hourly real-time pricing is offered to the state's 4.7 million electric customers by its two investor-owned utilities. Under 2% of customers have taken it.
- In California, residential customers have been offered CPP for more than a decade. Only 2% of customers have taken it.[36]
- In Oklahoma, OG&E has had more success with a more advanced version of CPP known as variable-peak pricing (VPP). The price on critical days can rise to four different levels, depending on the severity of the demand-supply imbalance. Because of customer-friendly rate design and exceptionally good marketing, that pricing program has achieved an adoption rate of 14.7%. But it remains the exception to the rule.

New forms of pricing continue to evolve. The latest version is called Subscription Pricing. In that design, customers are offered a fixed bill based on their historical pattern of use. It's somewhat higher than their average monthly bill. It offers peace of mind to the customer and is akin to the type of pricing used by Internet providers and companies such as Netflix. A more advanced version of Subscription Pricing offers customers a chance to lower

[35] See, for example, Severin Borenstein (2005), Ahmad Faruqui (2010), William Hogan (2010), and Schittekatte et al. (2023, forthcoming).

[36] For experimental results from a small municipal utility in southern California, see Frank A. Wolak (2007).

their fixed bills by reducing their usage during critical hours when the demand-supply equation appears to be going out of balance. It's called Subscription+.[37]

Utilities are beginning to realize that the best way to enhance customer satisfaction is to give them choices of rates. Some want bill stability and are willing to pay a bit more for that. That's where subscription pricing comes in. Others want flat rates. Still others are willing to move some of their consumption out of the peak period to off-peak periods and are happy to go on a TVR. Most of the last group of customers are interested in a two or three period TOU rate but some are willing to try variants of dynamic pricing. They come with added risk but also can yield the lowest bills.

Section 5: Conclusions

The evolution of TVR in the US has been very slow over the past four decades for a number of reasons. Among them, lack of metering, consumer reluctance to try something new, and a fear that these rates will raise bills. Long peak pricing periods that spanned most of the day time hours were a major barrier to customer adoption.

Consumers don't put much stock in notions such as allocative efficiency that have the status of an axiomatic truth among economists. They don't care much about rates being cost based, consistent with the principles put forward by Bonbright.

Utilities have been reluctant to offer them on an optional basis, concerned that only those who would lower their bills would sign up for time-varying tariffs, eroding revenues. They have also been skeptical that TVR would induce load shifting from peak to off-peak periods, and lower costs for all customers by reducing the need for new capacity additions.

For decades, TVR were an exotic service offering, requiring the installation of a special interval meter. Today, smart meters are deployed in nearly 70% of American households. So are programmable thermostats, many come with WIFI capability, but even today few customers bother to program them. Many appliances such as dishwashers have timers built into them but that feature is rarely used. Customer apathy is still very much a part of life.

But what has really begun to move the needle is the arrival of electric vehicles (EVs). Consumers have begun asking for TVR because they can reduce their cost of charging by more than half. Utilities are more than happy to offer TVR to EV owners since they encourage off-peak charging and avoid the need to invest in expensive peaking capacity.

An additional reason why utilities are interested in moving customers to TVR is the installation of rooftop solar panels (PVs) by customers.

The new generation of TVR are designed with customer lifestyles and convenience in mind. Peak periods are shorter than they used to be, and prices are dropped substantially in a third pricing period, which usually occurs during the night, to encourage the charging of EVs. Lessons have been learned.

[37] Ryan Hledik, "Direct Testimony on behalf of Evergy Missouri West," January 7, 2022. https://efis.psc.mo.gov/mpsc/commoncomponents/viewdocument.asp?DocId=939607385.

As a result, TVR are being offered by more utilities, often accompanied by bill calculators on web portals to help customers pick their best rate. As a sign of the times, a few states have decided to make TVR the default option for their customers and one has made them mandatory.

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