Forthcoming chapter, **Handbook on Electricity Regulation.**

Time-varying rates are moving from the periphery to the mainstream of electricity pricing for residential customers in the United States

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"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 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, later part of the Department of Energy. 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

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[2] *Cost and Tariffs in Electricity Supply",* London: Chapman & Hall, Ltd., 37 Essex Street W. C. 2, 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.

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.

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 introduced across the US.[8] DSM included utility energy efficiency programs and government codes and standards to promote energy efficiency and load management. Tariff reform took a back seat.

To offset rising bills, retail choice of providers became a priority in the 1990s. While retail choice succeeded with large commercial and industrial customers, it made little headway with households, most of whom stayed with their existing utility suppliers, except in Texas where default supply was eliminated, as it was in the United Kingdom.

TOU rates languished in the US until California's energy crisis of 2000-01 gave it a spur. Soon thereafter, time-varying rates including TOU rates and newly introduced dynamic pricing emerged as a priority. Dynamic pricing included critical-peak pricing (CPP) and real-time pricing (RTP).

A second generation of pilots was carried out, initially in California[9], and later in a variety of other states including Connecticut, Florida, Illinois Maryland and Michigan.[10] Simultaneously, smart meters began to be rolled out.

Today, 97.7 million smart meters are deployed to households in the US, representing 69% of all residential meters. Time-varying rates are finally getting significant attention. In 2021, 8.7% 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 the time this decade ends.

A major driver is the concerted effort to reach Net Zero carbon emissions. A variety of new technologies are being incentivized through federal and state legislation, including photovoltaic panels (PV), battery energy storage systems (BESS), heat pumps and electric vehicles (EVs).

This chapter is organized into 5 sections:

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[7] For the early history of the EURDS, see Robert G. Uhler, "Should Utility Rates be Redesigned," *EPRI Journal*, March 1976, 12-17. He was the first Executive Director and was succeeded by Rene Males.

[8] Clark W. Gellings and John H. Chamberlin, *Demand-Side Management: Concepts and Methods*, Fairmont Press, 2nd edition, 1993.

[9] Ahmad Faruqui and Stephen S. George. 2005. "Quantifying Customer Response to Dynamic Pricing." *The Electricity Journal*, 18(4): 53-63.

[10] Ahmad Faruqui and Sanem Sergici. 2011. "Dynamic Pricing of Electricity in the Mid-Atlantic Region: Econometric Results from the Baltimore Gas and Electric Company Experiment." *Journal of Regulatory Economics,* 40(1): 82-109; Ahmad Faruqui, Sanem Sergici and Lamine Akaba. 2013. "Dynamic Pricing of Electricity for Residential Customers: The Evidence from Michigan." *Energy Efficiency*; Ahmad Faruqui, Neil Lessem, and Sanem Sergici, 2017. "Dynamic Pricing Works in a Hot, Humid Climate," *Public Utilities Fortnightly*, May; Ahmad Faruqui, Sanem Sergici and Lamine Akaba. 2014. "Dynamic Pricing in a Moderate Climate: The Evidence from Connecticut," with Sanem Sergici and Lamine Akaba, *Energy Journal*, 35:1, pp. 137-160, January.

Section 1: The Evolution of Time-Varying Rates

With rare exceptions, electric rates for households in the US did not feature time variation until the 1960's.[11] The preferred medium for managing peak loads was direct load control of water heaters and central air conditioners.

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. Some commissions directed electric utilities to implement TOU tariffs. 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 Federal Energy Administration (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. 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.[12]

In an interview with the EPRI Journal, he was quite vocal about the merits of time-varying rates: "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."[13]

[11] F. M. Westfield, "Electric Utility Rate Design Study: Economic Theory of Marginal-cost Pricing and its Application by Electric Utilities in France and Great Britain", *EPRI*, August 12, 1980.
[12] "Alfred E. Kahn," *Wikipedia*, last modified February 5, 2023, https://en.wikipedia.org/wiki/Alfred_E._Kahn.
[13] "Alfred Kahn breaks tradition," *EPRI Journal*, December 1976, 42-45.

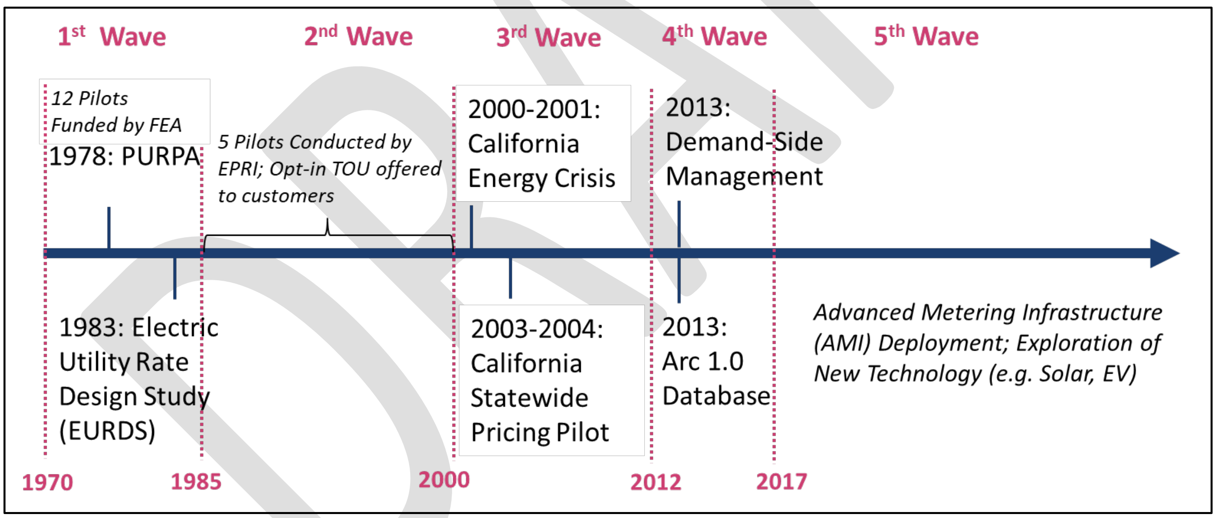
J. Robert Malko, an economist from the Wisconsin Commission, managed EURDS.[14] Several advisory committees drawn from commissions and utilities guided the work of the EURDS. The utility staff were drawn from investor-owned utilities, municipal utilities and cooperatives.

The EURDS advisers agreed that TOU rates should be cost reflective, in accordance with the widely accepted Bonbright principles.[15] 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.[16]

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 time-varying rates and how it interacted with other driving factors.

FIGURE 1 THE EVOLUTION OF TIME-VARYING RATES



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.[17] The FEA found that higher peak-to-off-peak price ratios and shorter

[14] Faruqui worked for him in the EURDS.

[15] James C. Bonbright, Albert L. Danielson, David R. Kamerschen, *Principles of Public Utility Rates*, Public utilities reports, 2nd edition, March 1, 1988.

[16] For a detailed review of the EURDS, consult: Hethie S. Parmesano and Catherine S. Martin, "The Evolution in U.S. Electric Utility Rate Design," *Annual Review of Energy*, 1983, 8:45-94. https://www.annualreviews.org/doi/pdf/10.1146/annurev.eg.08.110183.000401

[17] Ahmad Faruqui and J. Robert Malko. 1983. "The Residential Demand for Electricity by Time-of-Use: A Survey of Twelve Experiments with Peak Load Pricing," *Energy* 8(10): 781–795.

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.[18] 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.

Third wave

The 2000–01 California energy crisis gave impetus to the next wave of pilots with time-varying rates. In addition to TOU rates, they featured dynamic pricing designs.[19] 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.

By 2013, more than 30 pilots featuring more than 160 energy-only pricing treatments were carried out around the globe. Through those pilots, utilities and regulators learned more about the efficiency benefits time-varying rates could offer, and about factors that improve customer responsiveness during peak demand periods.

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.[20] 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.[21] 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

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[18] Douglas W. Caves, Laurits R. Christensen, and Joseph A. Herriges. 1984. "Consistency of Residential Customer Response in Time-of-Use Electricity Pricing Experiments." *Journal of Econometrics* 26(1–2): 179–203.

[19] Ahmad Faruqui et al., "Analyzing California's Power Crisis," *Energy Journal* 22(4): 29–52 (2001).

[20] "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.

[21] Ahmad Faruqui, Sanem Sergici and Cody Warner, "Arcturus 2.0: A meta-analysis of time-varying rates for electricity," *The Electricity Journal*, Volume 30, Issue 10, 2017. *Also* Ahmad Faruqui, Sanem Sergici and Ziyi Tang, "Do Customers Respond to Time-Varying Rates: A Preview of Arcturus 3.0", The Brattle Group, January 2023, accessed at https://www.brattle.com/wp-content/uploads/2023/02/Do-Customers-Respond-to-Time-Varying-Rates-A-Preview-of-Arcturus-3.0.pdf.

customer responsiveness, as demonstrated by the dotted curve.[22] 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

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.[23] One of the findings was that in 2010, Pacific Gas and Electric called 13 events under its CPP program. Although there were no observable conservation effects, average peak reduction was 14% (with load shifting to subsequent hours) and customers saved an average of 8.2% on their bills. Low-income customers provided about the same percentage of peak demand reduction as other customers.

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 time-varying rates. 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.[24]

Figure 3 Price Ratio in Two-Period Time-of-Use Rates

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[22] The difference between the curves is statistically significant and each of the curves by itself is also statistically significant.

[23] Ahmad Faruqui, Ryan Hledik, and Jennifer Palmer, "Time-Varying and Dynamic Rate Design", Global Power Best Practice Series, The Regulatory Assistance Project (RAP), July 23, 2012, accessed at: https://www.raponline.org/wp-content/uploads/2016/05/rap-faruquihledikpalmer-timevaryingdynamicratedesign-2012-jul-23.pdf.

[24] Utility Rate Database, OpenEI, last modified February 2023, accessed at https://openei.org/wiki/Utility_Rate_Database.

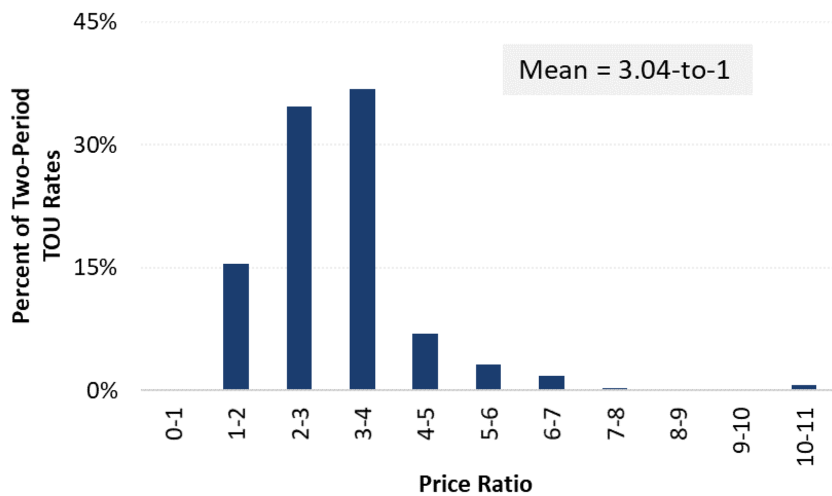
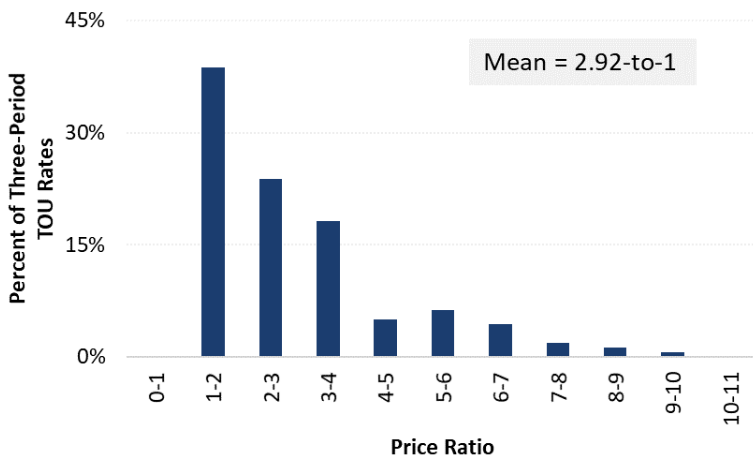


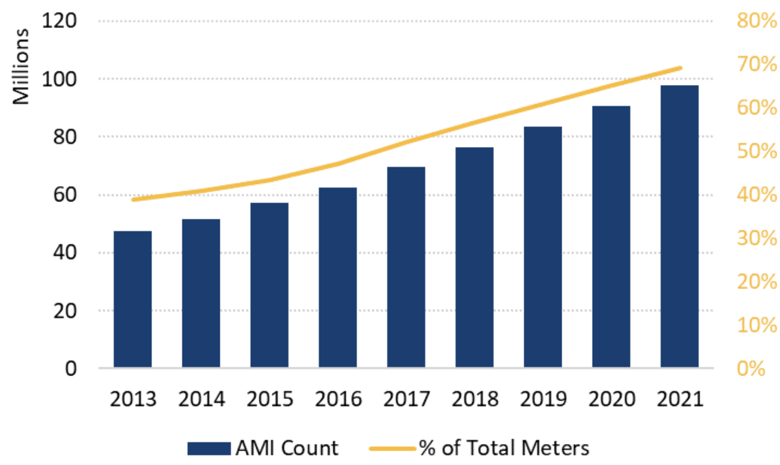
Figure 4 Price Ratio in Three-Period Time-of-Use Rates



In the fourth wave, the implementation of time-varying rates did not keep pace with the installation of advanced metering infrastructure. According to EIA-861 Survey, 97.7 million households have advanced metering infrastructure, which is about 69% of total residential electric meters in 2021.[25]

Figure 5 Smart meter installation (2013-2021)

[25] Annual Electric Power Industry Report, From EIA-861, U.S Energy Information Administration, Oct 6, 2022, accessed at https://www.eia.gov/electricity/data/eia861/.



But only 12.3 million households are enrolled on a time-varying rate, which is about 9% of total number of residential customers. The barriers to large-scale implementation of time-varying rates 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 time-varying rates will more efficiently and fairly allocate costs among individual customers but it will definitely raise bills for customers whose load factors 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. Understanding and enabling residential customer responsiveness under time-varying rates 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 time-varying rates.

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".[26] 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, 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.[27] 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 Four Decades of Deploying Time-varying Rates

Several lessons can be gleaned from the past four decades which would help in designing better rates in the future. These are summarized in this section.

[26] Stephen Barrager, and Edward Cazalet, *Transactive Energy: A Sustainable Business and Regulatory Model for Electricity*", Baker Street Publishing, October 24, 2014.

[27] "Advanced Strategies for Demand Flexibility Management and Customer DER Compensation", Energy Division White Paper and Staff Proposal, California Public Utilities Commission, June 22, 2022, accessed at https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/energy-division/documents/demand-response/demand-response-workshops/advanced-der---demand-flexibility-management/ed-white-paper---advanced-strategies-for-demand-flexibility-management.pdf.

1. Do not oversell the benefits of time-varying rates

In the early 2000s, a mid-size U.S. utility in the Pacific Northwest rolled out what the CEO termed a “dynamic pricing” program. The new rate was simply a TOU rate. It featured three periods with modest price differentials: the peak and off-peak prices were designed to be 15 percent higher and lower than the mid-peak, respectively. It was not a dynamic pricing program. The utility introduced the new rate on an opt-out basis to 300,000 of its residential and small commercial customers, about 30 percent of its total customers. Advanced metering infrastructure (AMI) was in place so the utility relied on Automatic Meter Reading (AMR).

The immediate reception from customers was positive. The utility heavily advertised the new program, promising that participation would save customers money. Despite the modest price differential, some customers shifted nearly half their loads from peak to off-peak in response to TOU, convinced by the utility’s intensive marketing that they would get large bill savings. Customers felt greater control over energy use, rate plans and social responsibility, which also enhanced customer satisfaction. During the first year, 55 percent of residential customers experienced saving. But actual savings were nowhere near the advertised levels.

A working group was set up to monitor the progress of the program. The group conducted a cost-benefit analysis and found that the customers were misled. Relative to the standard rate (what customers had paid before), most customers saved somewhere between 50 cents to a dollar a month. Many customers lost just about as much. Further, accounting for the $1 monthly fee levied on participating customers for covering the cost of data retrieval, some 94 percent of customers ended up paying more money by participating in the program. Customers felt cheated. Ten percent dropped out of the program. Local and national media outlets reported on the story. The backlash was severe. As a result, the utility ended the program and refunded the increased amounts to participating customers. This incident led another utility to cancel its own TOU pilot. TOU rates got a bad name nationwide.

Lesson: Don’t oversell the savings from time-varying rates.

2. Pilots are not Always Needed

In the aftermath of the California energy crisis, experts concluded that price-responsive demand could have helped the state respond to the crisis. The Ontario Energy Board felt the pressure to avoid the same fate. To link retail market prices to wholesale market prices, the regulators turned to TOU tariff as a solution. They decided to deploy smart meters universally and once those had been deployed, to move all customers to a default TOU rate for the energy portion of the bill. No pilot preceded the province-wide TOU deployment. About 90 percent of the customers stayed on the program while the other 10 percent chose to go with retail providers.

The province had previously offered a two-tiered inclining block rate (IBR) to customers with a modest, 1-penny differential between the blocks. The TOU rates replaced the IBR.

The TOU program took off because of strong leadership from the Premier. He did not conduct a benefit-cost analysis because “it was obvious.” The regulators considered changing the TOU rates to dynamic pricing rates at one point but there was no interest in such a rate among stakeholders. They were not deployed. However, in the past few years, some pilots have been done with dynamic pricing rates and at some point, those rates may be offered as alternatives to the default rate.

Lesson: If meters are already in place, or have an obvious business case, and if there is strong leadership, a pilot may not be needed, especially if pilots have been done elsewhere.

3. *Embrace Gradualism*

One of the most successful TOU programs in the U.S. was launched by SMUD, a municipal utility located in California. The utility believed that time-varying rates were the wave of the future. It decided to initiate pilots with CPP and TOU (enabled by technology). The CPP pilot had a default option as well as a technology-enabled option. Results from the pilots were positive, and the utility decided to introduce them to its customers. The success of the roll-out campaign can be attributed to the utility's smooth transition plans. To socialize and prepare customers for the new rates, the utility gradually flattened the existing IBR to a flat rate over a period of three years. With the customers on board, the utility moved all of its customers to a TOU rate. As of today, 98 percent of its residential customers are on TOU rates. This utility is way ahead of some of the largest IOUs in the region.

On the other side of the globe, the Australia Energy Market Commission concluded that TOU rates were needed for distribution charges because the volumetric charges being offered by competitive retailers were not cost-reflective. The regulator's solution to address potential "social justice" issues that are common in any rate design transition was elegant. The new TOU rates would be 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.

The rollout of rate designs takes multiple steps and may require coordination with multiple stakeholder groups. The utility needs to set a goal, and then begin to march toward that goal one step at a time.

4. *Think Outside the (Service Territory) Box*

Prior to 1990, real-time pricing (RTP) was just an academic concept in the US until Georgia Power, a large southeastern utility, 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 there for large mining customers. Because mining requires high power demand, and because their discrete 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 new RTP program 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. The rate attracted a number of heavy industrial customers to the state. It was observed that load dropped 17 percent on average whenever wholesale price exceeded $1/kWh. It took about 6 years for the system operators to be convinced that the changes in load shape brought about by the hourly prices were real and could be used for system dispatch. 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. Also, customer engagement pays off in the end, attracting customers beyond the utility's service territory.

5. Key Decision Makers Need to be On Board

TVA, a federal agency, serves power to more than 150 publicly owned utilities in seven southeastern states in the US and also designs their rates. TVA wished to bring the benefits of advanced rate designs to customers. However, smart metering technology was not available at the time. To brainstorm solutions, the agency organized a two-day workshop with its 150 distribution utilities but the group failed to reach any consensus after four hours of discussion. The group broke for lunch. In the post-lunch session, seasonal rates were proposed by the consultant. There was immediate consensus on proceeding with those. However, that idea was never implemented. It turns out that the design did not win the approval of the Board of Directors. It was not clear what happened. Rumors surfaced that 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 and be aware of political barriers to success.

6. Mind the Transition Costs

Dynamic pricing programs were offered by OGE, a southwestern U.S. utility in the 2000s. The CEO of the utility asked his leadership team to explore demand-side solutions instead of building a 600-MW power plant. After doing comprehensive market research with its customers, including conjoint analysis, the utility reached the conclusion that there was enough appetite for the utility to develop a sophisticated variable-peak pricing (VPP) program 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 VPP program worked very well in the pilot, so the utility offered it to their 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 utility also adopted prices-to-devices method, which simplified the process. Under this method, prices come directly to devices (such as a thermostat), where the customer has programmed the device to take the necessary actions in response to changing prices.

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

7. When There's a Will, there's a Way (Until Rules are Changed).

In the course of exploring rate design reforms in the late 2000s, BGE, a utility in the Mid-Atlantic region, 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. To pay for the rebates, the utility passed on the capacity credit it received from the regional system operator (PJM) for the demand reductions to its customers. 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%.

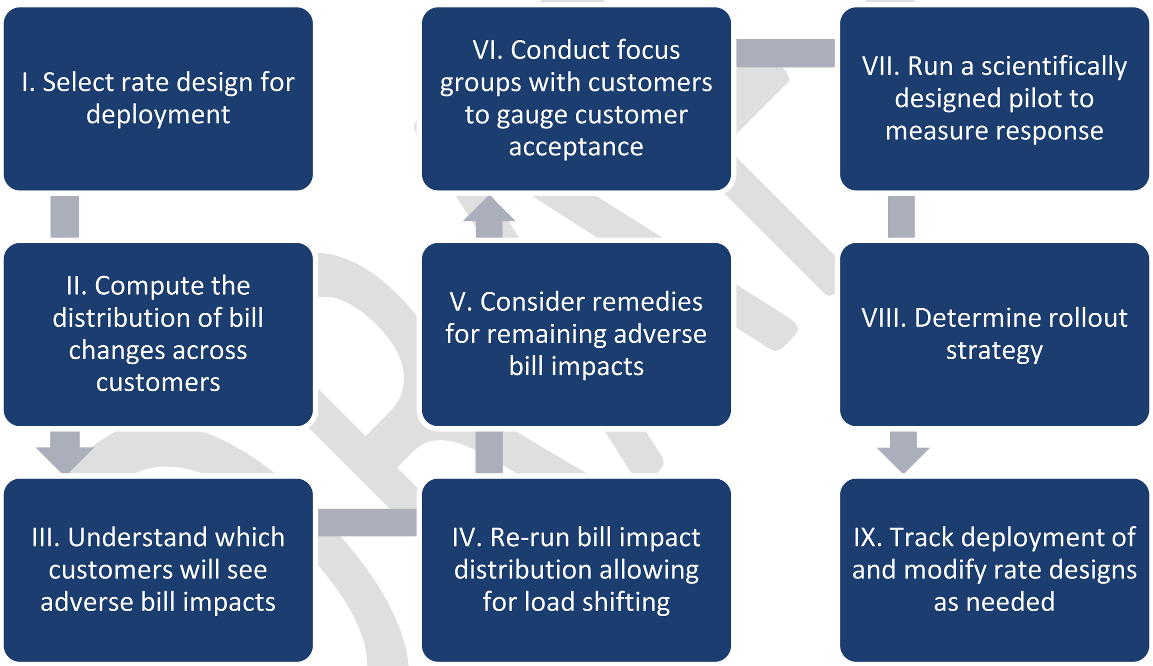
Lesson: A PTR may be more palatable than a CPP rate.

Section 3: Strategies for Rate Modernization

How does a utility begin the process of rate modernization?

Each utility follows its own pathway, depending on its particular circumstances. In general, most utilities follow most of the steps in Figure 6.

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.[28] 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.

[28] Ahmad Faruqui and Cecile Bourbonnais, "The Tariffs of Tomorrow", *IEEE Power and Energy Magazine,* May/June 2020, https://magazine.ieee-pes.org/wp-content/uploads/sites/50/2020/05/PE_MayJun_Faruqui.pdf.

FIGURE 7 THE EFFICIENT PRICING FRONTIER

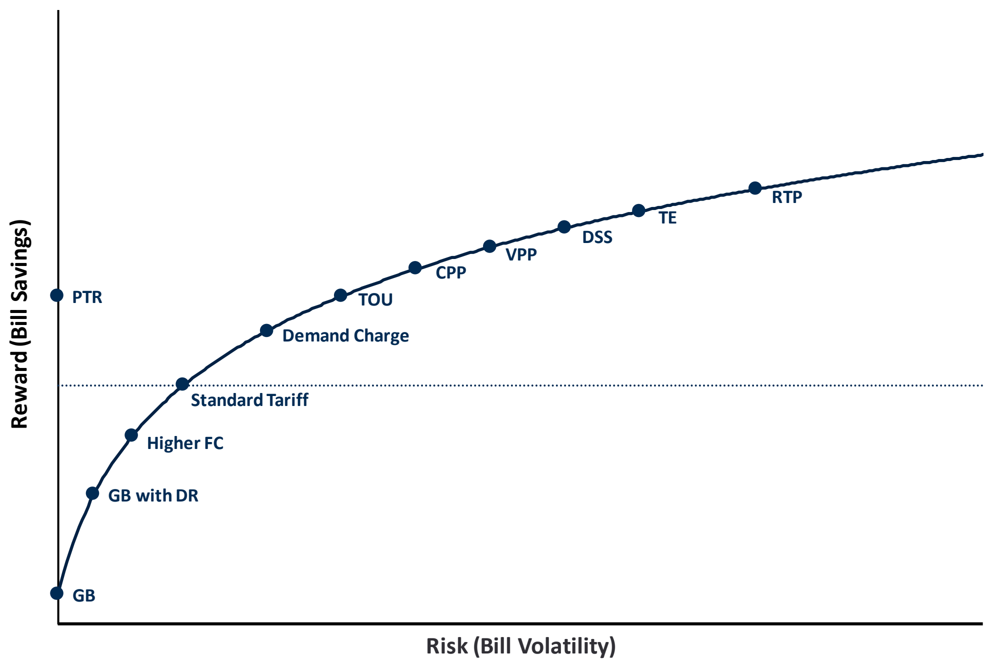


TABLE 1 RATE DESIGN OPTIONS

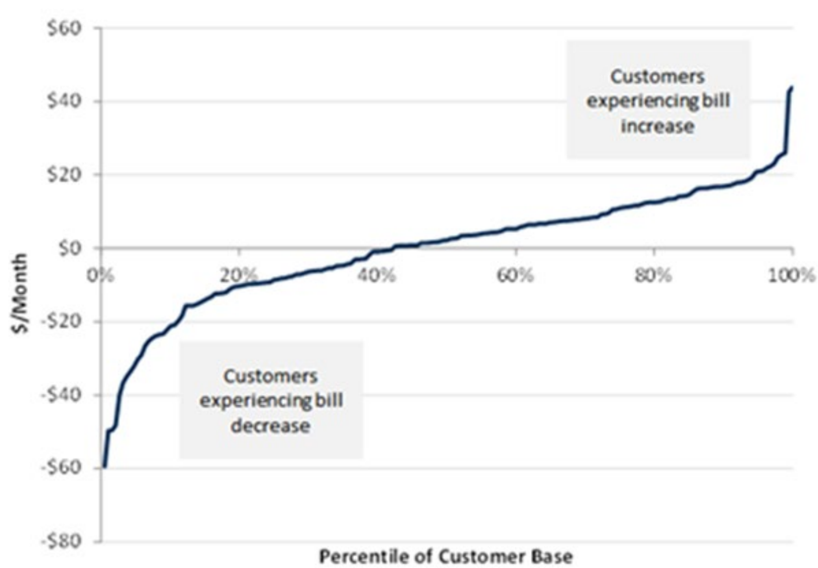
Rate Design	Definition
Guaranteed Bill (GB)	Customers pay the same bill every month, regardless of usage.
Flat Rate	A uniform $/kWh rate is applied to all usage.
Demand Charge	Customers are charged based on peak electricity consumption, typically over a span of 15, 30, or 60 minutes.
Time-of-Use (TOU)	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.

II. Compute 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 8 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. These include the Arcturus database and PRISM model, both products of The Brattle Group. Both are based on actual empirical experience with modern time-varying rates across the globe. 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 (and possibly in the rate design parameters, such as the magnitude of the fixed charge, the demand charge, and the charges for energy by time-of-use, as well as the duration and temporal location of the peak period) to make the modern rate designs understandable to customers. The purpose of this step is to maximize customer acceptance of modern rates.

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. A few case studies are noted below.

- In Oklahoma, an investor-owned utility has deployed what is probably the most sophisticated dynamic pricing rate for residential customers in the US. It's offered on an opt-in basis. The utility provides its customers the option to install smart thermostats through the program and automate the price response. One in seven customers have signed onto the rate and are saving significantly on their electric bills. The deployment was preceded by extensive market research carried out via conjoint analysis and a scientifically designed pilot. The utility now offers three dynamic rate designs on opt-in basis to customers in its service area.

- In Maryland, two investor-owned utilities have rolled out dynamic, peak time rebates as the default tariff to all their customers. Upwards of 80 percent of customers have availed themselves of the rate. They respond to critical events by lowering their peak demand by 15-20% and earning rebates. The default rollout was preceded by a pilot that ran for four years.
- In Arizona, a variety of TOU rates are offered on an opt-in basis by two utilities, one of which is investor owned (utility A) and the other is not (utility B). Around 61 percent of utility A's residential customers and 35 percent of utility B's residential customers take service on a TOU rate. Analyses from a sample of customer numbers show that TOU rates with a shorter peak yields to an average reduction of 17% of on-peak kWh and TOU with a longer duration has an average of 8% reduction. Neither utility conducted pilots for two-period TOU prior to deployment but one of the two utilities has conducted a pilot for its three-period TOU rate.
- In Colorado, a municipal utility moved all its residential customers from traditional volumetric rates to TOU energy 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. An investor-owned utility began rolling out a default TOU rate in 2022 to all customers with smart meters. The deployment will be completed by 2025. It was preceded by a pilot that ran for two years. A cooperative has just announced plans to roll out a TOU rates as the default tariff. It will feature two pricing periods and the ratio of peak to off-peak rates will be 2:1. They will also have a three-period TOU rate for customers with EVs. It will have a 4:1 ratio between the peak and night-time rates, and a ratio of 2:1 between the peak and the off-peak rates and also a ratio of 2:1 between the off-peak and night-time rates.[29]
- In California, the three-investor owned utilities have almost completed transitioning all their residential customers to TOU rates. The deployment began in 2018. The deployment was preceded by extensive market research and a series of pilots going back almost two decades. A municipality offers a default TOU energy rate along with a $23.5 a month service charge. Only 3 percent of customers have opted out of the TOU rate. The deployment was preceded by a very well-designed pilot.
- In Michigan, an investor-owned utility serving the Lower Peninsula 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%. The other investor-owned utility has also rolled out TOU rates as the default tariff. Customers can opt-out to other rates but all of them are TOU rates. In that sense, the state has implemented mandatory TOU rates.
- In Illinois, about 178,000 residential customers of two investor-owned utilities are on an opt-in TOU or a real-time pricing rate. Only 2% of the customers are on a real-time pricing rate.
- In Georgia, a utility has been granted permission to rollout a few TOU rates to its residential customers, including a rate with a significantly lower off-peak rate of a penny a kWh designed specifically for EV owners and a three-part rate.

[29] https://www.gvp.org/2023-rates.

- In Missouri, regulators in Missouri have approved two new default rates of the two major investor-owned utilities with peak to off-peak price ratio of 5:1 and 4:1 in 2023, the highest such ratios in default TOU rates in the US.[30]
- In Ontario, Canada, mildly time-differentiated TOU rates were rolled out as the default tariff for energy supply to residential and small commercial customers in 2007, once AMI deployment was completed. About 90 percent of these customers are on such rates while the remainder are taking competitive supply from retailers. TOU rates have consistently lowered peak loads.[31]

IX. Track deployment of and 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.

The deployment of smart meters enables the provision of modern rate designs. As customers invest in smart energy using technologies, it becomes easier for them to respond to these rate designs. This chapter has laid out the steps that are needed to begin the process of rate modernization. Many jurisdictions have successfully made the transition using one or more of these methods. Utilities that have not begun to make the transition can study the lessons learned from these deployments and begin their own journey.

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 a wide range of incentives from all the entities mentioned above are electric vehicles (EVs) and heat pumps. Also, faced with rising bills, and seeking to move toward an organic lifestyle, customers themselves are moving forward by installing photovoltaic (PV) or solar 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. Net energy metering is still in place in several states but two states have ended it.

California, which has seen the largest deployment of solar panels in the US and which has more than a million homes with PVs, replaced NEM in April 2023 with a net billing tariff that significantly reduces export

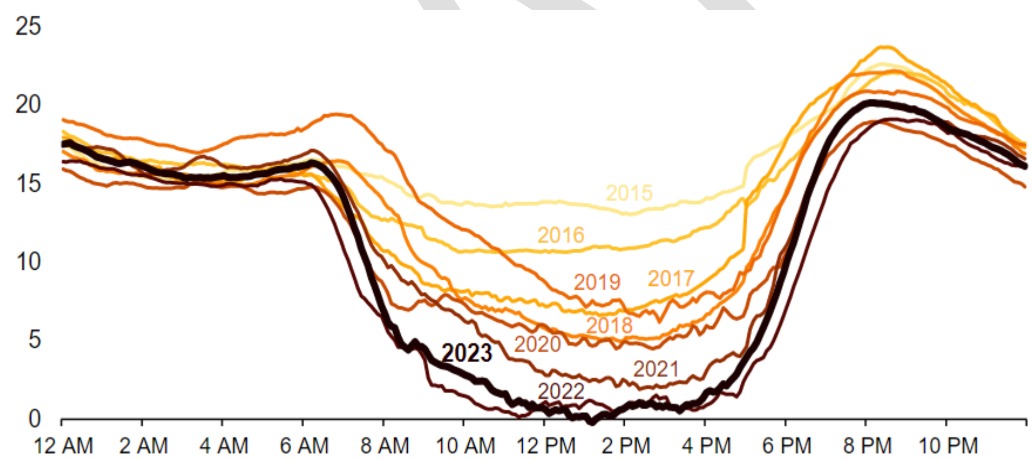
[30] Jeffrey Tomich, "Missouri overhauls electric rates, raising rewards – and risks – for customers", *EnergyWire*, July 12,2023, https://www.eenews.net/articles/missouri-overhauls-electric-rates-raising-rewards-and-risks-for-customers/.

[31] Ahmad Faruqui, Neil Lessem, Sanem Sergici, and Dean Mountain. 2017. "The Impact of Time-of-Use Rates in Ontario,", *Public Utilities Fortnightly*, February; Ahmad Faruqui, Sanem Sergici, Neil Lessem, and Dean Mountain. 2015. "Impact Measurement of Tariff Changes when Experimentation is not an Option – A case study of Ontario, Canada," with, *Energy Economics*, 52, December, pp. 39-48.

compensation. The state of Hawaii, which has the highest percentage of rooftop solar deployment in the US, ended NEM in 2015.

As EVs and heat pumps are widely deployed, utilities will need to find a way for managing the growth in peak loads that will occur with 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.[32] 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.

FIGURE 9 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 when there is a surplus of solar energy.

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.

[32] "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.

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,[33] 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.
- 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 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+.[34]

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 time-varying rate. 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

[33] See, for example, William Hogan, https://scholar.harvard.edu/whogan/files/hogan_tou_rtp_newark_082314.pdf, Severin Borenstein, "The Long-run Efficiency of Real-Time Pricing." *The Energy Journal*, 26(3): 93-116 and Ahmad Faruqui, "The Ethics of Dynamic Pricing." *The Electricity Journal*, 23(6): 13-27.

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

The evolution of time-varying rates in the US has been very slow over the past four decades, as exciting as watching paint dry, to quote Fred Baird, an economist from New Zealand.

It has been slow for a number of reasons: lack of metering, consumer reluctance to try something new when it comes to electric rates, and a fear that higher peak prices will more than offset lower off-peak prices, resulting in higher bills. Long peak pricing periods that spanned most of the day time hours have also been a major barrier to customer adoption of time-varying rates.

For decades, consumers did not care much for notions such as allocative efficiency that have the status of an axiomatic truth among economists. They did not care much about rates being cost based, consistent with the principles put forward by Bonbright. They were apprehensive that their bills would rise if rates began to vary with time.

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 cautious about predictions by economists that time-varying rates would induce load shifting from peak to off-peak periods, and lower costs for all customers by reducing the need for new capacity additions.

Four decades ago, they 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 few customers bother to program them. Many appliances such as dishwashers have timers built into them. Customer apathy explains the indifference.

But what has really begun to move the needle is the arrival of electric vehicles (EVs). Consumers have begun asking for time-varying rates because they can reduce their cost of charging by more than half. Utilities are more than happy to offer time-varying rates 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 time-varying rates is the installation of rooftop solar panels (PVs) by customers.

The new generation of time-varying rates 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.

As a result, time-varying rates 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 time-varying rates the default option for their customers and one has made them mandatory.

REFERENCES

Allcott, Hunt. 2011. “Rethinking Real-Time Electricity Pricing.” *Resource and Energy Economics*, 33(4): 820-842.

Aubin, Christophe, Denis Fougère , Emmanuel Husson, and Marc Ivaldi. 1995. “Real-time pricing of electricity for residential customers: Econometric analysis of an experiment.” *Journal of Applied Econometrics* 10: S171–S191.

Borenstein, Severin, Michael Jaske, and Arthur Rosenfeld. 2002. “Dynamic pricing, advanced metering, and Demand Response in Electricity Markets.” In Energy series: A Joint Project of the Hewlett Foundation & the Energy Foundation, California Energy Commission & the UC Energy Institute, San Francisco.

Borenstein, Severin. 2005. "The Long-run Efficiency of Real-Time Pricing." *The Energy Journal*, 26(3): 93-116.

California Public Utilities Commission. 2022. "Advanced Strategies for Demand Flexibility Management and Customer DER Compensation." Energy Division White Paper and Staff Proposal.

Cabot, Clément. 2023. "Second-best electricity pricing (1.0)." *Zenodo*.

Caves, Douglas W., Laurits R. Christensen, and Joseph A. Herriges. 1984. "Consistency of Residential Customer Response in Time-of-Use Electricity Pricing Experiments." *Journal of Econometrics* 26(1–2): 179–203.

Chao, Hung-po. 1983. "Peak-Load Pricing and Capacity Planning with Demand and Supply Uncertainty." *Bell Journal of Economics* 14(1): 170-90.

Charles River Associates. 2005. "Impact Evaluation of the California Statewide Pricing Pilot."

Crew, Michael A. 1994. "Incentive Regulation for Public Utilities." *Springer*.

Crew, Michael A., Chitru S. Fernando and Paul R. Kleindorfer. 1995. "The Theory of Peak Load Pricing: A Survey." *Journal of Regulatory Economics,* 8: 215-248.

Faruqui, Ahmad, J. Robert Malko. 1983. "The Residential Demand for Electricity by Time-of-Use: A Survey of Twelve Experiments with Peak Load Pricing," *Energy* 8(10): 781–795.

Faruqui, Ahmad, Hung-po Chao, Vic Niemeyer, Jeremy Platt, and Karl Stahlkopf. 2001. "Analyzing California's Power Crisis." *Energy Journal* 22(4): 29–52.

Faruqui, Ahmad and Stephen S. George. 2003. "Demise of PSE's TOU program imparts lessons." *Electric Light & Power* 81(01): 14–15.

Faruqui, Ahmad and Stephen S. George. 2005. "Quantifying Customer Response to Dynamic Pricing." *The Electricity Journal*, 18(4): 53-63.

Faruqui, Ahmad and Sanem Sergici. 2009. "Household Response to Dynamic Pricing of Electricity – A Survey of 15 Experiments." *Journal of Regulatory Economics*, 38(2): 193-225.

Faruqui, Ahmad, Ryan Hledik, Sanem Sergici. 2009. "Piloting the Smart Grid." *The Electricity Journal*, 22(7): 55-69.

Faruqui, Ahmad. 2010. "The Ethics of Dynamic Pricing." *The Electricity Journal*, 23(6): 13-27.

Faruqui, Ahmad, Phil Hanser, Ryan Hledik and Jenny Palmer. 2010. "Assessing Ontario's Regulated Price Plan." prepared for the Ontario Energy Board.

Faruqui, Ahmad, Sanem Sergici, and Jennifer Palmer. 2010. "The Impact of Dynamic Pricing on Low Income Customers." The Institute for Electric Efficiency.

Faruqui, Ahmad and Sanem Sergici. 2011. "Dynamic Pricing of Electricity in the Mid-Atlantic Region: Econometric Results from the Baltimore Gas and Electric Company Experiment." *Journal of Regulatory Economics,* 40(1): 82-109.

Faruqui, Ahmad, Ryan Hledik, and Jennifer Palmer. 2012. "Time-Varying and Dynamic Rate Design," Global Power Best Practice Series, The Regulatory Assistance Project (RAP).

Faruqui, Ahmad, Sanem Sergici and Lamine Akaba. 2013. "Dynamic Pricing of Electricity for Residential Customers: The Evidence from Michigan." *Energy Efficiency*.

Faruqui, Ahmad, Sanem Sergici and Lamine Akaba. 2014. "Dynamic Pricing in a Moderate Climate: The Evidence from Connecticut," with Sanem Sergici and Lamine Akaba, *Energy Journal*, 35:1, pp. 137-160, January.

Ahmad Faruqui, Sanem Sergici, Neil Lessem, and Dean Mountain. 2015. "Impact Measurement of Tariff Changes when Experimentation is not an Option – A case study of Ontario, Canada," *Energy Economics*, 52, December, pp. 39-48.

Faruqui, Ahmad. 2016. "An Economist's Dilemma: To PV or Not to PV, That Is the Question," *Electricity Daily*.

Faruqui, Ahmad, Wade Davis, Josephine Duh, and Cody Warner. 2016. "Curating the Future of Rate Design for Residential Customers." *Electricity Daily*.

Faruqui, Ahmad, Sanem Sergici and Cody Warner. 2017, "Arcturus 2.0: A Meta-analysis of Time-varying Rates for Electricity." *The Electricity Journal*, Volume 30, Issue 10.

Faruqui, Ahmad, Neil Lessem, Sanem Sergici, and Dean Mountain. 2017. "The Impact of Time-of-Use Rates in Ontario,", *Public Utilities Fortnightly*, February.

Faruqui, Ahmad. 2022. "Ten Lesson in Rate Design: A Meditation," *The Electricity Journal*, Volume 35, Issue 10, December.

Faruqui, Ahmad, Sanem Sergici and Ziyi Tang. 2023. "Do Customers Respond to Time-Varying Rates: A Preview of Arcturus 3.0." The Brattle Group.

Fowlie, Meredith Fowlie, Catherine Wolfram, Patrick Baylis, C Anna Spurlock, Annika Todd-Blick, and Peter Cappers. 2021. "Default Effects and Follow-On Behaviour: Evidence from An Electricity Pricing Program." *The Review of Economic Studies*, Volume 88, Issue 6.

Gellings, Clark W. and John H. Chamberlin, *Demand-Side Management: Concepts and Methods*, Fairmont Press, 2nd edition, 1993.

George, Stephen S., and Eric Bell. 2018. "Key findings from California's Recent Statewide TOU Pricing Pilots." *The Electricity Journal* 31(8) 52-56.

Herter, Karen. 2007. "Residential Implementation of Critical-peak Pricing of Electricity." *Energy Policy*, 35(4): 2121-2130.

Herter, Karen, Patrick McAuliffe and Arthur Rosenfeld. 2007. "An Exploratory Analysis of California Residential Customer Response to Critical Peak Pricing of Electricity." *Energy*, 32(1): 25-34.

Hogan, William W. 2014. "Time-of-Use Rates and Real-Time Prices," unpublished paper, Harvard University, August 23.

Houthakker, H. S. 1951. "Electricity Tariffs in Theory and Practice," *The Economic Journal*, Volume 61, 1 March, pages 1-25.

Joskow, P. L. and C. D. Wolfram. 2012. "Dynamic Pricing of Electricity." *American Economic Review*.

Kahn, A.E. 1970. *The Economics of Regulation: Principles and Institutions.* John Wiley & Sons, Inc.: New York.

Lazar, Jim, and Wilson Gonzalez. 2015. *Smart Rate Design for a Smart Future.* Regulatory Assistance Project.

Lesgards, Valerie et Edouard Rossat. 2022. « Où est passée la 5ème énergie ? L'impératif du signal de la rareté » ; La revue de l'énergie N° 665 Nov-dec 2022.

Littlechild, Stephen. 1975. "Two-Part Tariffs and Consumption Externalities." *The Bell Journal of Economics* 6(2):661-670.

Littlechild, Stephen. 2003. "Wholesale Spot Price Pass-Through." *Journal of Regulatory Economics*, 23(1): 61-91.

Newsham, Guy R. and Brent G. Bowker. 2010. "The Effect of Utility Time-varying Pricing and Load Control Strategies on Residential Summer Peak Electricity Use: A review." *Energy Policy*, 38(7): 3289–96.

Parmesano, Hethie S. and Catherine S. Martin, "The Evolution in U.S. Electric Utility Rate Design," *Annual Review of Energy*, 1983, 8:45-94.

Rowlands, Ian H. and Ian M. Furst. 2011. "The Cost Impacts of a Mandatory Move to Time-of-use Pricing on Residential Customers: an Ontario (Canada) Case-study," *Energy Efficiency*, 4(4): 571-85.

Schweppe, Fred. 1978. "Power System '2000': Hierarchical control strategies," *IEEE Spectrum*, November 1978.

Schittekatte, Tim, Dharik Mallapragada, Paul L. Joskow, and Richard Schmalensee, "Electricity Retail Rate Design in a Decarbonizing Economy: An Analysis of Time-of-Use and Critical Peak Pricing," MIT CEEPR Working Paper Series, October 2022. Forthcoming, *Energy Journal*, https://www.iaee.org/energyjournal/article/4151.

Turvey, Ralph. 1969. "Marginal Cost." *The Economic Journal*, Volume 79, Issue 314, 1 June 1969, Pages 282–299.

Turvey, Ralph (editor). 1971. *Public Enterprise*, Penguin Modern Economics Readings.

Uhler, Robert G. "Should Utility Rates be Redesigned," *EPRI Journal*, March 1976, 12-17.

Vickrey, W. S. 1971. "Responsive Pricing of Public Utility Services," *Bell Journal of Economics*, 2(1): 337-46.

Westfield, F M. 1980. "Electric Utility Rate Design Study: Economic Theory of Marginal-cost Pricing and its Application by Electric Utilities in France and Great Britain."

Wolak, Frank A. 2011. "Do Residential Customers Respond to Hourly Prices: Evidence from a Dynamic Pricing Experiment." *American Economic Review: Papers and Proceedings*, http://www.stanford.edu/group/fwolak/cgibin/sites/default/files/files/hourly_pricing_aer_ paper.pdf.

Wolak, Frank A. 2007. Residential Customer Response to Real-time Pricing: The Anaheim Critical Peak Pricing Experiment. Unpublished paper, UC Berkeley.

Wood, Lisa and Ahmad Faruqui. 2010. "Dynamic Pricing and Low-Income Customers," *Public Utilities Fortnightly*, November 2010: 60–64.