PNNL-33384

Understanding the Behavioral Aspects of Rate Design

September 2022

Daniel Boff
Sumitrra Ganguli
Abhishek Somani

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes **any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights**. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <https://www.ntis.gov/about>
Online ordering: http://www.ntis.gov

PNNL-33384

Understanding the Behavioral Aspects of Rate Design

September 2022

Daniel Boff
Sumitrra Ganguli
Abhishek Somani

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99354

Abstract

Consumer demand for electricity has often been thought of as homogenous and inelastic. However, consumers may have preferences for their electricity consumption that they have been unable to realize due to the structures of electricity rates, limited access to distributed energy resources, and historic methods of regulation. As ratemaking becomes more dynamic, consumers will have a newfound ability to realize these preferences. This paper conducts a review of this issue through the lenses of utility regulation, neoclassical economics, and behavioral economics. It surveys what aspects of consumer preferences and behavior have been well established for the electricity sector and identifies gaps that could be filled by future research. This analysis has implications for stakeholders looking to understand how households will function in transactive and real-time pricing environments.

Acronyms and Abbreviations

C&I	Commercial and Industrial
DERs	Distributed Energy Resources
EIA	Energy Information Administration
IOU	Investor Owned Utility
OECD	Organization for Economic Cooperation
RTP	Real Time Pricing
TE	Transactive Energy
TOU	Time of Use
WTA	Willingness to Accept
WTP	Willingness to Pay

Contents

Figures

Tables

1.0 Introduction

Electricity sector ratemaking has historically been focused recovering the costs associated with maintaining a reliable system. Regulators focused on maintaining system operations and allocated the costs of doing so to rate classes based on their overall share of consumption (Lazar, Chernick, et al. 2020). Consumer demand was thought to be inelastic, and regard for preferences in the rate making process were few and far between (Farugui 2020). Residential customers primarily had flat bipartite rates, with demand growing in line with incomes and GDP (Faruqi, Hledik and Sergici 2019, EIA 2017). However, this paradigm has been changing rapidly. Distributed energy resources (DERs) like solar PV, and electric vehicles are giving households more flexibility over their electricity consumption patterns and hence their preferences, and also allow them to operate as prosumers (i.e., both buyers and sellers of electricity). Figure 1 shows how DERs are expected to grow over the next few years, as these technologies become more mainstream. Increased customer knowledge about rate structures and rate options, coupled with the increasing role of DERs and smart technologies, will create more options for prosumers to participate in the market by altering their consumption patterns. As this phenomenon takes effect, the role of preferences in the rate making process will need to assume a more central role.

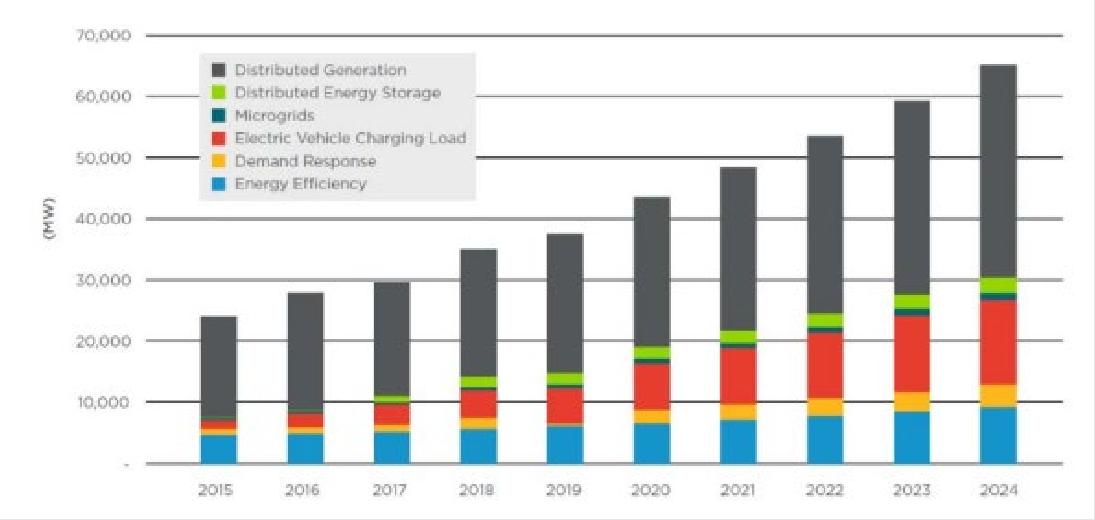


Figure 1: Forecast of DER deployment (Navigent 2016)

In parallel, ratemakers themselves have changed their thinking around rate structures. Instead of just a cost sharing mechanism, rates are increasingly being construed as a mechanism to influence behavior. These rates can promote consumption at times when renewable energy production is plentiful and discourage it during times of scarcity. So, while increasing block rates incentivize energy conservation, time of use (TOU) and real time pricing (RTP) encourage the intraday shift in consumption patterns, while reflecting cost causation. Though only a small number of customers are on time varying rates, interest is growing rapidly with half of all investor-owned utilities (IOU) offering a TOU option (Faruqi, Hledik and Sergici 2019). Some utilities are even looking to more advance rate structures and transactive energy programs, which will provide consumers with even more dynamic rate structures (Boff, Somani and Wildergren 2022).

Transactive energy (TE) is a relatively novel mechanism for coordinating the electricity system. It uses price and quantity signals, alongside a high level of interoperability to dispatch resources and guide consumption based on value (Gridwise AC 2020). In a transactive system, households and even individual devices can issue buy and sell signals based on preferences and system constraints, which can lead to more efficient and nimble operations (Reeve, et al. 2022). It also offers consumers an enormous opportunity to exercise their preferences. Prosumers can bid on electricity supply and demand, based not only on comfort, convenience, and price, but potentially based on factors like reliability, sustainability, and proximity.

These emerging trends (some involving the consumer and others, the ratemaker), will create new challenges and opportunities for the electricity sector. While DERs present consumers with greater control and more opportunities to act in accordance with their preferences for features like clean energy, reliability, risk, self-consumption, and equity, rate structures have not yet evolved to capture these aspects of human behavior. Understanding these gaps will help regulators predict how customers will act to satisfy their preferences, and where necessary correct this behavior to promote systemwide goals.

This paper provides a review of consumer preferences in rate making, and summarizes work that has been done to measure, manage, or otherwise understand the role that human behavior plays in the operation of the electricity system. It begins in Section 2.0 with a historical overview of rate design and describes best practices that have emerged in response to DERs and the growth of renewable energy. Section 3.0 focuses on behavioral economics and the ways that social norms and nudge theory have been used to improve consumer responsiveness to policy goals. Section 4 explores an emerging issue with households that both produce and consume electricity: the willingness to pay (WTP) willingness to accept (WTA) gap. Section 5 discusses how consumer preferences can impact equity. Section 6 concludes with an analysis of findings and gaps in the literature. Here we find that researchers have focused considerably on examining issues like the WTP and WTA for features within the electricity system, the effectiveness of different behavioral interventions, and potential distribution effects from dynamic rates. However, insights into the heterogeneity of preferences, as well as empirical analysis of more dynamic rates were less common. These gaps could be filled through future research.

2.0 Rate design traditional and emerging practices

2.1 Traditional best practices for rate design

The first guidelines for rate design were outlined by Bonbright in 1961 and were supplemented by Garfield & Lovejoy in 1964. These works detailed the manner in which utilities should be compensated, and fair mechanisms for recovering these costs from consumers. Bonbright, in particular outlined eight principles, which formed the cornerstone of the rate making process. They are:

- The related, practical attributes of simplicity, understandability, public acceptability, and feasibility of application.
- Freedom from controversies as to proper interpretation.
- Effectiveness in yielding total revenue requirements under the fair-return standard.
- Revenue stability from year to year.
- Stability of the rates themselves, with a minimum of unexpected changes seriously adverse to existing customers.
- Fairness of the specific rates in the apportionment of total costs of service among the different consumers.
- Avoidance of undue discrimination in rate relationships.
- Efficiency of the rate classes and rate blocks in discouraging wasteful use of service while promoting all justified types and amounts of use: (a) in the control of the total amounts of service supplied by the company; and (b) in the control of the relative uses of alternative types of service (Bonbright 1961).

These principles focused broadly on stability, simplicity, and consistency, while limiting opportunities for cross subsidization. This led the near ubiquity of the flat bipartite rate structure, with customer specific costs being recovered through a flat monthly charge, and systemic costs being recovered through a flat volumetric charge on consumption. Though potentially well suited to a traditional electricity system, with large vertically integrated utilities, issues with flat volumetric rates became clear first as the electricity system undertook a restructuring in the 1990s, and then as renewables became a notable component of the power system in the late 2000s.

2.2 Emerging rate structures

There is an increasing consensus that flat volumetric rates are becoming antiquated in a world where households have access to technologies that can effectively manage their load, generate, or store electricity. Many have found that flat tariffs fail at both accurately reflecting system costs and incentivizing customers to use these technologies in a way that benefits the system (Sherwood, et al. 2016). Despite an evolving electricity system, regulators have broadly adhered to Bonbright's principles when changing or updating rate structures. However, at times they have placed different weights on specific objectives. For example, increasing block prices were introduced to help promote energy conservation, and to incentivize investment in energy efficient technologies (Faruqui 2021).

A desire to limit potential cross subsidization and promote more efficient utilization of DERs led the Rocky Mountain Institute and the New York Department of Public Service to develop new guidelines for ratemakers. While some of these points align broadly with Bonbright, they put a greater emphasis on the demand-side and acknowledge that rates should align with the overall preferences of consumers and can be used both to support policy goals. The revised principles are:

- Ensure cost recovery: Utility should be able to continue providing reliable service with a low cost of capital to ensure economic efficiency.
- Capture cost causation: Accurately incorporate the impact of customers' use on system cost of service and consider both embedded costs and long-run marginal and future costs.
- Decision-making: Should be well informed and economically efficient.
- Support for desired outcomes: Account for energy efficiency, peak load reduction, improved grid resilience and flexibility, and reduced environmental impacts – in a technology neutral manner.
- Transparency: Any incentives or subsidies need to be explicit, transparent, and in support of policy goals.
- Fair value of services: Applicable both to services provided by the grid and to services from customers.
- Customer-orientation: Customer experience needs to be practical, simple, and understandable.
- Stability: Customers' bills should be predictable, even if the underlying rates use some form of dynamic price signals.
- Access: Vulnerable customers should have access to affordable electricity.
- Gradualism: Changes to rate design should not cause large, abrupt increases in bills (Sherwood, et al. 2016).

These new principles guided regulators away from flat volumetric pricing to more dynamic approaches. Two newer pricing mechanisms: time of use and real time pricing have emerged that are better aligned with the goals of cost causation and can be used to help utilities meet policy goals. However, these rate structures are considerably more complex than flat pricing and can cause regulators and utilities to be hesitant to transition to these structures.

2.2.1 Best practices for time of use pricing

Numerous pilots, along with a handful of mandatory programs in California and the Mid-Atlantic have led to the creation of a handful of best practices for these rate structures. They also draw broadly from the principles listed above with regards to fairness, stability, and access. In general TOU rates have been found to be transparent and easy to understand, with customer surveys consistently showing that households are able to comprehend and effectively respond to TOU pricing (Hledik, Faruqui and Warner 2017). Despite this, only a fraction of residential customers are on a TOU rate.

Analysts generally recommend restricting the number of time blocks to two or three (e.g. on-peak, off-peak, mid-peak) in order to limit the cognitive burden on households (Lazar and Gonzalez 2015). Needlessly complex rates may limit customer responsiveness and violate the customer orientation principle. Blocks themselves should have a fairly steep price differential, with on-peak prices that are roughly double off-peak prices being common (Hledik, Faruqui and Warner 2017). However, these tiers should also be structured with cost causation in mind, and result in limited net bill impacts to customers, so as not to violate basic rate making principles. Time blocks should similarly be structured to revolve around peak demand, with 3-8 hour peak blocks being commonplace (Hledik, Faruqui and Warner 2017). Such rates have been effective in reducing customer peak demand by up to 15%, creating substantial savings for the electricity system (Sergici, et al. 2020).

Consumer preferences, behavior, and TOU pricing

Though utilities and ratemakers have been focused on ensuring effectiveness and fairness for TOU rates (Faruqi, Hledik and Sergici 2019), research has also occurred on behavior and consumer preferences. For example, an analysis of responsiveness to TOU programs found that only half of the behavior change (i.e., shifting from on-peak to off-peak) is attributable to prices (Faruqui and Palmer 2012). That is, a change in rate structure can result in a behavior change that is greater (or less) than what the price alone would imply. The idea that TOU rates could result in savings in excess of their price impact is a powerful motivator for the rate structure, but it also shows that noneconomic factors may be at play. This could be the result of framing techniques used by the utility, smart devices and automation, or preferences for clean energy (if, for example, the utility told participants that the shift to TOU rates would allow them to use more renewable power).

Consumer behavior also influences overall participation in utility programs, not just responsiveness. Utilities will therefore have to convince customers to engage with these new rate structures before influencing consumption patterns. In particular, many utilities allow customers to choose whether to participate in a TOU program (i.e., opt-in), rather than transition all customers to the tariff, while allowing households to retain their old rate if desired (i.e. opt-out). Discrepancies in the outcomes of opt-in versus opt-out choices, are a classic example of default bias, where individuals are more likely to accept the status quo option over a change (Schneider and Sunstein 2017). Nudge theory (described in greater detail in Section 3.1) in particular argues for a shift to opt-out structures to overcome default bias (Thaler and Sunstein 2008). Empirical data supports this, with meta-analysis finding that about 20% of customers will opt-in to a TOU rate, but only 2% will opt-out (Cappers, et al. 2016).

2.2.2 Best practices for real time and transactive pricing

While TOU rates are becoming well established in the electricity industry, RTP and transactive energy systems (which use dynamic prices at the retail and distribution level) have seen less acceptance. This is largely due to the fact that these systems are more challenging to implement than TOU or flat pricing schemes, and because they expose the consumer to greater levels of risk (Figure 2). TOU pricing presents a moderate risk to customers, while RTP is more extreme. This is perhaps best illustrated by customers on RTP tariffs during the Texas blackouts of 2021, many of whom faced bills of nearly $9,000 due to wholesale price spikes (Ivanova 2021).[1] As a result some analysts generally recommend that RTP be optional or reserved for large commercial and industrial customers, who are more sophisticated, and potentially have better energy management systems (Lazar and Gonzalez, Smart Rate Design for a Smart Future 2015). Better risk management and consumer guardrails (e.g. price caps) will be necessary for residential customers.

Transactive energy is an even newer and more dynamic form of RTP, where agents are able to bid their supply and demand and settle in real time (typically in a forward market). Active programs that incorporate TE are rare, and typically focused on larger commercial and industrial (C&I) customers; however, many pilots and demonstrations have incorporated residential customers (Boff, Somani and Wildergren 2022). More experience and greater acceptance from regulators will be needed to develop best practices for rate designs that feature transactive elements.

---

[1] Regulators later forgave these bills and will recover these costs through the broader ratebase.

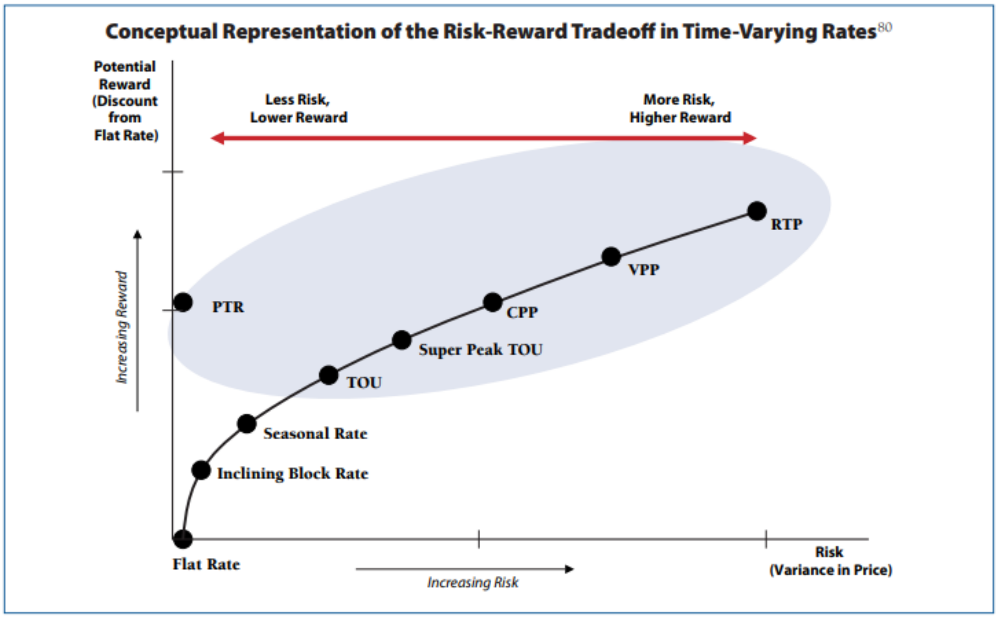


Figure 2: Risk profiles of electricity rates (Faruqui 2021).

Consumer preferences, behavior, and real time pricing

In addition to default bias, which will occur anytime consumers are offered a choice between rate structures, researchers caution that high information costs and other heuristics can skew consumer behavior under real-time pricing schemes (Schneider and Sunstein 2017). Households are unaccustomed to paying attention to their consumption on an hourly basis and may be more likely to tie their demand to a general time of day (where prices are usually high), rather than the price itself. This makes the efficiency gains from moving from TOU to RTP, smaller than what would be produced under an optimal consumption path. RTP may also violate the ratemaking principles related to stability and customer-orientation. As a result, Schneider and Sunstein recommend tying automated devices to a real-time (or potentially transactive) rate, while leaving non-automated loads on a TOU rate.

3.0 Behavioral economics

Behavioral economics represents a fusion of consumer psychology and traditional economics. While neoclassical economics is often described as identifying how consumers behave (i.e., when making rational choices based on well-defined preferences and well-informed self-interested decisions), behavioral. Behavioral economics attempts to show how consumers actually behave when making economic decisions and describe these deviations and biases from rational behavior (Witynski n.d.). Behavioral economics relies more heavily on experiments than neo-classical economics.

Interventions are frequently used in the electricity sector to achieve personal or system-wide goals such as bill savings and program participation. Interventions typically use nonmonetary approaches to promote a behavior change that influences a consumer's consumption patterns. Two applications of behavioral economics are used frequently in the electricity sector: social norms and nudge theory. Both have a proven track record for changing household's behavior. These interventions are best when used in conjunction with (rather than in place of) traditional economic incentives to influence consumer decision making.

3.1 Nudge theory

3.1.1 Underlying academic foundation

Nudge theory, also called libertarian paternalism, seeks to alter behavior without bans or regulations and has two primary components (Thaler and Sunstein 2003). First, nudges are liberty-preserving, i.e., the agent must retain control and have the ability to diverge from the intervention seamlessly. Second, the intervention must target individual welfare, i.e., the intervention must make the agent better off by their own definition. Nudges are typically targeted towards internalities (i.e., a negative consequences to the individual that are not considered when making a decision such as eating a sugary diet that damages their health over time). This is opposed to externalities (goods or services that have an unpriced cost to society; for example untaxed or unregulated pollution).[1]

The mechanism through which the nudge takes shape is called the choice architecture. Thaler and Sunstein define the choice architecture as any environment where people make decisions. They encourage choice architects (i.e., anyone who constructs this environment) to consider how this environment may influence users towards one outcome or another (Thaler and Sunstein 2008). The architect may then alter the choice architecture slightly to coerce (i.e., nudge) the users to a more desired outcome. Perhaps the most famous application of nudge theory has to do with retirement savings. Historically, employers have matched a set percentage of employee contributions to their 401k accounts (e.g., 5%). Despite the fact that most employees felt that their saving rate was too low, many participants only contributed the amount required to receive the employer matching contribution, but no more. Altering the employer benefit to match 50% of contributions up to 10%, rather than 100% up to 5% encourages employees to save more of their income for retirement, while allowing them to choose other savings options if they desire (Benartzi and Thaler 2007).

---

[1] Though many interventions that are targeted towards externalities are referred to as nudges colloquially, most behavioral economists would label these techniques as behavioral regulations (Oliver 2015).

Though nudges are used widely in public policy, the theory is not without criticism. Some disagree on ethical grounds. Opponents of paternalism, in general, are often critical of libertarian paternalism. Others criticize their effectiveness. Nudges often result in marginal changes and are preferred by some policymakers because they are cheap to implement (Oliver 2015). Meta-analysis has reported mixed results for nudges overall with some finding strong effects (Mertens, et al. 2021), but others finding limited impact (Szaszi, et al. 2022). Critics also argue that more expansive policies (i.e., bans and regulation) are needed to create changes on a more meaningful scale.

3.1.2 Applications to the electricity sector

Perhaps the most important lesson from nudge theory is that the design of the choice architecture has a tremendous impact on outcomes.[1] Utilities provide numerous choice environments for consumers, which should be carefully considered (e.g. bills and payment portals, customer messaging, marketing, and behavior around devices). Existing architectures may be nudging households towards an undesired outcome (as they do when allowing customers to opt-in, rather than opt-out to a new rate structure) and should be corrected to ensure that they are not unknowingly influencing consumer behavior.

Nudges are often used to shift behavior in the electricity sector. Consumers make numerous choices (knowingly or unknowingly) about their energy consumption, and these choices can be influenced by modifying the choice architecture. The aforementioned opt-in vs opt-out mechanism for rate selection (the “default option” in nudge theory based interventions) is one of the most powerful opportunities for using nudges in the electricity industry. Feedback or priming is another form of nudging that has been successful in reducing consumption by at least a few percentage points (Schleich, et al. 2013). Numerous studies have been conducted with the goal of identifying optimal feedback and delivery mechanisms (Kua and Wong 2012). Other studies have examined the durability and longevity of effects (Ma, Lin and Li 2018), and the impacts on different demographic groups (Taylor, Jones and Kipp 2014). The effectiveness of these feedback mechanisms varies based on the goal, targeted population, and the mechanism itself.

3.2 Social norms

3.2.1 Underlying academic foundation

Social norms (sometimes referred to as social preferences) explore how individuals are influenced by their relation to others. How one views their place in society, and how they would like others to view them, influences how they behave and consume. Expectations, approval, and image all influence purchases alongside price. Interventions that successfully appeal to social norms often show that an individual’s behavior is out of line with their peers.[2] For example, a hotel may place a notecard in their rooms reminding customers that most of their guests reuse their towels. Many customers then reuse their towels, as an expectation has been set, and deviating from it would put them out of line with their peers (Goldstein, Cialdini and Griskevicius

---

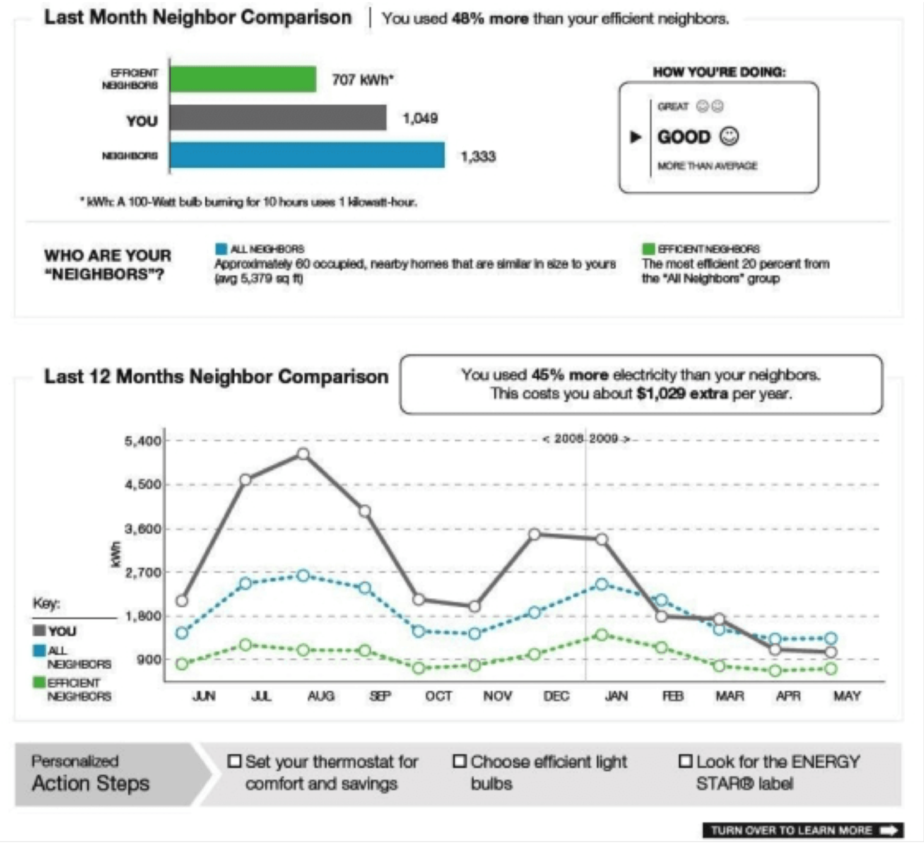
[1] The choice architecture’s ability to influence outcomes has been evaluated in other areas including health insurance (Barnes, et al. 2019), retirement savings (Benartzi and Thaler 2007), and nutrition (Rantala, et al. 2021).

[2] Social norms can be thought of as a nudging tactic, as they often use a modification of the choice architecture. However, they need not be liberty preserving (though they typically are), and unlike nudges are used to target both externalities and internalities.

2008). Techniques like these are often used to promote conservation or demand shifting in the electricity sector.

3.2.2 Applications to the electricity sector

Social norms are one of the most established and widely used behavioral interventions in the utility sector and have been in widespread use for over a decade. Alcott (2011) was the first to measure the impact of such programs and found that gross consumption could be reduced by over 6% in aggregate, though the effects were heterogeneous. The particular program that Alcott examined was Opower's home energy report (Figure 3), which is included as an insert to a customer's utility bill. The report uses a number of behavioral prompts, but the cornerstone is the last month's comparison section, where a household's consumption is compared to their "efficient neighbors." The comparison with efficient neighbors (i.e., an appeal to social norms), is one of the key innovations of the program, and has produced more impactful results than other efficiency programs (Allcott 2011). Opower and competitors, like Ohm Connect, also provide behaviorally motivated interventions that support utility goals like load shifting and EV adoption using similar socially motivated prompts.



Last Month Neighbor Comparison | You used **48% more** than your efficient neighbors.

* kWh: A 100-Watt bulb burning for 10 hours uses 1 kilowatt-hour.

WHO ARE YOUR "NEIGHBORS"?

🟦 ALL NEIGHBORS
Approximately 60 occupied, nearby homes that are similar in size to yours (avg 5,379 sq ft)

🟩 EFFICIENT NEIGHBORS
The most efficient 20 percent from the "All Neighbors" group

Last 12 Months Neighbor Comparison

You used **45% more** electricity than your neighbors.
This costs you about **$1,029 extra** per year.

Personalized Action Steps

☐ Set your thermostat for comfort and savings

☐ Choose efficient light bulbs

☐ Look for the ENERGY STAR® label

TURN OVER TO LEARN MORE

Figure 3. Opower example bill (Opower 2020)

4.0 Willingness to Pay/Willingness to Accept

4.1 Underlying academic foundation

While the features discussed so far have focused on how system operators can influence the behavior of households, these options do not necessarily represent consumers' own preferences. A household or individual may have their own preferences for the characteristics of their electricity mix and consumption patterns, which could diverge from system goals. Understanding these preferences will be increasingly critical as the grid becomes more transactive and decentralized since consumers will have more opportunities to realize these preferences than they would under a traditional flat rate structure.

Economists measure these preferences with metrics like willingness to pay (WTP) and willingness to accept (WTA). Willingness to pay is relevant for buyers and is the maximum price a customer is willing to pay for a service. Willingness to accept is relevant to sellers and represents a minimum price that a customer would take to provide a good or service. These metrics are also used to value externalities, and many economists have worked to estimate consumer WTP to avoid environmental degradation (Arrow, et al. 1993).

Within the electricity sector, WTP and WTA becomes especially relevant when households begin to both consume and generate power1. Households with technologies like distributed solar PV, or load control devices (for the purposes of demand response) effectively act as sellers of services, rather than consumers, and utilities and regulators will need to understand household WTA in order to provide these services. In traditional welfare economics WTA is thought to be equivalent to a goods marginal cost of production (inclusive of opportunity costs) in a well-functioning market. For large-scale generators and sophisticated commercial and industrial customers, this is likely to be the case, but behavioral factors are likely to alter WTA for residential households. Additionally, WTA and WTP for electricity system features (like reliability, clean or renewable power, or local generation) may be heterogeneous and lead to a misallocation of resources. Ganguli, Boff and Somani (2022) explore these issues and find that while well understood in economics, generally, they have been under explored within the electricity sector.

4.2 Methodologies

For market goods, price and price elasticities are typically used to understand WTP and WTA. However, valuing non-market goods is less straightforward. Economists use two broad methodologies to measure WTP and WTA when well-functioning markets for the good or service at hand do not exist: revealed and stated preference techniques. Revealed preferences attempt to estimate WTP and WTA using existing market data. Stated preference techniques use tools like surveys to elicit WTP and WTA.

The most common form of revealed preference techniques is called hedonic price analysis.2 Hedonic analysis is based on the idea that some goods are effectively a bundle of different features (Chau and Chin 2002). For an example, the value of a house may be driven by its square footage, number of bedrooms, location, and school district. By comparing a large

---

[1] It is important to note that WTA has multiple definitions.

[2] Another method called travel costs is used to measure WTA for environmental features through their recreational value but is less relevant to the analysis of the electricity sector.

number of houses, one could tease out the WTP for one of these individual features. Though often used in environmental valuation, our review of literature found it to be less common in analysis of the electricity sector. The technique also has several drawbacks, as it relies on the assumptions of perfect completion and information and can only be used when buyers can enter and exit the market freely (Chau and Chin 2002).[1]

Stated preference techniques use highly structured surveys to estimate WTP and WTA. These techniques are widely used by economists in analysis of the electricity sector. Two main forms of stated preference techniques exist. The first is contingent valuation, which at its most basic level asks a large group of people their WTP or WTA (with appropriate context) and compiles the results using regression analysis. Choice experiments (which are the current best practice) provide respondents with a series of discrete options and ask them to choose their preferred one.[2] WTA or WTP are estimated based on from the selections made (OECD 2018).

Though powerful, stated preference techniques are sensitive to both study design and the population in question (i.e. WTP and WTA may vary across regions and nations). Fortunately, the technique's long history has led to a comprehensive list of best practices to which users should adhere. Johnston et al. (2017) provide a comprehensive list of recommendations regarding survey and experimental design, sampling, value elicitation methods, and validation. In terms of WTP and WTA, specifically Horowitz and McConnell (2002) provide guidance on the use of metrics, and Kahneman, Knetsch, and Thaler (1991) illustrate how WTP and WTA compare across certain goods.

4.3 The endowment effect and the WTP/WTA gap

In many cases, an individual or household may act as both a buyer and seller. For example, a home with rooftop solar PV panels may both buy electricity from the utility and sell back the output of the system. While most traditional economists (and transactive energy systems) assume a seller's supply curve is closely tied to marginal costs, behavioral economists have found that other factors influence an individual's WTA. In particular, human beings feel losses more deeply than gains, and, as a result will often require a higher price to sell an item that they own, than they would pay to obtain an identical item. This phenomenon is often called the endowment effect and can be theorized as a gap between WTP and WTA (Kahneman, Knetsch and Thaler 1991). Using the previous example, a household operating with an endowment effect would require payment in excess of their WTP to sell back their solar generation, and generally choose to keep the generation onsite, unless offered a high price.

Debate about the magnitude of the endowment effect has occurred since it was first identified, with some claiming that the phenomenon is the result of measurement error (e.g. Plott and Zeiler 2005). However, most claim that while the estimated gap can be reduced through better experimental design, it typically cannot be eliminated (Horowitz and McConnell 2002). Best practices for designing surveys to ensure that the endowment effect is accurately measured are provided in Frondel, Sommer, and Tomber (2019) and Haab and McConnell (1997). Despite measurement in other areas (e.g. Horowitz and McConnell 2002), the WTP-WTA gap has not

---

[1] Perfect competition refers to an idealized market structure where all firms are price takers (i.e. marginal costs are equal to marginal revenue, which in turn equals price), can enter and exit the market without barriers, and face no transaction costs. A market with perfect competition is by Pareto Efficient. Perfect information (itself a requirement of perfect competition) means that buyers and sellers both have identical and complete knowledge of the good in question.

[2] For more information on choice experiments see Champ, et al. (2003) or OECD (2018)

been well examined for the electricity sector (Ganguli, Boff and Somani 2022). A greater understanding of this phenomenon will be essential for system operators seeking to move to more dynamic rate structures.

4.4 Studies in practice: willingness to pay for electricity characteristics

As mentioned in Section 104.1, consumers may be willing to pay for certain electricity system features. Using the methodologies described in Section 4.2. researchers have worked to measure many of these features and have found that consumers are willing to pay for renewables, reliability, equity, and proximity. Table 1 summarizes some of these findings. Notably, WTP can vary significantly by location, time, and demography, so the sample that each study draws from is critical.

Table 1. Studies examining WTP for electricity system features.

Location	Metric	WTP	Study
USA	WTP for renewable power	WTP $5-15/month	(Farhar 1999)
USA	WTP for renewable power (national clean energy standard)	WTP $13.50/month for an 80% clean energy standard	(Kotchen and Leiserowitz 2012)
Austria	WTP for reliability	WTP €0.171 per kWh of electricity not supplied	(Reich, Schmidthaler and Schneider 2013)
South Korea	WTP to avoid a rolling blackout	WTP $2.83-3.56/month	(Kim, Nam and Cho 2015)
Germany	WTP for local and renewable power	WTP €1.24/month for power from a local cooperative WTP €2.70-3.55/month for renewables	(Kalkbrenner, Yonezawa and Roosen 2017)
Spain (Canary Islands)	WTP for reliability and renewables	WTP €1.99/ month to reduce power outages by a single outage m WTP €0.2-0.59/month for renewables Results vary by income and education	(Amador, González and Ramos-Real 2013)
Sweden	WTP for reliability	WTP 3-350 kroner to avoid an outage depending on the length	(Carlsson, Martinsson and Akay 2011)

		of outage and whether it is planned or unplanned	
Cypress	WTP for reliability	WTP TL 29.78 per month to reduce outages	(Ozbafli and Jenkins 2015)

4.5 Studies in practice: willingness to accept demand-side management

As they have for WTP, many economists have tried to elicit WTA in cases where households act as a seller. This can include the selling of onsite generation, and the provision of services like demand response. However, these studies are far less common than WTP analyses. In general, these studies (summarized in Table 2) find that WTA prices are higher than WTP prices and lend support to the existence of a WTP/WTA gap.

Table 2. Studies examining WTP for electricity system features.

Location	Metric	WTP	Study
Sweden	WTA demand response	WTA 833-3000 kroner/year	(Broberg and Persson 2016)
Ireland	WTA demand response	WTA €4-40/month, depending on appliance	(Curtis, et al. 2020)

5.0 Impacts to equity

5.1 Overview of equity issues in electricity sector

In 2015, 25 million households in the US had to forgo food or medicine in order to pay energy bills, and one in three households experienced energy poverty (EIA 2018). These issues also influence preferences and behavior. For example, low-income households often sacrifice comfort for savings (Cong, et al. 2022). While this is a rational response to a budget constraint, it has important ethical and policy ramifications that can be addressed through rate design. Borenstein (2007) finds that flat usage rates result in substantial wealth transfers between customers that can be corrected through dynamic rates (2007).Equity issues also impact system-wide cost and efficiency. Lower income households are also likely to have difficulty affording energy efficiency technologies that could both improve comfort and lower costs.

As explained in section 2.0, issues of fairness and equity are often prominent to ratemakers. Regulators often focus on two separate issues when considering equity in rate design. First, is the issue of fairness or the idea that is that underrepresented or disadvantaged individuals should not have to dedicate an undue share of their income towards their electricity bills. Second, is the premise of cost causation – the idea that the customer's bill is reflective of their costs to the system. By extension this means that no customer cross-subsidizes another. Navigating this tension is a critical but less than straightforward task for ratemakers.

5.2 Implications for equity in rate design

Both of these forms of equity impacts have important lessons for rate design. For example, real time pricing (and transactive energy by extension) can lessen instances of cross-subsidization, and result in system cost savings. However, in an analysis of RTP in New York, Horowitz and Lave (2014) found that a large scale rollout of RTP would result in 50% of customers losing money in the short run, with smaller consumers of energy (who are more likely to be low income) facing higher bills while larger consumers were more likely to see savings. This also suggests that large customers are cross-subsidizing smaller ones. However, since RTP results in system-wide savings, this surplus could be reallocated to low-income customers. Policymakers could factor transfers like these when analyzing the impacts of dynamic prices. Increasing block prices, on the other hand, can more easily be designed to limit impacts to low-income customers (Schoengold and Zilberman 2014, Borenstein 2008).

Transactive and RTP schemes also require energy efficient and smart technologies in order to respond to price signals effectively. These systems require upfront investment, which may be less accessible to low-income customers. A greater emphasis on outreach, education, and investment in low-income communities has the potential of improving equity in transactive energy programs (Tarufelli and Bender 2022). Further, grid hosting capacity may also limit access to advanced energy technologies (e.g. solar PV, electric vehicles). In California, low-income and minority communities are generally located in areas with less available capacity, a potential limit to new technologies and thus equitable participation (Brockway, Conde and Callaway 2021).

While these are barriers, many of these issues can be corrected with policy instruments. Well-designed metrics will be increasingly necessary to understand whether the impacts of energy programs are equitable and should be a priority for policymakers (Tarekegne, et al. 2021). Many utilities already offer reduced rates for low-income customers, and such programs could be reconfigured for dynamic pricing. Government investments could be targeted to provide greater access to smart energy technologies for low-income communities (as an example, Connecticut Green Bank 2021). Analysis of behavior will also be critical in understanding if disavantaged households are sacrifing comfort for savings to too great a degree, and regulators can design programs with comfort and savings in mind.

5.3 Willingness to pay for equity

Consumers also may have a preference for equity that can be weighed alongside potential efficiency gains. For example, consumers could be willing to sacrifice some system-wide costs savings to promote more equitable outcomes. Techniques, like those described Section 4.2, can be used to measure the WTP for equity. Though studies have been limited in the United States, a study in Germany found that reducing cost burdens on low-income households increased WTP for green electricity significantly (Andor, Frondel and Sommer 2018). Findings like these could have important considerations for the design and, perhaps more critically, the communication of rate structures. However additional analysis will be necessary to understand if this phenomenon is applicable to the United States.

6.0 Summary and next steps

This report explored the intersections of rate design and consumer behavior, with the goal of identifying potential impacts these issues may have as the electricity sector becomes more dynamic and distributed. As TE and RTP are still relatively novel (and in the case of transactive, still in a demonstration stage), many impacts stemming from behavior are still unknown for these systems. Practitioners hoping to use TE and RTP can draw from these studies, as they develop programs. Researchers can identify solutions by filling gaps in the literature that will assist these rate structures and operational strategies in becoming mainstream.

6.1 Questions answered by literature

This review found that many issues were well established in the literature, even if they have not been fully adopted by utilities. For example, researchers have identified numerous best practices as the industry transitions from flat to dynamic rates (Faruqui 2021). TOU rates, being the most widely adopted form of time-varying pricing, have a wealth of literature to support their adoption, and attest to their effectiveness (Lazar and Gonzalez 2015, Cappers, et al. 2016, Faruqi, Hledik and Sergici 2019). Consumer WTP for certain electricity system features (e.g. Kotchen and Leiserowitz 2012), rate impacts on ratepayers and underrepresented groups (Borenstein 2008, Borenstein 2007, Horowitz and Lave 2014), as well effective price setting (i.e., number of blocks, and price ratios for on and off-peak periods) (Faruqi, Hledik and Sergici 2019, Lazar and Gonzalez 2015) have been well examined in the literature.

RTP schemes are less common both in the literature and in practice, and much of the analysis surrounding their impacts has been simulated (e.g. Horowitz and Lave 2014). Best practices for these rates are often normative, given that there are fewer test beds to draw empirical results from. Transactive systems are still in a period of experimentation as they are the newest and most dynamic rate structure is still in a period of field demonstration, though practitioners can draw from findings under RTP and TOU programs.

Researchers have examined a number of nonmonetary incentives that can be used alongside rates to influence consumption in terms of consumer behavior. Appeals to social norms are particularly effective in spurring conservation (Allcott 2011), though a number of other nudges (namely, priming) are also in use (Schleich, et al. 2013). Behavioral economists also recommend that utilities and regulators focus on the choice architecture when designing new rates and programs (Schneider and Sunstein 2017). The use of opt-out, rather than opt-in rates for TOU programs is based on this idea.

Researchers have also explored consumers' preferences in the electricity sector (often measured in WTA or WTP). Well established methods have been created to measure WTP and WTA (Johnston, et al. 2017), and economists have estimated WTP and WTA for renewable power (Farhar 1999), demand response (Broberg and Persson 2016), equitable outcomes (Andor, Frondel and Sommer 2018) and local or regional power (Kalkbrenner, Yonezawa and Roosen 2017). WTP and WTA can vary temporally, geographically, and demographically, and thus will change over time and based on the population in question.

Finally, considerable effort by researchers has been dedicated to examining the distributional effects of rate structures, in particular for TOU and RTP programs. Balancing equity and cost causation can be difficult but these issues are acute for many policymakers, and many have begun to develop programs to resolve some of these tensions. Metrics for equity and processes for evaluation are also apparent throughout these studies (Tarekegne, et al. 2021).

6.2 Unanswered questions

Though some topics have been well explored, many questions, particularly surrounding more dynamic rate structures remain unanswered. Work extending empirical findings from traditional fixed rate structures to dynamic ones will help real-time pricing gain broader regulatory acceptance. This research will develop as transactive field programs become more prominent. The effects of behavioral interventions in dynamic price environments have similarly been underexplored. Nudges, and appeals to social norms are likely to be used alongside these rate structures in the future, and their effects could be different then they are under more traditional rates.

Likewise, many studies focus on average or marginal effects, while potentially heterogeneous impacts are unexplored. While some studies break down WTP and WTA by demographic group, it has only become a best practice recently. Understanding how WTP and WTA vary can help utilities to target consumers more accurately, develop more precise techniques for aligning consumer and system goals. Additionally, the endowment effect or a gap between WTP and WTA is well established in economics and psychology, but researchers have not worked to measure it in the electricity sector. Under a flat rate structure, consumers have few opportunities to exercise these preferences, but the issue has the potential to create headaches for a dynamic system.

6.3 Topics for further research

As a novel combination of technology and market design, transactive energy (and associated dynamic pricing) is just beginning to see widespread demonstration projects. As a result regulators are unable to draw on best practices to implement these programs, as they would for a rate structure like TOU. Replicating many of the findings identified for existing structures will be necessary as TE becomes more mature. Empirical analysis of these programs, especially with regards to how they can best be aligned with the regulatory priorities identified in Section 2.2 will be useful for policymakers and system operators.

Unlike transactive systems, flat rate structures offer few opportunities for customers to exercise their preferences, and given the novel status of RTP and TE, there is limited understanding of how these preferences will be exercised under dynamic pricing environments. Effort to translate preferences to bidding strategies, and finally onto operations will help transactive system operators understand the volume of resources that can be mobilized at a given price. Preferences for self-generation may also result in a gap between WTA and WTP, with customers keeping generation onsite in a manner that appears uneconomical to system operators. The gap between WTA and WTP has been largely unexplored in the electricity sector and research could be done to benchmark this phenomenon.

Consumer preferences may also be heterogenous. Understanding how these preferences may vary among demographic groups will help aid system planning. For example, WTA a demand response tariff may vary by race or income. If a group with a high WTA is located within a congested network, then demand response may not be a cost-effective mechanism for resolving network constraints. Similarly, groups that value local power highly may prefer peer-to-peer trading of distributed generation, while other groups may be indifferent.

Behavioral interventions have been an effective conservation strategy in traditional rate environments and could be used alongside TE to promote system goals. Work comparing the relative impacts of behavioral and monetary programs could help utilities to target customers more effectively in order to support the operations of the system.

Finally, guidelines for equity and fairness under a transactive system have not been developed. Work could be done to better understand which households are likely to be “winners” or “losers” in a transactive system (as compared to a traditional rate environment). This, in turn, could be used for risk management by developing guardrails or corrective policies to protect vulnerable communities. Dynamic pricing also has the ability to create system-wide savings. Processes for allocating these savings in ways that reduce energy poverty or promote equity and fairness would be useful for regulators who are uncertain about the distributional effects of these programs.

While more work is needed to understand how rate design and consumer preferences impact an increasingly dynamic electricity system, there are clear areas where researchers can work to fill these knowledge gaps and ensure that a dynamic system is one that is designed with customers in mind.

7.0 References

Allcott, Hunt. 2011. "Social Norms and Energy Conservation." *Journal of Public Economics* 1082-1095.

Amador, Francisco Javier, Rosa Marina González, and Francisco Javier Ramos-Real. 2013. "Supplier choice and WTP for electricity attributes in an emerging market: The role of perceived past experience, environmental concern and energy saving behavior." *Energy Eonomics* 953-966.

Andor, Mark A., Manuel Frondel, and Stephan Sommer. 2018. "Equity and the willingness to pay for green electricity in Germany." *Nature Energy* 876-881.

Arrow, Kenneth, Robert Solow, Paul Portney, Edward Leamer, Roy Radner, and Howard Schuman. 1993. *Report of the NOAA Panel on Contingent Valuation.* Washington, DC: National Oceanic and Atmospheric Administrationq.

Barnes, Andrew J., Michael Karpman, Sharon Long, Yaniv Hanoch, and Thomas Rice. 2019. *More Intelligent Designs: Comparing the Effectiveness of Choice Architectures in US Health Insurance Marketplaces.* Washington, DC: The Urban Institute .

Benartzi, Shlomo, and Richard Thaler. 2007. "The Behavioral Economics of Retirement Savings Behavior." *Journal of Economic Perspectives* 81-104.

Boff, Daniel, Abhishek Somani, and Steve Wildergren. 2022. *Transactive Energy Practices Survey.* Technical Report, Richland, WA: Pacific Northwest National Laboratory.

Bonbright, J.C. 1961. *Principles of public utility rates (PUR).* New York, NY: Columbia University Press.

Borenstein, Severin. 2008. *Equity Effects of Increasing-Block Electricity Pricing.* Berkeley, CA : Center for the Study of Energy Markets.

Borenstein, Severin. 2007. "Wealth Transfers Among Large Customers from Implementing Real-Time Retail Electricity Pricing." *The Energy Journal* 131-149.

Broberg, Thomas, and Lars Persson. 2016. "Is our everyday comfort for sale? Preferences for demand management on the electricity market." *Energy Economics* 24-32.

Brockway, Anna M., Jennifer Conde, and Duncan Callaway. 2021. "Inequitable access to distributed energy resources due to grid infrastructure limits in California." *Nature Energy* 892-903.

Cappers, Peter, C. Anna Spurlock, Annika Todd, Patrick Baylis, Meredith Fowlie, and Catherine Wolfram. 2016. *Time-of-Use as a Default Rate for Residential Customers: Issues and Insights.* Berkeley, CA : Lawrence Berkeley National Laboratory.

Carlsson, Fredrik, Peter Martinsson, and Alpaslan Akay. 2011. "The effect of power outages and cheap talk on willingness to pay to reduce outages." *Energy Economics* 790-798.

Champ, Patricia, Kevin Boyle, and Thomas Brown. 2003. *A Primer on Nonmarket Valuation.* Springer Nature .

Chau, K.W., and T.L. Chin. 2002. "A Critical Review of Literature on the Hedonic Price Model." *International Journal for Housing Science and Its Applications* 145-165.

Cong, Shuchen, Destenie Nock, Yueming Lucy Qiu, and Bo Xing. 2022. "Unveiling hidden energy poverty using the energy equity gap." *Nature Communications.*

Connecticut Green Bank . 2021. *Solar For all Program.* Accessed September 7, 2022. https://www.ctgreenbank.com/solarforall/.

Curtis, John, Gianluca Grilli, William Brazil, and Jason Harold. 2020. "Why do preferences for electricity services differ? Domestic appliance curtailment contracts in Ireland." *Energy Research & Social Science.*

EIA. 2018. *2015 Residential Energy Consumption Survey.* Washington, DC: Energy Information Administration.

—. 2017. *Link between growth in economic activity and electricity use is changing around the world.* November 20. Accessed September 13, 2022. https://www.eia.gov/todayinenergy/detail.php?id=33812.

Farhar, Barbara C. 1999. *Willingness to Pay for Electricity from Renewable Resources: A Review of Utility Market Research.* Golden, CO: NREL.

Farugui, Ahmad. 2020. "Refocusing on the Consumer." *Regulation.*

Faruqi, Ahmad, Ryan Hledik, and Sanem Sergici. 2019. *A Survey of Residential Time-of-Use (TOU) Rates.* The Brattle Group.

Faruqui, Ahmad. 2021. "The Rate Design Imperative." *IEEE Power and Energy.*

Faruqui, Ahmad, and Jenny Palmer. 2012. "The Discovery of Price Responsiveness – A Survey of Experiments Involving Dynamic Pricing of Electricity." *SSRN.*

Frondel, Manuel, Stephan Sommer, and Lukas Tomberg. 2019. *WTA-WTP disparity: The role of perceived realism of the valuation setting.* Essen, Germany: Ruhr Economic Papers.

Ganguli, Sumitrra, Daniel Boff, and Abhishek Somani. 2022. "Consumer Preferences in Rate Design: Will Households Act the Same when they Become Sellers?" *IEEE PES Transactive Energy Systems Conference (Forthcoming).*

Garfield, P.J, and W.F. Lovejoy. 1964. *Public Utility Economics.* Englewood Cliffs, NJ: Prentice-Hall.

Goldstein, Noah, Robert Cialdini, and Vladas Griskevicius. 2008. "A Room with a Viewpoint: Using Social Norms to Motivate Environmental Conservation in Hotels." *Journal of Consumer Research* 472-482.

Gridwise AC. 2020. *Transactive Energy FAQ - a GWAC Resource document.* August. Accessed March 29, 2022. https://gridwiseac.org/pdfs/gwac_twitter_friendly_te_faq.pdf.

Haab, Timothy, and Kenneth McConnell. 1997. "Referendum Models and Negative Willingness to Pay: Alternative Solutions." *Journal of Environmental Economics and Management* 251-270.

Hledik, Ryan, Ahmad Faruqui, and Cody Warner. 2017. *The National Landscape of Residential TOU Rates.* The Brattle Group.

Horowitz, John, and Kenneth McConnell. 2002. "A Review of WTA/WTP Studies." *Journal of Environmental Economics and Management* 426-447.

Horowitz, Shira, and Lester Lave. 2014. "Equity in Residential Electricity Pricing." *The Energy Journal* 1-23.

Ivanova, Irina. 2021. *Griddy Energy settles with Texas, releasing customers from $9,000 power bills during freeze.* August 31. Accessed August 26, 2022. https://www.cbsnews.com/news/griddy-energy-charged-9000-power-bills-settles-with-texas/.

Johnston, Robert J., Kevin J. Boyle, Wiktor (Vic) Adamowicz, Jeff Bennett, Roy Brouwer, Trudy Ann Cameron, W. Michael Hanemann, et al. 2017. "Contemporary Guidance for Stated Preference Studies." *Journal of the Association of Environmental and Resource Economists.*

Kahneman, Daniel, Jack Knetsch, and Richard Thaler. 1991. "Anomalies: The Endowment Effect, Loss Aversion, and Status Quo Bias." *Journal of Economic Perspectives* 193-206.

Kalkbrenner, Bernhard J., Koichi Yonezawa, and Jutta Roosen. 2017. "Consumer preferences for electricity tariffs: Does proximity matter?" *Energy Policy* 413-424.

Kim, Kayoung, Heekoo Nam, and Youngsang Cho. 2015. "Estimation of the inconvenience cost of a rolling blackout in the residential sector: The case of South Korea." *Energy Policy* 76-86.

Kotchen, Joseph E. Aldy Matthew J., and Anthony A. Leiserowitz. 2012. "Willingness to pay and political support for a US national clean energy standard." *Nature Climate Change* 596-599.

Kua, H.W., and S.E. Wong. 2012. "Lessons for integrated household energy conservation policies from an intervention study in Singapore." *Energy Policy* 49-56.

Lazar, Jim, and William Gonzalez. 2015. *Smart Rate Design for a Smart Future.* Montpelier, VT: Regulatory Assistance Project.

Lazar, Jim, Paul Chernick, William Marcus, and Mark LeBel. 2020. *Electric Cost Allocation for a New Era.* Montpelier, VT: Regulatory Assistence Project.

Ma, Guofeng, Jing Lin, and Nan Li. 2018. "Longitudinal assessment of the behavior-changing effect of app-based eco-feedback in residential buildings." *Energy and Buildings* 486-494.

Mertens, Stephanie, Mario Herberz, Ulf J. J. Hahnel, and Tobias Brosch. 2021. "The effectiveness of nudging: A meta-analysis of choice architecture interventions across behavioral domains." *Proceedings of the National Academy of Sciences.*

Navigent. 2016. *Take Control of Your Future, Part II: The Power of Customer.* Navigant Research.

OECD . 2018. *Cost-Benefit Analysis and the Environment: Further Developments and Policy Use.* Paris : OECD Publishing.

Oliver, Adam. 2015. "Nudging, Shoving, and Budging: Behavioural Economic-Informed Policy." *Public Administration* 700-714.

Opower. 2020. *Home Energy Reports.* Oracle Utilities.

Ozbafli, Aygul, and Glenn P. Jenkins. 2015. "The willingness to pay by households for improved reliability of electricity service in North Cyprus." *Energy Policy* 359-369.

Plott, Charles, and Kathryn Zeiler. 2005. "The Willingness to Pay-Willingness to Accept Gap, the "Endowment Effect," Subject Misconceptions, and Experimental Procedures for Eliciting Valuations." *American Economic Review* 530-545.

Rantala, Eeva, Saara Vanhatalo, Tanja Tilles-Tirkkonen, Markus Kanerva, Pelle Guldborg Hansen, Marjukka Kolehmainen, Reija Männikkö, et al. 2021. "Choice Architecture Cueing to Healthier Dietary Choices and Physical Activity at the Workplace: Implementation and Feasibility Evaluation." *Nutrients* (Nutrients).

Reeve, Hayden M, Steve Widergren, Rob Pratt, Bishnu Bhattarai, Sarmad Hanif, Sadie Bender, Trevor Hardy, and Mitch Pelton. 2022. *Distribution System Operator with Transactive (DSO+T) Study.* Richland, WA: Pacific Northwest National Laboratory.

Reich, Johannes, Michael Schmidthaler, and Friedrich Schneider. 2013. "The value of supply security: The costs of power outages to Austrian households, firms and the public sector." *Energy Economics* 256-261.

Schleich, Joachim, Marian Klobasa, Sebastian Gölz, and Marc Brunner. 2013. "Effects of feedback on residential electricity demand—Findings from a field trial in Austria ." *Energy Policy* 1097-1106.

Schneider, Ian, and Cass Sunstein. 2017. "Behavioral considerations for effective time-varying electricity prices." *Behavioural Public Policy.*

Schoengold, Karina, and David Zilberman. 2014. "The economics of tiered pricing and cost functions: Are equity, cost recovery, and economic efficiency compatible goals?" *Water Resources and Economics* 1-18.

Sergici, Sanem, Ahmad Faruqui, Nicholas Powers, Sai Shetty, and Jinchen Jiang. 2020. *PC44 Time of Use Pilots: Year One Evaluation.* The Brattle Group.

Sherwood, J., A. Chitara, D. Cross-Call, and B. Li. 2016. *A Review of Alternative Rate Designs,".* Snowmass, CO: Rocky Mountain Institute.

Szaszi, arnabas, Anthony Higney, Aaron Charlton, Andrew Gelman, Ignazio Ziano, Balazs Aczel, Daniel G. Goldstein, David S. Yeager, and Elizabeth Tipton. 2022. "No reason to expect large and consistent effects of nudgeinterventions." *Proceedings of the National Academy of Sciences.*

Tarekegne, Bethel W, Grace R Pennell, Danielle C Preziuso, and Rebecca S O’Neil. 2021. *Review of Energy Equity Metrics.* Technical Report, Richland, WA: Pacific Northwest National Laboratory.

Tarufelli, Brittany, and Sadie Bender. 2022. "Equity in Transactive Energy Systems." *IEEE PES Transactive Energy Systems Conference (Forthcoming).*

Taylor, Nicholas, Pierce Jones, and Jennison Kipp. 2014. "Targeting utility customers to improve energy savings from conservation and efficiency programs." *Applied Energy* 25-36.

Thaler, Richard, and Cass Sunstein. 2003. "Libertarian Paternalism." *American Economic Review* 175-179.

—. 2008. *Nudge: Improving decisions about health, wealth, and happiness.* New Haven, CT: Yale University Press.

Witynski, Max. n.d. *Behavioral economics, explained.* Accessed September 13, 2022. https://news.uchicago.edu/explainer/what-is-behavioral-economics.

Pacific Northwest National Laboratory

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99354
1-888-375-PNNL (7665)

www.pnnl.gov