

DOE's Smart Grid Investment Grant Consumer Behavior Studies

1.0 Introduction

The U.S. Department of Energy's (DOE's) Smart Grid Investment Grant (SGIG) program is working with a subset of SGIG award recipients to examine the response of consumers to variable electricity prices (referred to as time-based rate programs) in conjunction with the deployment of advanced metering infrastructure (AMI) and associated technologies. The effort presents an opportunity to advance the electric industry's understanding of consumer behavior by addressing uncertainties surrounding questions of impacts and acceptance using statistically rigorous experimental methods. This paper provides information on the rationale, scope, and approach for these consumer behavior studies, as well as what DOE hopes to learn from them and how results and lessons learned will be conveyed to the public.

2.0 Background

As far back as 1894, the electric industry has been debating the issue of how to efficiently and optimally charge customers for consuming electricity (Hausman and Neufeld, 1984). At that time, there were emerging but very contentious discussions among economists about the merits of pricing the new commodity differentially based on time. The early uses of electricity were for lighting between dusk and dawn, which meant that the generation facilities used to power incandescent lamps were left largely idle during the daylight hours. As a means to more efficiently utilize these power plants, two different types of pricing schemes were heavily debated: one based on a customer's consumption coincident with the system's instantaneous maximum demand (i.e., system peak) and another based on a customer's consumption coincident with different pre-determined time periods (e.g., nighttime between 6 p.m. and 6 a.m. vs. all other hours). The challenge with both rate designs revolved around metering – cost-effective technology did not exist at that time to allow electricity consumption to be captured at the required level of detail. Thus, virtually all customers were charged for their electricity consumption at a rate that was time-invariant (i.e., flat).

By the 1970s, the debate had moved beyond issues of economic efficiency and instead turned towards more practical concerns about consumer behavior – could mass-market (i.e., residential and small commercial) customers manage their electricity under time-based rate programs. The Federal Energy Administration, the predecessor to the U.S. Department of Energy, sponsored several studies in the late 1970s and early 1980s to determine if and how residential customers would respond to time-of-use pricing (e.g., one price during weekday hours of 12 noon to 6 p.m. and another price for all other hours).

The results of the studies indicated customers were, in fact, capable of managing their electricity consumption by moving it away from the expensive "peak" period to the less-expensive "off-peak" period (see Faruqui and Malko, 1983 for a meta-analysis of these experiments). In spite of this evidence, the lack of low cost interval or period-based metering would continue to limit the industries' ability to

expand the application of time-based rate programs at the residential level through the end of the 20th century.

2.1 Time-based Rate Programs and AMI

Over the past ten years, the costs of interval meters, the communications networks to connect the meters with utilities, and the back-office systems necessary to maintain and support them (i.e., advanced metering infrastructure or AMI) have all dramatically decreased. The implementation of AMI and interval meters by utilities, which allows electricity consumption information to be captured, stored, and reported at 5 to 60-minute intervals in most cases, provides an opportunity for utilities and public policymakers to of time-based rate programs and more fully engage electricity customers in better managing their own usage.

Utilities can now collect customer electricity usage data at a level that allows them to offer time-based rate programs, which provides customers with opportunities to respond to diurnal and/or seasonal differences in the cost of producing power (i.e., time-of-use pricing) and/or dynamically to deteriorating power system conditions, high wholesale power costs, or both (i.e., critical peak pricing, real-time pricing). Under these new "dynamic pricing" schemes, rates can change hour-to-hour and day-to-day. Customers also have the ability with AMI to better understand their own overall daily and even hourly usage patterns, whereas before only monthly consumption information was available to them in their monthly bills.

By introducing more dynamic rates and providing customers with more detailed information about their usage patterns, AMI provides customers with an incentive to invest in control technologies that can make it easier for them to change their consumption patterns with real and predictable impacts on their overall electricity bills. For example, programmable communicating thermostats (PCTs) allow customers to pre-program an adjustment in the thermostat temperature setting in direct response to receipt of electricity price increases via the utility's AMI. Otherwise, customers would have to receive the event notification signal through some form of mass communication method (e.g., email, phone, and pager) and then be home to adjust the thermostat themselves.

In regulatory proceedings across the country, many utilities are outlining rationales to policymakers and stakeholders and making the business case for investments in AMI. Three core issues have been consistently raised in these proceedings: (1) cost recovery of the investment, (2) benefits from utility operational savings, and (3) benefits from the introduction of time-based rate programs. Many of the key stakeholders (e.g., public utility commissioners and consumer advocates) want to understand what the full cost of implementing the utility's AMI plan will be, the risks to ratepayers and shareholders if there are cost overruns, cost recovery mechanisms through rates (e.g., \$/kWh, \$/customer, \$/kW), and cost allocations among customer classes (e.g., residential, commercial, industrial).

In addition, stakeholders want to better understand how AMI investments will reduce utility expenditures on operations and maintenance efforts over time (e.g., elimination of meter reading

positions, reduced truck rolls, etc.). For some utilities, operational savings provide sufficient benefits to justify AMI investments. However, for other utilities, operational savings alone may not be sufficient to provide acceptable paybacks and other benefit streams are needed, such as those from reductions in peak demand from demand response and time-based rate programs, to make a financially attractive business case for AMI.

To assess the benefits associated with demand response and time-based rate programs, it is necessary to measure the timing and magnitude of changes in electricity consumption patterns by customers in response to dynamic pricing and determine the extent of measurable financial effects on the cost of service. For example, reductions in coincident system peak demand may result in future deferral of new investment in electric generating facilities and/or transmission and distribution facilities and upgrades. And, overall shifts in electricity consumption away from expensive periods may reduce the average price of electricity for consumers.

Since the financial attractiveness of many AMI business cases may rest on the financial benefits derived from the responses of customers to time-based rate programs, it is crucial to properly and accurately estimate these benefits. These estimates may be derived from statistical studies of consumers and their consumption patterns and often hinge on assumptions concerning the number of customers who sign-up for time-based rate programs (enrollment), and the degree of change each customer exhibits in its consumption of electricity (performance).

Over the past 20 years, more than 100 studies have been published that assess how customers change their consumption patterns in response to time-based rate programs and how those responses are helped or hindered by greater access to usage information via Web portals and in-home displays or control technologies that automate the electricity-consuming devices such as programmable communicating thermostats. (Faruqui and Sergici, 2010). From a policy perspective, these studies have shown substantial diversity in customer responses, even those that normalized the results and reported elasticity values (EPRI, 2008). The diversity of results has led many states to wonder about their applicability. As a result, many utilities interested in AMI investments have been required to run their own pilot projects, so that policymakers in that state can see results for themselves.

2.2 The Need for Consumer Behavior Studies

The American Recovery and Reinvestment Act of 2009 included \$3.4B for the SGIG program with a goal of creating jobs to accelerate the transformation of the nation's electric transmission and distribution systems by promoting investments in smarter grid technologies, tools, and techniques for immediate commercial use. Among other topics, the Funding Opportunity Announcement (DE-FOA-000058) identified interest in AMI projects that involved time-based rate programs and use of statistically rigorous randomized and controlled experimental designs for estimating impacts and benefits. DOE encouraged FOA applicants to propose such studies and collect hourly load and customer demographic data for investigating AMI and its ability to integrate pricing and customer systems to accomplish changes in the electricity usage and behaviors of consumers.

DOE's aim is for studies undertaken in this manner to further the electric industry's understanding of the magnitude of these changes, the incremental effects of causal factors, and the key drivers that motivate the changes. If carried out properly, because the studies involve statistically rigorous techniques, they can provide more definitive answers to policymakers and stakeholders to key questions in the areas of acceptance of and response to time-based rate programs and customers systems.

For example, in the area of pricing the electric industry knows a fair amount about customer opinions of time-based rate programs after customers have gained some experience with them but little about what motivates customers to accept these rate offerings in the first place and stick with them over time. The SGIG consumer behavior studies can provide an opportunity for researchers to study how acceptance may differ across market segments (e.g., age, income, and usage), including the value of consumers having more comprehensive access to electricity consumption information, and having use of various automation and control technologies. Research in this area may better assess the factors that have been driving the wide diversity of responses to time-based rate programs across different market segments that have been measured in previous studies and pilot projects.

The SGIG consumer behavior studies may also assess customer acceptance and response to control or automation technologies at the end-use level, including refrigerators, dryers, or other major appliances. A number of recent studies have shown that these types of technologies hold promise for addressing renewable resource integration issues in bulk power markets.(see Cappers et al., 2011 for a comprehensive literature review).

The SGIG consumer behavior studies may also assess customer responses to various time-based rate programs and how the increased access to information about electricity consumption, both at the household and end-use levels, as well as across different delivery mechanisms (e.g., bill comparisons, web portals, and in-home displays) can affect customer behavior and electricity use patterns. Many prior studies have shown that access to information alone does indeed induce a change in electricity consumption, but little is understood about the persistence of these effects over time or how that change in behavior differs if time-based rate programs are jointly implemented (EPRI, 2009). New studies should attempt to address these key gaps in our knowledge base.



Advanced metering infrastructure (AMI) provides the opportunity to expand a utility's offering of time-based rate programs for electricity, potentially changing customer behavior through the interaction of pricing mechanisms, technology and information systems in the home. The investment in AMI can provide an opportunity for researchers to study how acceptance of and response to these elements may differ across market segments (e.g. income level, age level).

3.0 DOE's Analysis Framework and Approach

DOE is interested in applying a consistent analysis framework for the SGIG consumer behavior studies. The aim is to collect information across the studies on variables and impacts that have been defined in a consistent manner. This will enable DOE to leverage the results of the individual studies and assess further the impacts of AMI, time-based rate programs, and associated technologies across all of the studies.

3.1 Required Statistical and Experimental Study Elements

To implement such a framework, DOE is requiring the SGIG consumer behavior studies to apply statistically rigorous, randomized, controlled experimental designs in their studies. In theory, evaluations employing random selection and random sampling possess more credible and precise estimates of effects (i.e., internal validity) that can be extrapolated to similar groups outside of the study (i.e., external validity) as compared to studies that do not use random selection.

Due to cost, complexity, and other reasons, many prior studies have opted to utilize less rigorous experimental designs than those pursued by DOE under SGIG. Typically, the increased costs and technical effort associated with more rigorous methods outweighed the potential advantages from greater statistical precision. However, it is DOE's intent, with the cooperation of the SGIG projects who are also interested in applying statistically rigorous methods, to develop the best possible information

for addressing some of the uncertainties about the business cases for AMI, time-based rates programs, and associated technologies.

The framework involves a series of guidance documents, developed by DOE and provided to the study teams, which convey DOE's expectations and requirements. These guidance documents cover such topics as:

- Appropriate application of sampling and sample design;
- Preferences for various study objectives associated with time-based rates and customer systems;
- Preferences for the collection of identified customer characteristic information via survey instruments;
- How the various study objectives should be evaluated; and
- What information needs to be collected and reported back to DOE.

3.2 Technical Advisory Groups

To assist the study teams in successfully applying statistically rigorous techniques and meeting DOE's requirements, DOE formed technical advisory groups (TAGs) to provide technical assistance and support. The table below provides a list of the experts serving as TAG members. These individuals are from national laboratories, universities, and consulting firms and bring hundreds of years of collective experience in designing, implementing, and evaluating consumer behavior studies. Individual TAGs are formed to work collaboratively with each of the SGIG consumer behavior study teams. One of each TAG's aims is to assist the study team to align DOE's methodological framework with the practical realities of regulatory environment in which each utility operates. The TAGs also attempt to make sure the study addresses issues of direct interest to the utility and to encourage the study teams, when appropriate, to consider evaluating issues that may be of broader interest to the entire electric power industry. The TAG is there to provide guidance to the SGIG consumer behavior study teams in all of these areas in a pragmatic and collaborative manner.

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Sanem Sergici	The Brattle Group
Ryan Hledik	The Brattle Group
Michael Sullivan	Freeman, Sullivan & Company
Stephen George	Freeman, Sullivan & Company
Josh Bode	Freeman, Sullivan & Company
Mary Sutter	Opinion Dynamics Corporation
Tami Buhr	Opinion Dynamics Corporation
Craig Boice	Boice Dunham Group, Inc.

3.3 Reporting Requirements

Each SGIG consumer behavior study team is required to submit to DOE for approval a Consumer Behavior Study Plan (CBSP) summarizing what they are proposing to do. Specifically, each CBSP documents the proposed study elements, including: objectives, research hypotheses, sample frame and development approach, enrollment method, and experimental treatments. In addition, details surrounding the implementation effort need to be addressed, including: schedule for regulatory approval and recruitment efforts, how the study sample will be achieved and maintained throughout the project and data collection processes. Finally, an analysis framework for the evaluation of the study to address the initial set of study objectives must be included as well.

Once the CBSP is approved, study teams are expected to undertake certain reporting requirements throughout the project to convey to DOE and the industry what was learned from the studies. DOE

requires each study team to submit an evaluation report at the end of the study, as well as at an interim point if the study is designed to last for two years or more. These evaluation reports are to contain:

- An identification of study objectives;
- A description of how the study is designed to meet these objectives;
- The analytical methods used to evaluate the study objectives;
- A summary of the data collected for use in the evaluation effort; and
- The results from the evaluation effort and a determination if the study objectives were successfully accomplished.

DOE will summarize impacts drawn from the interim and final evaluation reports across the different study teams.

Two other broad categories of data are to be provided to DOE. The first category involves data containing masked customer-level hourly consumption information from those participating in treatment and control groups in the studies. The second category involves customer-level demographic and characteristic data such as appliance holdings and age and income of the occupants. In both cases data privacy is paramount and protections are to be included so that under no circumstances can any of the data provided to DOE be tied back to the names and addresses of individual customers. The study data sets provided to DOE will be comprised of the same information used by the study teams in conducting their own analysis. This required data from the study teams will be used by DOE to perform a cross-study analysis that spans all of the approved SGIG consumer behavior studies.

3.4 Cross-Study Analysis Research Agenda

Given the scope of the topics of interest DOE has identified, as well as the availability of customer-level data across a variety of utilities and study elements, DOE has a unique opportunity to evaluate issues in a much more comprehensive way than has been done before.

DOE has identified the following analysis topics and questions as top priorities for its cross-study research agenda.

- **Customer acceptance**: What motivates customers to accept a time-based rate program?
 - Does the enrollment condition (i.e., opt-in, opt-out) affect acceptance?
 - Does the existence of control and/or automation technology affect acceptance?
 - Does the dissemination of a more comprehensive education package affect acceptance?
 - Does the offer of bill protection or a bill guarantee affect acceptance?
 - How do customer demographics (e.g., low-income, high usage, elderly households, college educated) affect acceptance?
- **Customer retention**: What motivates customers to remain on a time-based rate program?
 - Does the enrollment condition (i.e., opt-in, opt-out) affect retention?
 - Does the removal of bill protection or a bill guarantee affect retention?
 - How do customer demographics (e.g., low-income, high usage, elderly households, college educated) affect retention?

- **Customer response:** Will customers respond, and if so by how much will they respond, to time-based rate programs?
 - Does the enrollment condition (i.e., opt-in, opt-out) affect response?
 - Does the existence or removal of bill protection or a bill guarantee affect response?
 - Does experience with the time-based rate program (i.e., year 1 vs. year 2) affect response?
 - Does the existence of control and/or information technology affect response?
 - How do customer demographics (e.g., low-income, high usage, elderly households, college educated) affect response?
- **Role of customer systems on customer response:** Will customers respond, and if so by how much will they respond, to automation/control technology, information technology, and/or other non-rate elements either in isolation or in tandem with rates?
 - Does the existence of control technology affect response in the absence of time-based rate programs?
 - Does the existence of information technology affect response in the absence of time-based rate programs?

DOE plans to publish a series of different research reports to convey what was learned from the SGIG consumer behavior study evaluation effort. These include:

- **Analysis of customer acceptance:** Two different evaluation efforts will be undertaken to address this series of research questions. Results from an interim evaluation in this area will be released in Q4 of 2012 but will likely include only a subset of the studies, as they will not all have begun their studies or been able to provide data for the analysis to DOE. A final evaluation that includes data and results from all SGIG consumer behavior studies will be provided by Q3 2013.
- **Analysis of customer retention:** A single analysis will be undertaken to address this set of research questions with results being reported by Q4 2014 on the studies who have reported data by that time.
- **Analysis of customer response:** Two different evaluation efforts will be undertaken to address this series of research questions. Results from an interim evaluation in this area will be released in Q4 of 2013 but will likely include only a subset of studies, as they will not all have begun their studies or been able to provide data for the analysis. A final evaluation that includes data and results from all SGIG consumer behavior studies will be provided by Q4 2015.

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