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The mitigating effect of strategic behavior on the net benefits of a direct load control program☆

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ABSTRACT

Demand response is an important tool for utilities to manage load during peak periods. While the effects of demand response programs on peak load reductions are well studied and intuitive, assessments typically fail to recognize the potential for off-peak behavioral responses that may mitigate the total benefits of the program. Using smart meter consumption data on residential air conditioning units enrolled in a direct load control program, this paper examines the changes in consumption prior to and after curtailment events. The results suggest substantial increases in off-peak consumption, which reduce energy, monetary, and environmental benefits of the program by over 40%.

1. Introduction

Many electricity utilities are challenged to meet the demand during peak consumption, usually during summer afternoons.[1] Further, peak demand has been increasing at an average annual growth rate of 0.8% over the last 10 years (NERC, 2013) heightening the need for solutions. Importing capacity from other areas and firing peak generators are two costly solutions; these can increase the cost of generation by \$29.2–80/MWh (EIA, 2014). Alternatively, demand response (DR) programs offer the possibility of no or low cost reductions in peak load, and utilities are increasingly implementing these programs. In general, DR seeks to reduce peak load by changing consumption prices or offering incentives to consumers. One type of DR is direct load control (DLC), in which the utility can control usage of appliances for a few hours per day during critical event days.

Impact evaluations have demonstrated large benefits of DR programs (e.g., Berkhout et al., 2000; Binswanger, 2001; Crew et al., 1995; Faruqui and George, 2002; Gillingham et al., 2013; Herter, 2007; Herter et al., 2007; Matsukawa, 2001; Thomas and Azevedo, 2013), and comparison of load reduction during event hours shows that DLC programs are more effective than programs with time-varying price structures (Newsham and Bowker, 2010; Wolak, 2011). However, most of these assessments tend to only examine benefits in terms of peak reductions, thereby ignoring behavioral responses and potentially overestimating the total benefits.

The purpose of this paper is to rigorously estimate both peak and off peak changes in consumption to better understand the net benefits of DLC programs with no price incentive or behavioral aspect. We examine Pacific Gas and Electric's (PG&E) SmartAC program, which is designed to reduce peak cooling load by directly controlling air conditioning (AC) units of participants.

We use data from a stratified random sample of 294 participating AC units. Because there is no data for a control group, we estimate unit-specific non-linear consumption models and then compare load on event days to predicted load. Importantly, we use data from the summer 2007 training period. In contrast to subsequent summers and normal DR designs, during the training period curtailment days were called for many different temperature levels, not just the hottest days. This aspect means we are not predicting out of sample and we can have greater confidence in our econometric evidence. Our methodology is validated

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[1] California ISO defines peak period as being from 7 am to 10 pm, however the peak period we refer to in this paper is narrowly defined to be in line with PG&E's summer peak periods which is from 12 pm to 8 pm.

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by a falsification test in which we find no changes in consumption during peak or off-peak times on non-curtailment days that match the temperature and timing profile of actual curtailment days.

Several key results emerge from our analysis. First, we confirm that the SmartAC program, like other DR and DLC programs, reduces peak load during event days. In this case, peak consumption was reduced 21% on average. However, we also find a 14% increase in consumption in the hours preceding and the hours following an event. Essentially, some load is being displaced from peak to off-peak times. In addition to cutting the energy savings, these behavioral changes mitigate the monetary and environmental benefits of the program by over 40%.

The main contribution of this paper is to show that DR energy policies can lead to unintended consequences. We contribute to the emerging body of work on the perverse incentives in energy policies (e.g., Davis and Kahn, 2010; Fowlie, 2009; Goulder and Stavins, 2011). Particularly relevant to this paper are works by Holladay et al. (2014) and Jessoe and Rapson (2014). Holladay et al. (2014) examine the changes in energy production when media outlets relay emergency calls from utilities for electricity reduction during off-peak hours on curtailment days. They estimate that behavioral responses lead to an increase in generation cost of about $43.70/MWh to $61.70/MWh in the late morning and early evening on emergency days. We estimate a smaller increase in generation cost, around $21/MWh, but the results largely corroborate each other. In contrast to Jessoe and Rapson (2014) who find positive spillovers of load reduction during peak hours on non-event days due to learning, we find negative spillovers in non-event hours on curtailment days.

2. Background on the SmartAC program

PG&E's SmartAC program is a DLC program designed to reduce participating households' cooling loads during peak load times. The program works by directly controlling AC during peak hours on designated curtailment days. Curtailment events can only occur between the hours of 11 am to 7 pm from May 1 to October 31 and only for a total of six hours per day and for no more than 100 h per cooling season. Before and after each event, the customers have complete control over their AC units.

Typically, curtailment days are called when system load is expected to be burdensome, usually the hottest days of the year. The California Independent System Operator (ISO) may declare a system emergency when an electric-resource generation facility reaches or exceeds a certain heat rate (usually heat rates of 15,000 Btu per kW). However, PG&E can also call events to test the devices and for other discretionary reasons such as transmission or distribution system overload. Appendix A gives a more detailed description of the process of initiating a control event.

In contrast to the normal objective of the program, summer 2007 was a training period, and curtailment days were called on days with a variety of temperatures, not just the hottest days of the year. The inclusion of typical summer temperature days is important because it allows the utility to test the operational performance of the control devices.

The SmartAC program uses paging signals to reduce cooling load of enrolled AC units during times of peak system demand. The control devices are either programmable communicating thermostats (PCTs) and/or DLC adaptive switches (switches). Both technologies receive signals through a paging device but differ by how they lower AC load. Unlike the adaptive switch control devices, the thermostats provide additional functionality to participants. Demand reduction during curtailment events is achieved by either adjusting thermostat temperature set points or limiting the duty cycles of switches in the units. The PCTs implement load reduction by increasing the cooling set point temperature on the thermostat controls when an event signal is received. Increasing the PCT set point ensures that temperature increases are equitably distributed across the population irrespective of house, occupant temperature preference and air conditioner attributes. The switches, on the other hand, reduce AC load by directly controlling how the unit's compressor operates.[2] The SmartAC program was structured such that 70% of the program participants had control switches and 30% smart thermostats. Customers with either device can only opt out of an event by either calling a toll-free number or accessing the program website.[3]

There were two schedules by which load was reduced for those households with PCTs, and PG&E alternated between them. The first schedule set thermostats back 1 °F every other hour, resulting in a maximum setback of three degrees in each six-hour curtailment event. The second schedule set thermostats back 1 °F every hour for the first 4 h of the event and then held constant. This last strategy was done in an attempt to evenly spread the load reduction resulting in a gradual temperature decline compared to the steep temperature increase from the first strategy. For units with adaptive switches, load reduction during curtailment events was achieved by limiting compressor duty-cycle to a maximum amount in the curtailment period.

Using information from focus groups and similar program evaluation surveys in other locations, participants were recruited into the SmartAC program through direct mail campaigns. Participants in the SmartAC program were first enlisted in the spring of 2007 in San Joaquin County. However, this has been expanded to include all service areas covered by the utility. At the beginning of July 2007 when the first curtailment event was called, the program had enrolled over 2857 households. The 297 households sampled for this evaluation are located in the city of Stockton and its surrounding areas (San Joaquin County). And as of August 2007, which was the system peak, there were 8193 participants in the program, which was almost composed exclusively of residential customers with less than 1% commercial customers. The program has subsequently grown in popularity to such an extent that by January 2008, there were 26,000 households enrolled in the program with an additional 22,000 waiting to be supplied control technology. All program participants received a one-off incentive payment of $25 in return for up to 100 h/year of load control. In addition, participants in the program evaluation group were given a maximum payment of $110 based on the number of questionnaires answered in a survey conducted at the completion of the program's first year. Also, participants in the PCT group were given the thermostats free, with a market value of $200 (KEMA Inc., 2008). The goal of the program is to enroll a sufficient number of participants to achieve load reduction of 305 MW with over 95% coming from residential accounts.

3. Methodology

We develop a methodology that estimates AC load usage as a function of weather control (temperature and humidity) and time of day, parameterizing each unit separately. Then we use these predictions to compare actual usage on curtailment days to expected usage. While there are several methods for estimating baseline consumption patterns and load comparisons, we use a regression-based baseline modeling approach. The wide scale adoption of smart grid meters and availability of high-resolution, hourly or 15-minute energy consumption data has contributed a great deal to improvements in regression-based baseline models (Carrie Armel et al., 2013; Guerra Santin et al., 2009; Guerra-Santin and Itard, 2010; Newsham et al., 2011). Mathieu et al. (2011) find that the regression-based baseline model performs better than most models used in evaluating DR programs. In addition, the regression-based model allows for customer-specific response estimates to be used separately for decision making or easily averaged to

[2] Switches generally control air conditioner load by limiting the compressor run-time or duty cycle to a maximum over a period. When activated on curtailment days, the switches use an adaptive algorithm to reduce AC load to a percentage of the load on "learning days". The "learning days" are days with similar characteristics as potential curtailment days and are chosen by the program administrator. The observed duty cycle on these learning days provides an estimate of expected duty cycle on a curtailment day.

[3] While participants had the option to opt out of the program, this option was almost never used by the households (KEMA Inc., 2008).