What Goes on Behind the Meter: Real Customer Response to Residential Time-of-Use Pricing

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ABSTRACT

Numerous efforts are ongoing in California and nationally to determine residential customer response to market-based electricity prices. All focus on demand responsiveness as measured by changes in load shapes as a result of fluctuations in electricity prices. Although real-time peak load reduction is the primary objective of such programs, few studies have investigated what customers actually do behind the meter to bring about load changes.

It would be particularly useful in designing new demand-response technologies and programs to have information about customers' motivations for participating, their level of knowledge about how such programs work, ease of use and reliability of technology and equipment, the constraints and problems they encounter in responding to price signals and what they actually do during peak hours.

The Sacramento Municipal Utility District and the California Energy Commission partnered to pilot a customer-controlled time-of-use program, called Power Choice, which employed new load management technology and a time-of-use rate with a critical peak period. This technology allowed customers to control various end uses in response to prescribed and called hourly prices, and provided near real-time information about energy use.

As part of the pilot program evaluation, participants responded to an in-depth survey of their behaviors and energy use habits during on- and off-peak hours. These behaviors were correlated with estimates of consumption during the various time-of-use periods, and a strong relationship was found between what customers say they do to save or shift usage, and their estimated savings. The policy implications of these findings are discussed.

Introduction and Background

One of the results of the California energy crisis of 2001 has been increased policy attention to possibilities for reducing peak load through dynamic pricing mechanisms. While there have been numerous demand response experiments as well as full-scale programs for large commercial, industrial or institutional customers, there have been few such programs aimed at residential energy users. The primary reason for this has been the high cost of equipment relative to the small potential demand savings per residential customer. In addition, it has not been known whether residential customers have the will or ability to make the lifestyle changes necessary to benefit from market-based pricing.

To test the feasibility of dynamic pricing in the residential sector, the Sacramento Municipal Utility District (SMUD) and the California Energy Commission (CEC) partnered to pilot a customer-controlled critical peak time-of-use (TOU) program, called Power Choice. The overall objectives of the pilot were to: estimate energy savings overall and during peak (demand); estimate market potential of a full-scale program; measure customer acceptance and satisfaction with the equipment and the program; assess equipment function in the field; and determine resource requirements for a full-scale program (SMUD 2004).

Behavioral Demand Response Research

While there is a large body of econometric work on the effects of TOU rates on aggregate energy demand (e.g., see Faruqui and George 2002), the literature on actual residential behavioral response is very thin. A review of major California public opinion polls reveals that California consumers have rarely been asked about dynamic pricing (TOU, critical peak, etc.). A 2001 Field Poll did solicit opinions of alternative policies related for demand management. Overall support for TOU pricing was about 48%, down from 59% two decades earlier (Field Institute 1980, 2001).

In the summer of 2001, studies of the state's *Flex Your Power* conservation advertising campaign (Bender et al., 2002) and residential consumers' behavioral responses to the energy crisis (Lutzenhiser et al., 2003) found strong evidence of voluntary reductions in energy use resulting from a variety of consumer actions (e.g., turning off lights, using air conditioners less or adjusting thermostats upward, installing energy-efficient appliances, using appliances less frequently, etc.). These results suggest that many residential consumers are better able and more willing to alter their patterns of energy use than had previously been thought.

While the social science literature records studies of TOU experiments as early as the 1970s (Black 1978) there is very little recent work. This is hardly surprising, given the prevalence of "block" rate design. In California, the major utilities have made residential TOU electric rates available for some time, but few customers have adopted them.

A review of residential dynamic pricing developments in other states also shows a mixed picture. In some places new programs are being considered or introduced, while in others support has waned. The case of Puget Sound Energy (PSE), where an ambitious residential TOU program enrolled about 300,000 customers in 2001-2002 and was subsequently abandoned because of unexpected rate impacts (Lewis, 2002), has likely affected the adoption of residential dynamic pricing in other places. From the PSE program experience, Faruqui and George (2003) observed that, "…any program should make a majority of the customers better off, or it should not be offered."

The limited literature does suggest a need to fit prices, technologies and expectations to customer needs and circumstances. Customers, in turn, need to deploy effective behavioral responses, which may require mastery of complex technologies. However, further research related to dynamic pricing is needed in order to better understand consumer response patterns, load impacts and benefits, and possible distributional effects within the residential sector (e.g., see CRA 2004).

The Power Choice Pilot at SMUD

As part of the evaluation of the Power Choice pilot, SMUD and the CEC were particularly interested in obtaining information that would be useful in designing new demand-response programs and technologies that enabled customers to alter their lifestyles with minimal inconvenience, and to use the technology to its greatest functionality and savings potential. This type of information was gathered through an in-depth, web-based survey, and included questions about dwelling characteristics, appliance holdings, behavioral response to the TOU and critical price periods, installation and technology issues, satisfaction with program and technology attributes, and demographics.

In addition, survey data were correlated with estimated energy savings across the summer season by TOU period to determine which behaviors and program characteristics were most and least effective in generating savings. Energy savings were estimated for each household using fixed-effects panel regression models that combined weather data with whole-house 15-minute interval meter data collected through the Power Choice equipment.

Customer qualification and solicitation. Because of considerable uncertainty regarding customers' ability to save money under the Power Choice program, and because SMUD did not wish customers to be financially harmed by participation in the study, the population of interest was defined as those likely to benefit even if they do not change their energy use habits. To determine likelihood of benefiting, estimates of consumption during the Power Choice TOU periods were made for 50, 90 and 140 critical peak hours for the entire residential customer base, using prior year's consumption data and assuming typical residential summer and winter load profiles. These estimates were compared with all SMUD customers' actual consumption for the same period to calculate potential bill savings under the Power Choice program. If customers saved at least $50 given 90 critical peak hours and did not lose any money given 140 critical peak hours, they were considered to benefit. Other criteria for participation related to computer and Internet access and configuration of equipment and systems in customers' homes.

Customers estimated to benefit were solicited by telephone and mail between January and March 2003. Over 500 customers expressed an interest and met initial screening criteria, but only 79 had a panel box configuration that allowed installation of the equipment. As it happens, only a subset of dwellings built prior to 1986 have an electrical service panel that is compatible with the Power Choice equipment. The total number of customers that were ultimately enrolled was 78, of which 71 remained through the end of the study in May 2004.

Power Choice and standard rates. Table 1 below shows SMUD's summer season Power Choice and standard rates. As can be seen, the Power Choice rate has a fairly large price differential between the critical and low periods (3.8:1). The relative rates affect whether customers benefit simply by changing rates (and not energy use patterns). Because Tier 1 and Tier 2 standard rates are only 1¢ higher than the low and medium TOU period rates respectively, low users would have to use almost all their electricity during the low period hours to break even under Power Choice during the summer, whereas high users who pay Tier 2 and Tier 3 standard rates already use much of their electricity during low and medium TOU periods, and therefore are more likely to benefit during the summer under the rate alone without changing energy use behavior and patterns.

However, most of the benefit from the Power Choice program is gained in winter, where there are only two TOU periods (high and low), the rate differential between those periods is about a penny (8.411¢ / kWh vs. 7.260¢ / kWh), and the Tier 2 and Tier 3 standard rates are comparatively high (12.995¢ / kWh and 14.231¢ / kWh respectively). Given these relative rates, customers whose usage places them in the higher standard tiers in winter benefit under the TOU rate during that season, without either lowering their usage or shifting their time of use.

Table 1. Power Choice and Standard Summer Rates

Power Choice Summer TOU Rate		Standard Summer Rate	
Charge	**Rate**	**Charge**	**Rate**
Customer charge	$10 / month	Customer charge	$5 / month
Energy surcharge	.263¢ / kWh	Energy surcharge	.263¢ / kWh
Energy charge		Energy charge	
Low (10 pm-noon and weekends)	7.032¢ / kWh	Tier 1 (0-700 kWh)	8.058¢ / kWh
Medium (noon-2 pm, 8-10 pm weekdays)	12.948¢ / kWh	Tier 2 (701-1,000 kWh)	13.965¢ / kWh
High (2-8 pm weekdays)	20.070¢ / kWh	Tier 3 (1,001+ kWh)	15.688¢ / kWh
Critical (when called)	27.000¢ / kWh		

Equipment and training. The program equipment components, developed by Comverge, Inc., consisted of: a communications gateway, meter and meter adapter, which combine to record energy use per time period in 15-minute intervals and communicate the critical pricing events to the customer; the SuperStat™, an advanced programmable thermostat that allows customers control of the settings of their central heating and air conditioning; and load control relays installed on the electric water heater and/or pool pump motor wiring to control their use through the SuperStat™. In addition, a Power Choice website provided participants with general program and energy efficiency information, a portal to view their load profile and energy usage, and a means to contact the program manager via e-mail. At the time of installation, customers were also provided training about the rate schedule and benefits, critical pricing events, energy efficiency and conservation, appliance usage, and programming and use of the SuperStat™. Installations took place from April through August of 2003.

Critical pricing event protocols. Critical peak periods were initiated using the following protocols: temperature ≥ 95°F and system load forecast ≥ 2100 MW; or a spot market price forecast ≥ $90/MWh; or a system emergency is declared. SMUD's Rates and Pricing Department developed a model to forecast hourly temperatures, loads and prices. When a critical pricing event was forecast for the next day, customers were immediately notified by e-mail. One hour before the critical pricing event took place, the red indicator light on the thermostat would flash slowly; during the critical pricing event the light flashed quickly. A total of 57 critical price hours were called during the pilot, all due to the temperature/system load forecast protocol.

Evaluation Methodologies

Survey Methodology

The participant survey was fielded during December 2003 and January 2004. Fifty-seven participants, or 78%, completed either the Internet or a mail form of that survey. This survey was designed to assess:

- Characteristics of participant population
- Motivations for and barriers to participation
- Satisfaction with the equipment and the program
- Preferred features of the program and the thermostat/controller
- Energy use behaviors during the different TOU periods
- Relationships among energy use behaviors, program features and savings

Because participating customers live in older dwellings built prior to 1986, they are likely to use electricity differently from customers in newer dwellings. To determine the existence and extent of bias in the sample group due to *dwelling age*, a telephone survey of a random sample of 55 customers who had expressed an interest in participating but had incompatible panel configurations was conducted in February 2004, asking demographic and end use questions for comparison with participants. The only differences found were in heating fuel and number of stories, reflecting trends in home construction. The fact that there are no significant differences between the two groups in terms of dwelling size, education, income, estimated benefit or electricity consumption suggests there is no bias due to the age of dwellings.

To determine the existence and extent of bias in the sample due to *self-selection*, 622 customers were randomly selected for phone solicitation to participate in the program. During solicitation, they were asked demographic and dwelling questions. A comparison was made of participant survey responses with recruitment survey responses of 121 customers who qualified (except for equipment compatibility) and agreed to participate and 177 who qualified and declined. Results suggest self selection bias: participants differ from both groups (agreed and declined) in that they live in smaller, older (due to the equipment problem) homes that use less energy and are more likely to have gas heat. They are also better educated and more likely to have children and elderly in the home. Participant survey estimates are accurate within ±12%, recruitment survey estimates are accurate within ±7%, and tests are significant within 10% at a 95% level of confidence for all samples and comparisons.

To simplify and characterize participants' general behavioral reactions to the Power Choice program, a reaction typology was constructed by combining responses to several questions. A question about households' reactions to summer rates was combined with questions regarding whether shifting usage from higher priced periods to lower priced periods had become a habit, whether customers adjusted their thermostat default cooling settings, and what the settings were. In the reaction typology that emerged, eleven percent of participants said they made no changes at all, while 89% felt they had shifted down and/or conserved (32% shifted to weekend OR down, 38% shifted to weekend AND down, and 19% shifted and conserved). None of the survey respondents reported shifting energy use to a higher cost period.

Demand Savings Methodology

The demand response technology incorporates the capability to record energy usage in each time-of-use period in the form of whole house 15-minute interval data. These data were analyzed from approximately two weeks prior to customers being placed on the Power Choice TOU rate until the end of the summer season. Fixed effects panel models, incorporating meter data along with temperature and humidity measurements, were used to develop estimates of average energy reduction during each TOU period, both across households (i.e., cross-sectional) and over time (i.e., time-series). Model parameters are all significant within .001% at a 95% level of confidence. (For a more detailed description of the savings impact methodology and the aggregate model specification, see SMUD 2004.)

For analysis purposes, savings estimates by time-of-use were developed into six continuous and four categorical savings variables: overall kWh savings across the summer period; kWh savings during each of the four TOU periods; kWh savings across the summer during the peak (high including the critical) period; whether customers saved overall; whether customers generally shifted energy use to the lower or the higher periods; whether customers responded to critical calls; and a general demand response variable developed from a combination of the three categorical variables. With the exception of one customer who did not respond to the survey, all participants fell into one of five general demand response categories.

The resulting demand response typology and the percent in each category are shown in Table 2. As can be seen, 67% of participants used less overall, and 86% used less during high or critical periods. The largest group (35%) of participants both used less overall and responded to critical prices (LDR), whereas 14% simply did not respond to prices at all (MUN).

Table 2. Demand Response Typology

Demand Response	Percent
LDR: Used less all periods, responded to critical calls	35%
LDN: Used less, shifted down, did not respond to critical calls	11%
LUR: Used less, shifted up, responded to critical calls	21%
MUR: Used more all periods, responded to critical calls	19%
MUN: Used more, shifted up, did not respond to critical calls	14%

The final step in the analysis was to correlate the above savings estimates with behaviors and demographics from the survey, using cross tabulation, correlation and ANOVA. All comparisons are significant within 10% at a 95% level of confidence.

Findings

Characteristics of Participant Population

As a group, participants are very different from the general population. The decision to limit participation in the pilot to customers who would benefit under the Power Choice rate without changing their energy use behavior precludes extrapolation of findings to the general population. The survey of participants revealed that, compared to the general population[1], they:

- Are younger—29% vs. 44% are households with seniors
- Are more likely to have children—47% vs. 33% are households with children
- Are very well educated—72% vs. 37% have college degrees, 48% vs. 17% have advanced degrees
- Have higher incomes—50% vs. 12% make more than $100,000 per year
- Live in larger homes—approximately 2,000 vs. 1,600 square feet
- Use more electricity—approximately 1,600 vs. 800 kWh per month
- Are more likely to be home during peak hours in the summer—81% vs. 58%

Fifty-six percent of Power Choice participants also participate in the Peak Corps program vs. 24% of the general population.[2] Less than one-third of participants use budget billing or automatic withdrawal of SMUD bill payment from their bank account. Participation in budget

[1]General population data are derived from SMUD's Residential Appliance Saturation Survey conducted in 2001.
[2]Peak Corps is SMUD's residential air conditioning load management program where participants agree to have their air conditioners cycled off for a period of time on selected system peak days. Participation in Peak Corps did not affect the pilot because no cycle days were called in summer 2003.

billing or automatic withdrawal programs may affect price responsiveness since these programs can mask price signals on monthly bills.

Motivations for and Barriers to Participation

Participants were asked to indicate their reasons for participating in the program. Generally, customers decided to participate because they wanted to save money (88%), they wanted the ability to control their energy usage (54%), they thought participation might be interesting (33%), that it might help the environment (35%), or they wanted to help SMUD during the energy crisis (40%). Being able to monitor usage on the web was reported as a motive by only 23%, and getting a free thermostat was reported by only 4%. Participants were also asked if they had any reservations regarding participating in the program. Sixty percent had no reservations at all, while the remaining 40% had three primary concerns: making lifestyle changes, having equipment difficulties and experiencing bill increases.

Satisfaction with the Equipment and the Program

Overall, 80% of participants surveyed said they were either very or somewhat satisfied with the program, compared with 11% who expressed some level of dissatisfaction. Fifty-four percent of participants had problems programming and/or operating the thermostat, and 56% had trouble seeing the thermostat (small display and no backlight). These difficulties are reflected in the satisfaction ratings for the thermostat, where 68% were satisfied. Participants were least satisfied with the website (63%)—they primarily wanted thermostat control through the website and more detailed information on usage. They also wanted more hands-on training, especially using the website, and better written instructions on using the thermostat and website.

Participants were asked questions regarding their comfort level during the non-critical and critical peak hours. During non-critical periods most participants (83%) were as or more comfortable than before the program. However, during critical peak periods, one-third were somewhat to very uncomfortable. Participants were also asked their likelihood of continuing and recommending the program. Eighty-nine percent indicated they planned to continue the program and 83% would recommend it to others.

Preferred Program and Thermostat Features

Participants were asked to rate the importance of existing and potential program features. Most participants place high importance on the ability to save money (96%), control of the thermostat (90%) and appliances (78%), learning to manage power and use appliances efficiently (88%), information about energy usage (85%) and notification of critical peak events (88%). Fewer, but still a majority of participants value ease of programming the thermostat (71%) and education (67%).

Participants were also asked to rate the importance of potential program improvements. Important to most participants was a larger, backlit display on the thermostat (92%) and additional information about energy usage, such as 12 months' TOU billing information (84%), daily high and low usage (74%), and controlled appliance usage (72%). Less than half of participants value changes to the price schedule or the ability to opt out of one critical event.

Energy Use Behaviors

The survey asked several questions regarding general behavioral responses to the Power Choice program. As can be seen in Table 3, almost all participants (95%) felt that shifting usage became a habit in their household during the summer months. The large majority of participants (83%) checked the thermostat display to monitor for critical period calls. More than two-thirds invested in energy efficiency measures after joining the Power Choice program (59% replaced incandescent with compact fluorescent lamps, 11% replaced single- with dual-pane windows, 9% replaced an old refrigerator with a new high-efficiency one, 8% repaired air ducts, 5% replaced inefficient with high-efficiency air conditioning, and 5% installed ceiling or wall insulation). Almost 60% temporarily overrode the temperature settings, but only 42% changed default temperatures and 10% changed critical peak offset settings. Forty percent of households had disagreements about using energy at particular times—27% disagreed about using the air conditioner and 9% disagreed about doing laundry.

Table 3. Behavioral Responses

Behavior	Percent
Checked thermostat display for critical period	83%
Invested in energy efficiency after joining Power Choice	71%
Routinely adjusted air conditioning with override buttons	61%
Shifting became a habit in both summer and winter	55%
Changed the default setting of 78ºF for cooling	46%
Had disagreements about using energy at particular times	41%
Shifting became a habit in summer only	40%
Reprogrammed critical peak offsets	10%

The survey also asked about specific appliances used during each of the TOU periods. Table 4 shows the percentages of participants who responded that they "often" used the appliance during the period. Participants reported using air conditioners and dishwashers less, taking fewer showers or baths, and washing clothes and cooking indoors less during high and critical periods. However, participants continued to watch television and use the computer during high and critical periods, although less than during other periods. When asked what changes participants had *planned* to make that turned out to be too impractical or inconvenient, 22% of participants mentioned not running the air conditioner during peak hours on very hot days as being difficult.

Table 4. Often-Used Appliances

	Time-of-Use Period			
Behavior	Low	Medium	High	Critical
Ran air conditioner	51%	58%	48%	17%
Washed and dried clothes	83%	15%	6%	0%
Used dishwasher	81%	14%	6%	2%
Used computer/printer	72%	69%	**57%**	**45%**
Watched television	66%	84%	**79%**	**56%**
Showered or bathed	81%	27%	14%	12%
Cooked or baked	36%	43%	32%	12%
Barbequed outdoors	23%	38%	55%	49%

Estimates of Savings

The aggregate fixed-effects panel model explains 26% of the total hourly variation in kWh consumption—a high percentage, considering the total variability in hourly consumption and the relatively few hourly variables in the model. This model estimates that the Power Choice program had the following overall effects, *relative to consumption prior to program participation* (not relative to overall savings):

- KWh in the low price period *increased* by 1%
- KWh in the medium price period *declined* by 8%
- KWh in the high price period *declined* by 11%
- KWh during critical price periods *declined* by 16%
- KWh overall across the summer season *declined* by 4%

Table 5 below shows estimated average participant differences in kWh consumption for the summer season (June 1 through September 30) on the standard rate versus the Power Choice rate for three savings variables by demand response category: kWh savings overall, for the high period (not including critical), and for critical hours only. Negative numbers denote using less (savings) and positive numbers denote using more.

Table 5. kWh Savings by Demand Response Category

		Average kWh Savings		
Demand Response	**Percent**	**Overall**	**High**	**Critical**
LDR: Less, down, response to critical	35%	-3,433	-594	-775
LDN: Less, down, NO response to critical	11%	-2,038	-928	495
LUR: Less, up, response to critical	21%	-1,176	354	-937
MUR: More, up, response to critical	19%	2,109	883	-521
MUN: More, up, NO response to critical	14%	1,725	243	690

Relationships Among Energy Use Behaviors, Program Features and Savings

A clear relationship between what participants think they do to reduce peak energy usage, and their estimated savings was found. Customers who say they changed their routines and made a habit of shifting actually did use less energy overall (-1,010 kWh), while those who characterize themselves as not changing actually used more energy (1,745 kWh).

However, the extent to which customers are aware of their behavior differs. Comparing the general behavioral reaction variable with the general demand response variable, as shown in Table 6, yields interesting results. Participants who saved the most (LDR: used less/shifted down/responded to critical) all correctly described themselves as shifting and conserving. Some portion of all the other demand response groups incorrectly described themselves as shifting up or down, or making or not making changes (italicized percentages suggest an accurate characterization of household behaviors while bolded percentages suggest an inaccurate one). In particular, 57% of customers who saved the least (MUN: used more/shifted up/did not respond to critical calls) described themselves as shifting and/or conserving. The implication of this finding is that customers who save the most are aware of their energy use behaviors and their effects, while many of those who save the least are unable to correctly characterize their behaviors.

Table 6. Comparison of Behavioral Reaction with Demand Response

Behavioral Reaction	Demand Response					All
	LDR	LDN	LUR	MUR	MUN	
Made no changes	*0%*	**17%**	**13%**	*0%*	*43%*	11%
Shifted to weekends OR down	*35%*	*17%*	*13%*	*78%*	*0%*	32%
Shifted to weekends AND down	*35%*	*67%*	*50%*	**11%**	**43%**	38%
Shifted AND conserved	*25%*	*0%*	*25%*	**11%**	**14%**	19%
All	35%	11%	21%	19%	14%	100%

Table 7 shows the average savings of each behavioral reaction group relative to the others in terms of overall savings, high period (excluding critical) savings, and critical hour savings.

Table 7. KWh Savings by Behavioral Reaction Category

Behavioral Reaction	Percent	Average kWh Savings		
		Overall	High	Critical
Made no changes	11%	1,234	338	329
Shifted to weekends OR down	32%	-446	132	-535
Shifted to weekends AND down	38%	-1,474	-197	-359
Shifted AND conserved	19%	-1,819	-224	-586

Table 8 shows several variables that are related to demand response. The greater their savings, the more satisfied participants are with the Power Choice program and thermostat, and the more likely they are to want to participate again. Customers who are home during peak hours achieve one-half the critical hour savings (320 vs. 700 kWh) and one-third the peak hour savings (320 vs. 900 kWh) of those who are not home.

There is a positive relationship between critical hour savings and the frequency of checking the thermostat for a critical event, as well as the frequency of checking the website for usage data. Customers who checked the thermostat more than 10 times a month saved the most (-575 kWh), followed by customers who checked the thermostat one to 10 times (-455 kWh). Customers who never checked the thermostat used more energy during critical hours (255 kWh). Customers who checked the website for usage data saved more during critical hours (-760 kWh) and overall (-2,090 KWh) than those who never checked the website (-200 kWh and –285 kWh).

Participants who have invested in energy efficiency measures and appliances, either before or after joining Power Choice, saved during the peak period (high period including critical hours) (-600 kWh) and used less overall (-1,400 kWh), whereas those who have not invested in energy efficiency used more during peak (55 kWh) and overall (385 kWh).

Customers who adjusted the current air conditioning setting during critical periods, using the temporary up and down buttons, saved less overall (-165 kWh) than those who did not adjust settings (-1740 kWh). Likewise, those who changed the critical period setbacks used more overall (1,600 kWh), while those who did not adjust the setbacks saved overall (-1,115 kWh). These relationships are clear in Table 8, where customers who saved the most (LDR, LDN, LUR) overrode the current temperature the least, and did not change the setbacks at all.

Table 8. Variables Related to Demand Response

Variable	Demand Response					All
	LDR	LUR	LDN	MUR	MUN	
Satisfied with program	94%	50%	100%	89%	57%	80%
Satisfied with thermostat	75%	50%	100%	67%	33%	67%
Participate again	100%	88%	100%	89%	57%	89%
Home during peak	72%	63%	100%	89%	100%	81%
Invested in energy efficiency	78%	88%	83%	67%	57%	75%
Checked website	75%	75%	33%	33%	29%	54%
Shifting became a habit	100%	88%	100%	100%	71%	94%
Think program paid off	100%	71%	100%	75%	50%	81%
Changed routines	100%	83%	83%	100%	67%	91%
Overrode current temperature	33%	50%	17%	78%	86%	50%
Changed setbacks	0%	0%	0%	33%	14%	9%

Although the entire sample was estimated to benefit financially under the Power Choice rate without any change in behavior, there is an inverse relationship between estimated dollar benefit and energy savings: participants who benefited the least purely due to the rate change turned out to save the most during all periods except critical, and vice versa. This suggests that the greater the benefit without changing behavior, the less the price responsiveness. Those who saved the least weren't simply disinterested, however. Their motivations to participate (e.g., "help the environment," "control energy and costs," "help SMUD," etc.) were roughly the same as those who saved the most.

Participants did differ in price responsiveness based on life stage and education: households comprised of only adults under 65 used more energy on average (1,850 kWh), whereas those with adults plus seniors (no children) saved the most (-1,900 kWh); critical peak savings for participants with graduate degrees was higher (-760 kWh) than for those with bachelor's degrees and less (-60 kWh).

There were several areas where a relationship with demand response was expected but not found. Seemingly, a necessary condition to being able to respond to price signals in the various TOU periods is an understanding of the periods and rate structure. Eighty-seven percent of participants could correctly identify the summer peak period. However, 40% said they did not know the summer and winter price schedules. Knowledge of either price schedules or times of use, it turns out, is unrelated to savings. Similarly, participation in billing programs that could mask prices, such as Budget Billing and Automatic Payment, had no effect on savings. Also unrelated to savings are dwelling characteristics (e.g., age and square footage of home), as well as whether the electric water heater and pool pump were controlled through the thermostat. A final anomaly remains in the fact that some customers reported conservation actions and not changing equipment settings, but still used more energy.

Conclusions and Recommendations

Power Choice findings have implications for key questions energy policy makers are facing in implementing residential dynamic pricing: whether participation in such programs should be universal or elective, and how to define the TOU rate structure. Experience has shown that universal programs can fail if a majority of customers are unable to save money (Faruqui and George, 2002). Based on the Power Choice experiment, likely recruits to a voluntary program at SMUD are young, well-educated, financially well-off customers living in large, gas-heated homes that use twice the electricity overall and during peak than other customers. As such, these customers have greater total savings potential than other customers. However, these are also the same customers who are likely to benefit under a TOU/critical rate structure like Power Choice, without any change in usage behavior. The pilot has also shown that the more customers stand to benefit by virtue of the rate alone, the less price-responsive they are. So there is a built-in catch-22 in identifying the target market for demand response programs: the most likely participants with the greatest savings potential may be the least price responsive under certain rate structures. As a result, it may be particularly important to implement TOU rates in tandem with information and appeals that focus on non-financial (e.g., civic, environmental, altruistic) motives as well as potential cost savings.

These findings also suggest that universal programs could be regressive, hitting the poorer and least able to respond customers the hardest, depending upon the rate structure. It is, of course, possible to devise a rate structure that "naturally" benefits fewer or more customers. But this may also lower the total market potential for an elective program, or increase the burden on low-income households under a mandatory program, and may not reflect real market prices.

Another dilemma for voluntary programs centers on the issue of control. Customers clearly want control of their energy usage and the thermostat, including good quality information about both. However, the greatest savings may be experienced by customers who set the thermostat and leave it. Participants who expect to save from greater control but do not are more likely to leave a voluntary program. A potential solution that may help to retain customers and still provide control is to encourage and train participants to view their usage regularly—Power Choice participants who did so were more likely to benefit from the program.

It is particularly relevant that, of all Power Choice program features, participants were least satisfied with the thermostat and website, and they strongly preferred improvements to both. These results suggest that careful design of the thermostat and website for simplicity of operation, ease of viewing and meaningful content is a crucial element of demand response program success. Certainly in any universal program, easy access to usage information should be provided either through the thermostat, bills, Internet equipment or all three.

The larger lesson from the Power Choice study is that the majority of customers are both willing and able to reduce peak electricity usage significantly when provided with the proper equipment and information. Results show that two-thirds of participants saved energy overall, and 86% saved during the high or critical periods. Although this study cannot distinguish savings due to behavioral change (both programmed and conscious) from savings due to investment in energy efficiency, clearly there is value and synergy in linking energy efficiency with demand response through education: most participants made investments in energy efficiency after joining the program, and those who invested saved, while those who did not invest, did not save.

A secondary lesson is the high degree to which program features and elements are interrelated and affect customer response, which speaks to the need for careful planning and sound research in the design of programs. As a pilot study, Power Choice suffered from being a small sample as well as representative of only a small portion of the residential population. A strong recommendation for further research is to include sample participants from the full spectrum of residential customers, with the intent of identifying the range of behavioral responses to dynamic pricing, and the trade-offs among prices, responsiveness, customer dollar benefits (from changes in both rates and behaviors) and energy savings potential within the various customer segments.

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