The Brattle Group

A Discussion Paper

THE POWER OF EXPERIMENTATION
New evidence on residential demand response

This paper reviews evidence from the fourteen most recent pricing experiments with dynamic pricing. It finds that, on average, customers respond to higher prices by lowering usage. The magnitude of price response depends on several factors, such as the magnitude of the price increase, the presence of central air conditioning and the availability of enabling technologies such as two-way communicating thermostats and gateway systems. For the average customer, time-of-use rates are likely to induce a drop in peak usage of under 5% while critical-peak pricing tariffs a drop of around 10-25%. Customers with central air conditioning are likely to display responses in the 15-20% range while those with enabling technologies in the 25-45% range.

Ahmad Faruqui
Sanem Sergici

May 11, 2008

The authors are economists with *The Brattle Group* located in San Francisco, California and Cambridge, Massachusetts respectively. This paper is being circulated for review and comment. Some of the research on which the paper is based was funded by the Edison Electric Institute and the Electric Power Research Institute. Comments can be directed to ahmad.faruqui@brattle.com.

THE POWER OF EXPERIMENTATION: NEW EVIDENCE ON RESIDENTIAL DEMAND RESPONSE

Ahmad Faruqui and Sanem Sergici

INTRODUCTION

There is substantial evidence on the value of demand response[1]. A recent study showed that just a five percent reduction in U.S. peak electric demand would provide a benefit of $31 billion for the US as a whole.[2] Over the past several years, several demand response programs have been included in utility plans as alternatives for developing more generating stations and directed at large commercial and industrial customers. In most restructured states, customers who draw more than 500 kW demand from the grid are placed on a default real-time pricing rate. Others have the option of volunteering onto incentive-based demand response programs of various kinds. In certain other states, mostly located in the Southeastern U.S., large customers can volunteer onto real-time pricing rates on a day-ahead or hour-ahead basis. However, for residential customers, the only demand response program that has been widely deployed in recent years is some form of direct load control of end-uses such as central air conditioning or electric water heating.

Time-based pricing programs could substantially expand the benefits of demand response to customers, utilities, and society as a whole. However, such programs are still in their infancy, largely because of concerns that customers won't effectively respond to time-varying rates. Are these concerns valid or are they misplaced? This paper examines this issue by drawing upon fourteen recent residential pricing experiments that examine customer response.

---

[1] U.S. Department of Energy (DOE) defines demand response as "changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized." (February 2006 DOE EPAct Report)

[2] Faruqui, A., R. Hledik, S. Newell, and J. Pfeifenberger. 2007. "The Power of Five Percent." The Electricity Journal Vol. 20, Issue 8:68-77.

OVERVIEW

In the late 1970s and early 1980s, the first wave of electricity pricing experiments was carried out under the auspices of the U.S. Department of Energy and its predecessor agency, the Federal Energy Administration. Those experiments were focused on measuring customer response to simple (static) time-of-day and seasonal rates.[3] The top five experiments were analyzed collectively in a project carried out by the Electric Power Research Institute.[4] The results were quite conclusive: customers responded to higher prices during the peak period by reducing peak period usage and/or shifting it to less expensive off-peak periods. The results were consistent around the country once weather conditions and appliance holdings were held constant. Customer response was higher in warmer climates and within a given climate; it was higher for customers with central air conditioning systems.

However, despite the conclusive findings, time-varying rates were not widely accepted across the country. In part this was due to the high cost of time-of-use metering. In part it was because the peak periods that were offered in these rate designs were much too broad for customers to cope with. This lack of acceptance was also because the cost of peaking capacity did not vary sufficiently from the cost of off-peak capacity to bother offering time-of-use rates.

The California energy crisis of 2000-2001 rekindled interest in time-varying rates. A variety of academics, researchers and consultants called for the institution of rates that would be dynamically dispatchable during critical-price periods. These occur typically during the top one percent of the hours of the year where somewhere between 9 and 17 percent of the annual peak demand is concentrated. It is very expensive to serve power during these critical peak periods and even a modest reduction in demand during such periods can be very cost-effective. In addition, the introduction of digital technology in meters has brought with it the availability of advanced metering infrastructure, AMI, making dynamic pricing a cost-effective option in most situations.

[3] Faruqui, A. and J. R. Malko. 1983. “The Residential Demand for Electricity by Time-of-Use: A Survey of Twelve Experiments with Peak Load Pricing.” Energy Vol. 8: 781-795.

[4] Caves, D. W., L. R. Christensen, and J. A. Herriges. 1984. “Consistency of Residential Customer Response in Time-of Use Electricity Pricing Experiments.” Journal of Econometrics 26:179-203.

This article summarizes the results of several second-wave dynamic pricing experiments[5] that have been carried out in the U.S., Canada, France, and Australia. *Our review of these pilots reveals that dynamic electricity pricing programs are effective in reducing electricity usage for residential customers.* In general, critical peak pricing (CPP) programs supported with enabling technologies result in the largest reductions in load. However, CPP programs alone (without an enabling technology) also achieve significant reductions in load. Time of use (TOU) programs without enabling technologies reduce load somewhat; however, when TOU programs are supported with enabling technologies, the average load reduction is larger. Based on the pilot results, the combination of dynamic prices with enabling technologies appears to be the most effective program design for reducing electricity usage during high-priced periods. Summaries of the characteristics and impacts associated with the experiments reviewed in this article are shown in Table 1 and Figure 2.

Comparative results are presented for the following 14 experiments:

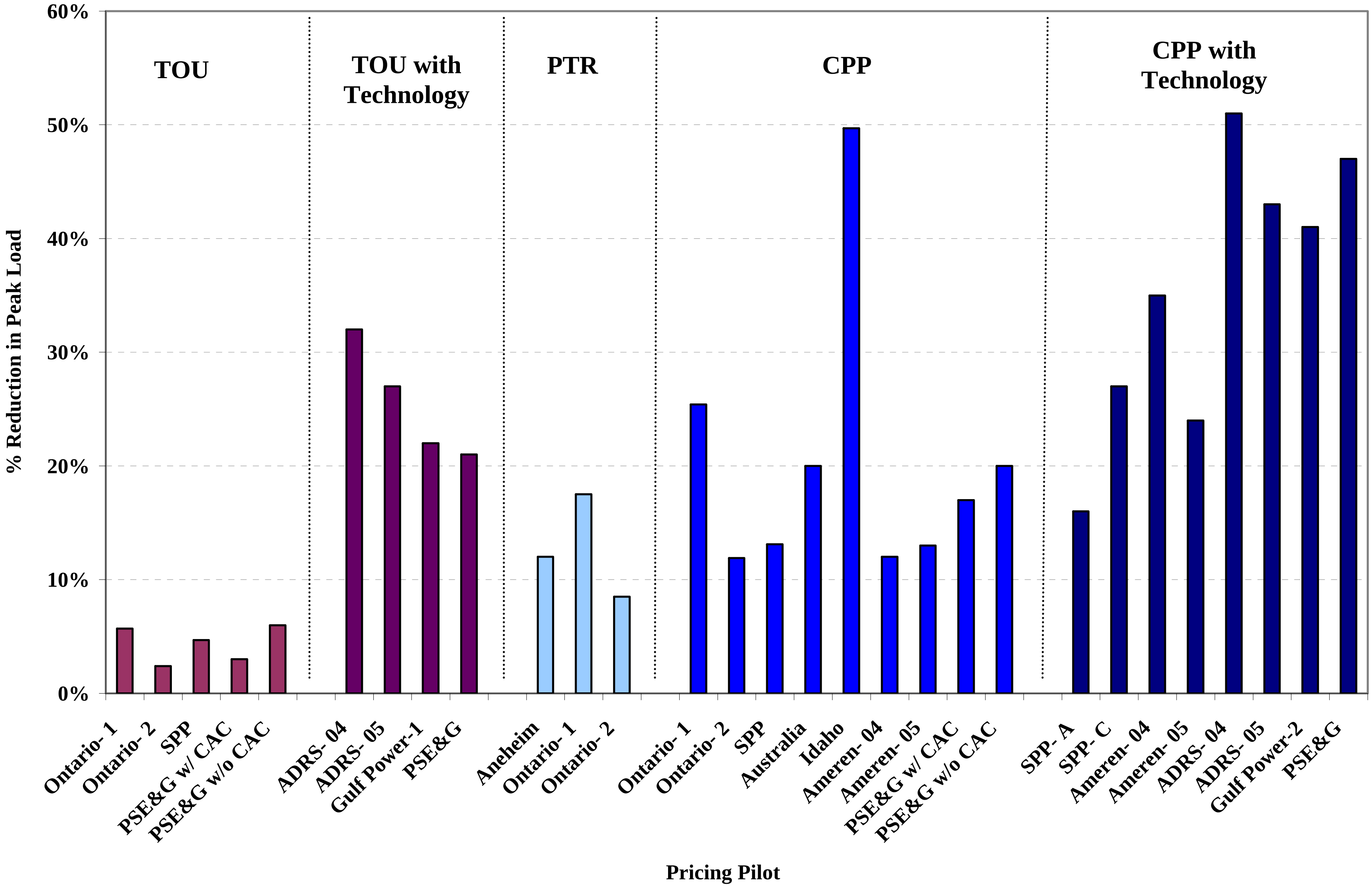
- **California-** Anaheim Peak Time Rebate Pricing Experiment
- **California-** Automated Demand Response System Experiment (ADRS), which was conducted as an adjunct to the statewide pricing pilot
- **California-** Statewide Pricing Pilot (SPP)
- **Florida-** The Gulf Power Select Program
- **France-** Electricite de France (EDF) Tempo Program
- **Idaho-** Idaho Residential Pilot Program
- **Illinois-** The Community Energy Cooperative's Energy-Smart Pricing Plan (ESPP)
- **Missouri-** AmerenUE Residential TOU Pilot Study
- **New Jersey-** GPU Pilot
- **New Jersey-** Public Service Electric and Gas (PSE&G) Residential Pilot Program
- **New South Wales/ Australia-** Energy Australia's Network Tariff Reform
- **Ontario/ Canada-** Ontario Energy Board Smart Price Pilot
- **Washington (Seattle Suburbs)-** Puget Sound Energy (PSE)'s TOU Program
- **Washington -** Olympic Peninsula Project

[5] We use the term "dynamic pricing" to refer to pricing signals that are triggered based on actual wholesale market prices and not set in advance. Thus, a time of use (TOU) rate is not a dynamic price, since the peak period is known in advance as its timing whereas under critical peak pricing (CPP), although the rate may be set in advance, the critical days are called based on wholesale market conditions.

Table 1. Overview of the Experiments

Pilot	State	Utility	Year	Number of Customers	Number of Rates Tested in the Pilot
Anaheim Critical Peak Pricing Experiment	California	Anaheim Public Utilities (APU)	2005	52 control, 71 treatment	1
California Automated Demand Response System Pilot (ADRS)	California	Pacific Gas & Electric (PG&E), Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E)	2004-2005	In 2004: 104 control, 122 treatment In 2005: 101 control, 98 treatment	1
California Statewide Pricing Pilot (SPP)	California	Pacific Gas & Electric (PG&E), Southern California Edison (SCE) and San Diego Gas & Electric (SDG&E)	2003-2004	2,500 customers	3
The Gulf Power Select Program	Florida	Gulf Power	2000-2001	2300 customers participating in the RSVP program	2
Electricite de France (EDF) Tempo Program	France	Electricite de France	Since 1996	400,000 customers	1
Idaho Residential Pilot Program	Idaho	Idaho Power Company	2005-2006	TOD Program- 420 control, 85 treatment EW Program- 355 control, 68 treatment	2
The Community Energy Cooperative's Energy-Smart Pricing Plan (ESPP)	Illinois	Community Energy Cooperative	2003-2005	1,500 customers	2
AmerenUE Residential TOU Pilot Study	Missouri	AmerenUE	2004-2005	TOU - 89 control, 88 treatment TOU/CPP- 89 control , 85 treatment TOU/CPP w/ Technology- 117 control, 77 treatment	2
GPU Pilot	New Jersey	GPU	1997	Not Available	2
Public Service Electric and Gas (PSE&G) Residential Pilot Program	New Jersey	Public Service Electric and Gas Company (PSE&G)	2006-2007	450 control, 836 treatment	1
Energy Australia's Network Tariff Reform	New South Wales	Energy Australia	2005	TOU program: 50,000 customers SPS: 1300 treatment	Tested several dynamic tariffs.
Ontario Energy Board Smart Price Pilot	Ontario/Canada	Hydro Ottawa	2006-2007	125 control, 373 treatment	3
Puget Sound Energy (PSE)'s TOU Program	Washington	Puget Sound Energy	2001-2002	300,000 customers	1
Olympic Peninsula Project	Washington and Oregon	Bonneville Power Administration, Clallam County PUD, The City of Port Angeles, Portland General Electric, and PacifiCorp	2005	28 control, 84 treatment	3

Figure 2. Estimated Demand Response Impact by Experiment



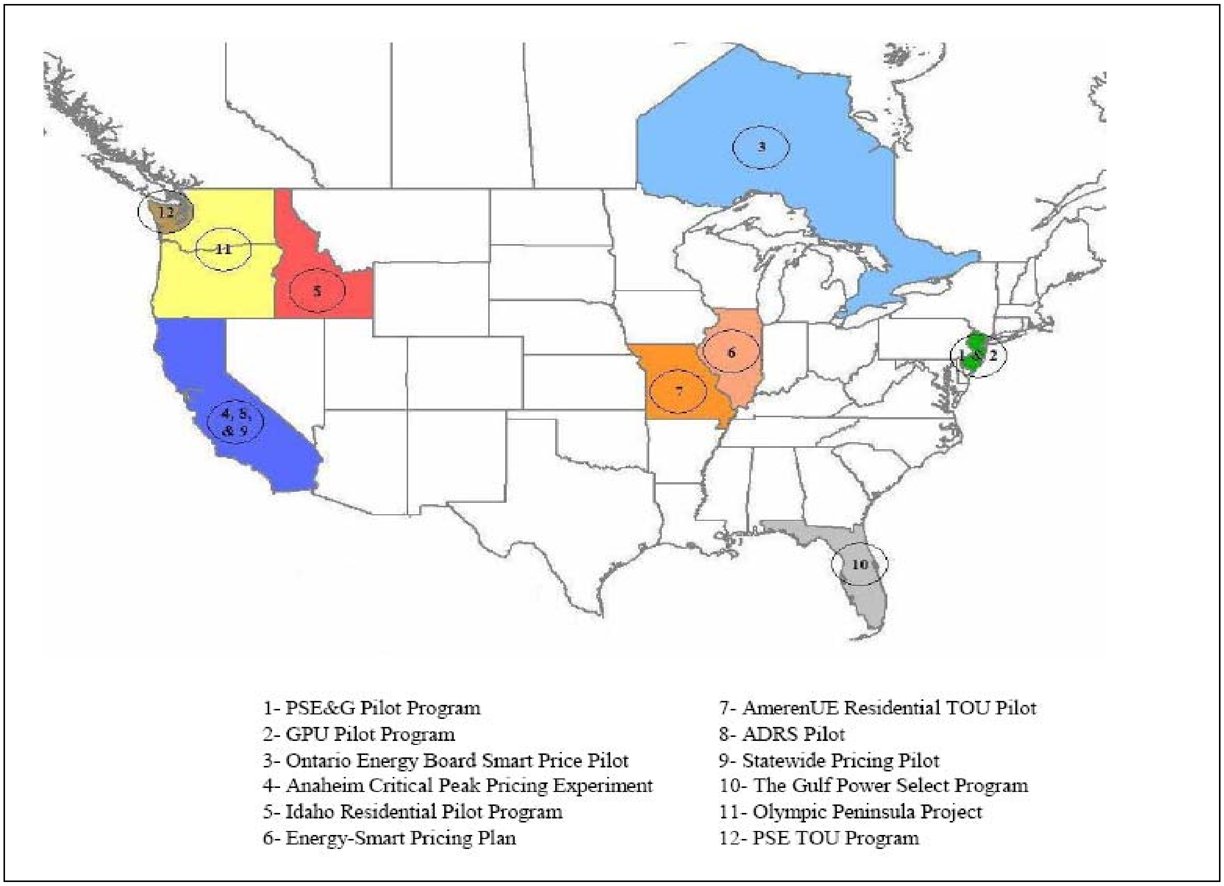
Notes:

*Percentage reduction in load is defined relative to different bases in different pilots. The following notes are intended to clarify these different definitions.

1. TOU with Technology and CPP with Technology refer to the pricing programs that had some form of enabling technologies.
2. TOU program impacts are defined relative to the usage during peak hours unless otherwise noted.
3. CPP program impacts are defined relative to the usage during peak hours on CPP days unless otherwise noted.
4. Ontario- 1 refer to the percentage impacts during the critical hours that represent only 3-4 hours of the entire peak period on a CPP day. Ontario- 2 refer to the percentage impacts of the programs during the entire peak period on a CPP day.
5. TOU impact from the SPP is based on the CPP-F treatment effect for normal weekdays on which critical prices were not offered.
6. ADRS- 04 and ADRS- 05 refer respectively to the 2004 and 2005 impacts. ADRS impacts on non-event days are represented in the TOU with Technology section.
7. CPP impact for Idaho is derived from the information provided in the reviewed study. Average of kW consumption per hour during the CPP hours (for all 10 event days) is approximately 2.5 kW for a control group customer while this value is 1.2 kW for a treatment group customer. Percentage impact from the CPP treatment is calculated as 50%.
8. Gulf Power-1 refers to the impact during peak hours on non-CPP days and therefore shown in the TOU with Technology section while Gulf Power- 2 refers to the impact during CPP hours on CPP days.
9. Ameren- 04 and Ameren- 05 refer to the impacts respectively from the summers of 2004 and 2005.
10. SPP- A refers to the impacts from the CPP-V program on Track A customers. Two thirds of Track A customers had some form of enabling technologies.
11. SPP- C refers to the impacts from the CPP-V program on Track C customers. All Track C customers had smart thermostats.

Figure 3 shows the geographical location of the North American pilot programs.

Figure 3. Geographic Coverage of the North America Pilot Programs



PRICING EXPERIMENTS

CALIFORNIA- ANAHEIM CRITICAL PEAK PRICING EXPERIMENT

The City of Anaheim Public Utilities (APU) conducted a residential Critical Peak Pricing Experiment between June 2005 and October 2005.[6] A total of 123 customers participated in the experiment: 52 in the control group and 71 in the treatment group. The CPP rate rewarded participants with a rebate of $0.35 for each kWh reduction below the reference level peak-period

[6] Wolak, Frank A., "Residential Customer Response to Real-Time Pricing: Anaheim Critical Peak Pricing Experiment," UCEI and Department of Economics, Stanford and NBER, 2007.

consumption on non-CPP days (i.e., the baseline consumption). Program rate design is presented in Table 2.

Table 2. Anaheim CPP Program Rate Design

Group	Charge	Applicable Period
Control	Standard increasing-block residential tariff: $0.0675/kWh if consumption <=240kWh per month $0.1102/kWh if consumption >240kWh per month	All hours
Treatment	Standard increasing-block residential tariff	All hours except except peak hours (12 a.m. - 6 p.m.) on CPP days
Treatment	$0.35 rebate for each kWh reduction relative to their typical peak consumption on non-CPP days.	Peak hours (12 a.m. - 6 p.m.) on CPP days

The results show that:

- The treatment group used 12% less electricity on average during the peak hours of the CPP days than the control group.
- The reduction in consumption by customers in the treatment group was greater on higher temperature CPP days.
- Comparison of the 15-minute average daily load profiles of the treatment and control groups in the pre-program period reveals that their difference is not statistically significant. This implies that the selection of treatment and control customers was random.

CALIFORNIA- AUTOMATED DEMAND RESPONSE SYSTEM PILOT[7]

California's Advanced Demand Response System (ADRS) pilot program by Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E) companies was initiated in 2004 and extended through the end of 2005. ADRS operated under a critical peak pricing tariff which was supported with a residential-scale, automated demand response technology. Participants of the pilot installed the GoodWatts system, an advanced home climate control system that allowed users to web-program their preferences for the control of home appliances. Under the CPP tariff, prices were higher during the peak period (2 p.m. to 7 p.m. on weekdays). All other hours, weekends, and holidays were subject to the base rate. When

[7] Rocky Mountain Institute, "Automated Demand Response System Pilot," 2006.

the “super peak events” were called, the peak price was three times higher than the regular peak price.

The results show that:

- Participants achieved substantial load reductions in both 2004 and 2005 compared to the control group.
- Load reductions on super peak event days were consistently about twice the load reductions during the peak periods on non-event days.
- Enabling technology appears to be the main driver of the load reductions especially on super peak event days and for the high consumption customers. Load reductions of the ADRS participants are consistently larger than those of the participants of other demand response programs without the technology.

Table 3 shows the impact estimates from the ADRS for high consumption customers on CPP event days and non-event days.

Table 3. Peak Period Load Reductions for High Consumption Customers

Program Year	Event Days		Non-Event Days	
	Average Reduction (kW)	% Reduction	Average Reduction (kW)	% Reduction
2004	1.84	51%	0.86	32%
2005	1.42	43%	0.73	27%

CALIFORNIA- STATEWIDE PRICING PILOT[8]

California’s three investor-owned utilities, Pacific Gas & Electric (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric (SDG&E), together with the two regulatory commissions conducted the Statewide Pricing Pilot (SPP) that ran from July 2003 to December 2004 to test the impact of several time-varying rates. The SPP included about 2,500 participants including residential and small-to-medium commercial and industrial (C&I) customers. SPP tested several rate structures:

- TOU-only rate where the peak price was twice the value of the off-peak price.

[8] Charles River Associates, “Impact Evaluation of the California Statewide Pricing Pilot.” 2005.

- CPP rate where the peak price during the critical days was roughly five times greater than the off-peak price. The SPP tested two variations of the CPP rates.
  - The CPP-F rate had a fixed period of critical peak and day-ahead notification. CPP-F customers did not have an enabling technology.
  - The CPP-V rate had a variable-length of peak duration during critical days and day-of notification. CPP-V customers had the choice of adopting an enabling technology.

The SPP utilized “standard demand models” derived from microeconomic theory to identify the impact of different rate and information structures on energy use. In addition to estimation of impacts associated with the average prices used in SPP, these demand models allowed estimation of the impacts from other potential prices. A demand system of two equations was estimated for each different rate structure. One of these equations models daily energy use while the other equation models the ratio of peak to off-peak usage.

In this article, we review the residential customer impacts for the three rates: CPP-F, TOU, and CPP-V.

CPP-F Impacts

The average price for customers on the standard rate was about $0.13 per kWh. Under the CPP-F rate, the average peak-period price on critical days was roughly $0.59 per kWh, the peak price on non-critical days was $0.22 per kWh, and the average off-peak price was $0.09 per kWh.

- On critical days, statewide average reduction in peak-period energy use was estimated to be 13.1 percent. Impacts varied across climate zones from a low of 7.6 percent to a high of 15.8 percent.
- The average peak-period impact on critical days during the inner summer months (July-September) was estimated to be 14.4 percent while the same impact was 8.1 percent during the outer summer months (May, June, and October).
- On normal weekdays, the average impact was 4.7 percent, with a range across climate zones from 2.2 percent to 6.5 percent.
- No change in total energy use across the entire year was found based on the average SPP prices.

- The impact of different customer characteristics on energy use by rate period was also examined. Central AC ownership and college education are the two customer characteristics that were associated with the largest reduction in energy use on critical days.

Table 4. Residential CPP-F Rate Impacts on Critical Days for Inner Summer Months (July, August, September) for All Customers

Year			Start Value (kWh/hr)	Impact (kWh/hr)	Estimate	T-stat	Impact (%)
2003	**Rate Period**	Peak	1.28	-0.163	#N/A	-20.94	-12.71
		Off-peak	0.8	0.021	#N/A	7.8	2.57
		Daily	0.9	-0.018	#N/A	-6.88	-1.95
	Elasticity	Substitution	#N/A	#N/A	-0.086	-20.51	#N/A
		Daily	#N/A	#N/A	-0.032	-6.8	#N/A
2004	**Rate Period**	Peak	1.28	-0.178	#N/A	-18.49	-13.93
		Off-peak	0.8	0.01	#N/A	2.95	1.25
		Daily	0.9	-0.029	#N/A	-8.7	-3.24
	Elasticity	Substitution	#N/A	#N/A	-0.087	-16.84	#N/A
		Daily	#N/A	#N/A	-0.054	-8.55	#N/A

Notes:

[1] Estimations are based on average customer approach. The average customer approach involves using the input values (e.g., weather, AC saturations and starting energy use values by rate period) for the average customer across all climate zones.
[2] All the numbers are based on average critical day weather in 2003/2004.

TOU Impacts

The average price for customers on the standard rate was about $0.13 per kWh. Under the TOU rate, the average peak-period price was roughly $0.22 per kWh and the average off-peak price was $ 0.09 per kWh.

- The reduction in peak period energy use during the inner summer months of 2003 was estimated to be 5.9 percent. However, this impact completely disappeared in 2004.
- Due to small sample problems in the estimation of TOU impacts, normal weekday elasticities from the CPP-F treatment may serve as better predictors of the impact of TOU rates on energy demand than the TOU price elasticity estimates.

Table 5. Residential TOU Rate Impacts for Inner Summer Months for All Customers

Year			Start Value (kWh/hr)	Impact (kWh/hr)	Estimate	T-stat	Impact (%)
2003	Rate Period	Peak	1.125	-0.063	#N/A	-11.08	-5.6
		Off-peak	0.744	0.011	#N/A	7.08	1.44
		Daily	0.823	-0.005	#N/A	-6.28	-0.57
		Weekend Daily	0.867	0.013	#N/A	4.46	1.45
	Elasticity	Substitution	#N/A	#N/A	-0.099	-10.17	#N/A
		Daily	#N/A	#N/A	-0.117	-6.26	#N/A
		Weekend Daily	#N/A	#N/A	-0.066	-4.49	#N/A
2004	Rate Period	Peak	1.125	-0.007	#N/A	#N/A	-0.6
		Off-peak	0.744	-0.005	#N/A	#N/A	-0.65
		Daily	0.823	-0.005	#N/A	#N/A	-0.64
		Weekend Daily	0.867	0.005	#N/A	#N/A	0.61
	Elasticity	Substitution	#N/A	#N/A	0.001	0.06	#N/A
		Daily	#N/A	#N/A	-0.132	-4.42	#N/A
		Weekend Daily	#N/A	#N/A	-0.028	-1.36	#N/A

Notes:

[1] Estimations are based on average customer approach.

CPP-V Impacts

The average price for customers on the standard rate was about $0.14 per kWh. Under the CPP-V rate, the average peak-period price on critical days was roughly $0.65 per kWh and the average off-peak price was $0.10 per kWh. This rate schedule was tested on two different treatment groups. Track A customers were drawn from a population with energy use greater than 600kWh per month. In this group, average income and central AC saturation was much higher than the general population. Track A customers were given a choice of installing an enabling technology and about two thirds of them opted for the enabling technology. The Track C group was formed from customers who previously volunteered for a smart thermostat pilot. All Track C customers had central AC and smart thermostats. Hence, two-thirds of Track A customers and all Track C customers had enabling technologies.

- As shown in Table 6, Track A customers reduced their peak-period energy use on critical days by about 16 percent (about 25 percent higher than the CPP-F rate impact).
- Track C customers reduced their peak-period use on critical days by about 27 percent.

Comparing the CPP-F and the CPP-V results suggest that usage impacts are significantly larger with an enabling technology than without it.

Table 6. Residential CPP-V Rate Impacts for Summer for All Customers

			Start Value (kWh/hr)	Impact (kWh/hr)	Estimate	t-stat	Impact (%)
Track A	Rate Period	Peak	2.14	-0.3374	#N/A	-10.89	-15.76
		Off-peak	1.33	0.0445	#N/A	4.26	3.34
		Daily	1.46	-0.0187	#N/A	-1.71	-1.28
		Weekend Daily	1.3	0.0173	#N/A	2.72	1.33
	Elasticity	Substitution	#N/A	#N/A	-0.111	-11.76	#N/A
		Daily	#N/A	#N/A	-0.027	-1.7	#N/A
		Weekend Daily	#N/A	#N/A	-0.043	-2.74	#N/A
Track C	Rate Period	Peak	2.33	-0.635	#N/A	-35.03	-27.23
		Off-peak	1.26	0.044	#N/A	3.19	3.52
		Daily	1.43	-0.059	#N/A	-9.85	-4.17
		Weekend Daily	1.34	0.016	#N/A	4.1	1.2
	Elasticity	Substitution	#N/A	#N/A	-0.077	-10.61	#N/A
		Technology Impact-Substitution	#N/A	#N/A	-0.214	-24.04	#N/A
		Daily	#N/A	#N/A	-0.044	-3.49	#N/A
		Technology Impact-Daily	#N/A	#N/A	-0.019	-3.49	#N/A
		Weekend Daily	#N/A	#N/A	-0.041	-4.12	#N/A

Notes:

[1] Estimations are based on average customer approach.
[2] Track A analysis was conducted for summer 2004.
[3] Track C analysis pools summers 2003 and 2004 and estimates a single model.

FLORIDA- THE GULF POWER SELECT PROGRAM[9]

In 2000, Gulf Power started a unique demand response program that provides customers with three different service options as described below.

- The standard residential service (RS) pricing option which involved a standard flat rate with no time varying rates.
- A conventional TOU pricing option (RST) which is a two-period TOU tariff.
- The Residential Service Variable Price (RSVP) pricing option which is a three-period CPP tariff.

[9] Borenstein, S., M. Jaske, and A. Rosenfeld, “Dynamic Pricing, Advanced Metering and Demand Response in Electricity Markets”, UCEI 2002.

Under the RSVP option, the energy company provides the price signals and customers modify their usage patterns through a combination of the price signals and advanced metering and appliance control. Gulf Power markets the RSVP option under the GoodCents Select program and charges the participants a monthly participation fee. By the end of 2001, approximately 2,300 homes were served by the RSVP.

Table 7 shows the rates under the Gulf Power demand response program.

Table 7. Residential Tariffs for Summer Months

Program	Period	Charge	Applicable
RS	Base	$0.057/kWh	All hours
RST	Off-peak	$0.027/kWh	12 a.m.-12 p.m. and 9 p.m.-12 a.m.
RST	Peak	$0.104/kWh	12 p.m.- 9 p.m.
RSVP	Off-peak	$0.035/kWh	12 a.m.-6 a.m. and 11 p.m.-12 a.m.
RSVP	Mid-peak	$0.046 /kWh	6 a.m.-11 a.m. and 8 p.m.-11 p.m.
RSVP	Peak	$0.093/kWh	11 a.m.-8 p.m.
RSVP	CPP	$0.29/kWh	When called

Gulf Power reports the base coincident peak demand as 6.1 KW per household (hh). RSVP program performance results presented in Table 8 show that RSVP program participants reduce their demand by 2.75 KW per household during the critical peak period corresponding to a 41% reduction in energy usage during the critical peak period.

Table 8. RSVP Program Performance by Period

Demand Reduction by Period	Performance
Average demand reduction (during peak period)	2.1 kW/hh
Average demand reduction (during critical peak period)	2.75 kW/hh
Average energy reduction (during peak period)	22%
Average energy reduction (during critical peak period)	41%

FRANCE- ÉLECTRICITÉ DE FRANCE (EDF) TEMPO PROGRAM[10]

Électricité de France (EDF) initiated the Tempo program in 1996. Rate design entails two price-tiers, peak and off-peak. A distinctive feature of the Tempo program is day-of-the-year pricing which groups the 365 days in a year into three day-types:

- *Blue days* are the least expensive 300 days.
- *White days* are moderately priced 43 days.
- *Red days* are the most expensive 22 days.

Customers learn which day would be in effect the next day through the use of several resources including web-resources, call-centers, subscription to e-mail alerts and plugging in an electrical device into their electrical sockets.

EDF implemented a pilot program before launching the Tempo on a full-scale. The pilot program set prices that were much higher than the Tempo prices. The own-price elasticity for peak demand was estimated at -0.79, much higher than any of the estimates for U.S. pilots. Own-price elasticity for off-peak usage was estimated to be -0.18.

IDAHO- IDAHO RESIDENTIAL PILOT PROGRAM[11]

Idaho Power Company initiated two residential pilot programs in the Emmett area of Idaho in the summer of 2005 and the summer of 2006: Time-of-day (TOD) and Energy Watch (EW).

Time-of-Day Pilot

The TOD pilot was designed as a conventional TOU program where the participants were charged different rates by time of the day as shown in Table 9. The TOD pilot included 85 treatment and 420 control group customers as of August 2006.

[10] Faruqui, A., S. George. 2002. "The Value of Dynamic Pricing in Mass Markets." *Electricity Journal* Vol.15.6: 45-55.

[11] Idaho Power Company, "2006 Analysis of the Residential Time-of-Day and Energy Watch Pilot Programs: Final Report," 2006.

Table 9. Rate Design for the Time-of-Day Pilot

Period	Charge	Applicable
On-Peak	$0.083/kWh	Weekdays from 1pm to 9pm
Mid-Peak	$0.061/kWh	Weekdays from 7am to 1pm
Off-Peak	$0.045/kWh	Weekdays from 9pm to 7am and all hours on weekends and holidays

As shown in Table 10, the results from the TOD pilot for the summer of 2006 show that, on average, the peak period percentage of total summer usage was the same for the treatment and control groups – about 22 percent. In fact, the percentage of usage during the mid-peak and off-peak periods was also the same between the two groups. This indicates that the TOD rates had no effect on shifting usage. However, in light of the very low ratio of on-peak to off-peak rates (about 1.84), this result is not so surprising. It suggests that a higher ratio of peak to off-peak rates is needed to induce customers to shift usage from peak to off peak periods.

Table 10. Summer 2006 (June-August) Usage under the TOD Pilot

	Average Use (kWh)		% of Total Summer Use		Program Impact	
Period	Treatment	Control	Treatment	Control	Difference (Control- Treatment)	T-stat
On-Peak	800	763	22%	22%	-36.46	0.66
Mid-Peak	591	568	16%	16%	-22.43	0.52
Off-Peak	2307	2162	62%	62%	-145.78	0.99
Summer 06 Usage	3698	3493	100%	100%	-204.67	0.87

Energy Watch Pilot

The Idaho Power Company Energy Watch (EW) pilot was designed as a critical peak pricing (CPP) pilot where the participants were notified of the CPP event on a day-ahead basis. A total of 10 EW days were called during the summer of 2006. EW was designed as follows:

- CPP hours from 5 p.m. to 9 p.m.
- Day-ahead notification
- CPP energy price of $0.20/kWh
- Non-CPP energy price of $0.054/kWh

The EW pilot included 68 treatment and 355 control group customers as of August 2006.

Table 11 shows the reduction in load (kW) on CPP days for each of the event days. Average hourly demand reduction ranged from 0.64 kW (on June 29) to 1.70 kW (on July 27). Average hourly load reduction for all ten event days was 1.26 kW. The average total load reduction for a 4-hour event was 5.03 kW.

Table 11. Energy Watch Day: Load Reductions (kW) On Each of the Ten Event Days

Hour Beginning	Hour Ending	29-Jun	11-Jul	14-Jul	18-Jul	19-Jul	25-Jul	27-Jul	3-Aug	9-Aug	15-Aug	Average
5pm	6pm	0.64	1.31	1.09	1.39	1.2	1.33	1.58	1.14	0.83	1.02	1.17
6pm	7pm	0.69	1.5	1.17	1.43	1.32	1.45	1.62	1.27	1.14	1.15	1.29
7pm	8pm	0.77	1.58	1.16	1.57	1.41	1.55	1.7	1.24	1.02	0.96	1.33
8pm	9pm	0.8	1.48	1.11	1.47	1.27	1.4	1.6	1.13	0.95	0.89	1.25
4-Hour Total		2.89	5.87	4.53	5.85	5.2	5.74	6.5	4.77	3.94	4.02	5.03
Average Hourly		0.72	1.47	1.13	1.46	1.3	1.43	1.62	1.19	0.99	1.01	1.26
Min Temp		68	65	65	61	62	75	68	59	62	67	65
Max Temp		85	100	98	94	98	99	104	92	85	92	95
Avg Temp		75	84	83	79	80	87	87	76	73	80	80

ILLINOIS- ENERGY SMART PRICING PLAN[12]

Community Energy Cooperative's Energy-Smart Pricing Plan (ESPP), a residential real-time pricing (RTP) program, started in Illinois in 2003. ESPP initially included 750 participants and expanded to nearly 1500 customers in 2005. ESPP is the only residential RTP program that has been tested at any scale. ESPP has a focus on low technology and tests the hypothesis that major benefits may result from RTP without expensive technology adoption. The ESPP design included:

- Day-ahead announcement of the hourly electricity prices for the next day (on the day of the event, customers were charged the hourly prices that had been posted the day before).
- High-price day notification via phone or email when the price of electricity is over $0.10 per kWh.

[12] Summit Blue Consulting, "Evaluation of the 2005 Energy-Smart Pricing Plan-Final Report," 2006.

- A price cap of $0.50 per kWh for participants meaning that the maximum hourly price is set at $0.50 per kWh during their participation in the program.
- Energy usage education for participants.

The main goals of the pilot were to determine the price elasticity of demand and the overall impact on energy conservation. A regression based analysis was conducted to estimate the price elasticity of demand for the summer months. Overall price elasticity was estimated to be -0.047[13].

Automatic cycling of the central-air conditioners using an enabling technology during high-price periods increased the overall price elasticity to -0.069. The largest response occurred on high-price notification days. For instance, on the day with the highest prices during the summer of 2005, participants reduced their peak hour consumption by 15% compared to what they would have consumed under the flat ComEd residential rate. Price responsiveness varied over the course of a day. Own price elasticities by time of the day are presented in Table 12.

Table 12. Elasticity Estimates from ESPP

Time of the Day	Elasticity Estimate
Daytime (8 a.m. to 4 p.m.)	-0.02
Late afternoon/evening hours (4 p.m. to midnight)	-0.03
Daytime+ High-Price Notification	-0.02
Late Daytime/Evening+High-Price Notification	-0.05

Results of the energy impact analysis indicates that ESPP participants consumed 35.2 kWh less per month during the summer months compared to what they would have consumed without the ESPP. These savings represented roughly 3 to 4% of the summer electricity usage. No statistically significant savings were found for the winter usage which is not surprising since most high price days occur in the summer months in this area. Overall, ESPP resulted in a net decrease in monthly energy usage.

[13] In other words, 100 percent increase in price leads to 4.7 percent reduction in demand.

MISSOURI- AMERENUE CRITICAL PEAK PRICING PILOT

First Year of the Pilot Program (2004)[14]

AmerenUE in collaboration with Missouri Collaborative formed by Office of Public Counsel (OPC), the Missouri Public Service Commission (MPSC), the Department of Natural Resources (DNR) and two industrial intervener groups initiated a residential TOU pilot study in Missouri during the spring of 2004. Program impacts associated with three different TOU programs were evaluated:

- TOU with peak, mid-peak, and off-peak rates
- TOU with a CPP component
- TOU with a CPP component and an enabling technology (smart thermostat)

Table 13 shows the rates evaluated in the pilot.

Table 13. Residential TOU Experiment Summer Rate Design

Program	Time	Charge	Applicable
TOU	Off Peak	$0.048/kWh	Weekday 10pm–10am, weekends, holidays
TOU	Mid Peak	$0.075/kWh	Weekdays 10am– 3pm and 7pm-10pm
TOU	Peak	$0.183/kWh	Weekdays 3pm – 7pm
TOU-CPP	Off Peak	$0.048/kWh	Weekdays 10pm–10am, weekends, holidays
TOU-CPP	Mid Peak	$0.075/kWh	Weekdays 10am– 3pm and 7pm-10pm
TOU-CPP	Peak	$0.168/kWh	Weekdays 3pm – 7pm
TOU-CPP	CPP	$0.30/kWh	Weekdays 3pm – 7pm, 10 times per summer

Table 14 shows the number of participants in the treatment and control groups by type of rate.

Table 14. Experiment Sample Allocation

Treatment	Treatment Sample Size	Control Sample Size
TOU	88	89
TOU-CPP	85	89
TOU-CPP-Tech	77	117
Total	250	295

14 RLW Analytics, "AmerenUE Residential TOU Pilot Study Load Research Analysis: First Look Results," 2004.

The following results are based on the data compiled from the pilot between June 1, 2004 and September 30, 2004. The results showed that:

- Participants in the TOU and TOU-CPP groups did not shift a statistically significant amount of load from the on-peak to off-peak or mid-peak periods. As shown in Table 15, under both TOU and TOU-CPP programs, off-peak consumption increased and peak consumption decreased only slightly for these treatment groups compared to the control groups. However, none of these differences in consumption between the treatment and control groups are statistically significant.
- As shown in Table 16, the TOU-CPP-Tech group reduced the usage by 24% during the CPP periods compared to the control group. This impact is statistically significant. While the TOU-CPP group also reduced their usage during the CPP period, this reduction is not statistically significant.

Average consumption by participants during the pilot is provided in Tables 15 and 16.

Table 15. Average Daily Participant Use by Program and Time Period- 2004

Program	June 1- September 30 Period	Control Group (kWh)	Treatment Group (kWh)	Difference	T-test	Pr> |t|	Statistical Significance of the Difference
TOU	Off Peak	33.63	34.87	-1.24	-0.71	0.479	Not Significant.
TOU	Mid Peak	23.59	22.78	0.81	0.71	0.476	Not Significant.
TOU	On Peak	13.81	13.36	0.45	0.67	0.505	Not Significant.
TOU	Seasonal	60.00	60.34	-0.34	-0.12	0.905	Not Significant.
TOU-CPP	Off Peak	35.84	38.36	-2.52	-1.19	0.235	Not Significant.
TOU-CPP	Mid Peak	24.11	24.54	-0.43	-0.34	0.733	Not Significant.
TOU-CPP	On Peak	13.82	13.29	0.54	0.73	0.466	Not Significant.
TOU-CPP	CPP	19.8	18.85	0.95	0.86	0.390	Not Significant.
TOU-CPP	Daily	62.87	65.3	-2.43	-0.72	0.473	Not Significant.
TOU-CPP-Tech	Off Peak	37.61	33.31	4.3	2.44	0.002	Significant.
TOU-CPP-Tech	Mid Peak	25.86	22.47	3.39	3	0.003	Significant.
TOU-CPP-Tech	On Peak	14.86	12.77	2.09	3.09	0.002	Significant.
TOU-CPP-Tech	CPP	21.39	15.48	5.92	6.5	0.000	Significant.
TOU-CPP-Tech	Daily	66.63	58.28	8.35	2.88	0.000	Significant.

Table 16. Average CPP Period Usage on the 6 Event Days in Summer 2004

Program	Control Group (kWh)	Treatment Group (kWh)	Difference	% Difference	T-test	Pr> |t|	Statistical Significance of the Difference
TOU-CPP	4.98	4.37	0.61	12%	2.09	0.038	Significant.
TOU-CPP-Tech	5.36	3.49	1.87	35%	8.09	0.000	Significant.

Second Year of the Pilot Program (2005)[15]

During the second year of AmerenUE Critical Peak Pricing Pilot, the first year rate design described earlier remained in effect (see Table 12). Table 17 summarizes the usage on peak periods of eight CPP days in the summer of 2005 while Table 18 provides average participant usage by time period and program.

Table 17. Average CPP Period Usage on the 8 Event Days in Summer 2005

Program	Control Group (kWh)	Treatment Group (kWh)	Difference	% Difference	T-test	Pr> |t|	Statistical Significance of the Difference
TOU-CPP	5.56	4.84	0.72	13%	3.9	0.0001	Significant.
TOU-CPP-Tech	5.29	4.05	1.14	24%	6.05	0.0001	Significant.

Table 18. Average Participant Use by Program and Time Period – 2005

Program	Jun 1- Aug 31 Period	Control Group (kWh)	Treatment Group (kWh)	Difference	T-test	Pr> |t|	Statistical Significance of the Difference
TOU-CPP	Off Peak	4495	4450	45	0.28	0.78	Not Significant.
TOU-CPP	Mid Peak	2054	2019	35	0.54	0.59	Not Significant.
TOU-CPP	On Peak	927	896	31	0.96	0.34	Not Significant.
TOU-CPP	CPP	252	219	33	3.92	0.00	Significant.
TOU-CPP-Tech	Off Peak	4147	4017	130	0.91	0.37	Not Significant.
TOU-CPP-Tech	Mid Peak	1934	1901	33	0.46	0.65	Not Significant.
TOU-CPP-Tech	On Peak	884	863	21	0.64	0.52	Not Significant.
TOU-CPP-Tech	CPP	240	182	58	5.99	0.00	Significant.

The results from Table 17 and 18 show that:

- In 2005, the TOU-CPP rate induced customers to reduce usage during CPP periods. This impact is statistically significant while the similar impact was not significant in 2004.
- In 2005, the TOU-CPP-Tech rate induced customers to reduce usage during CPP periods. This impact is statistically significant as the similar impact was in 2004.

---

15 Voytas, R., “AmerenUE Critical Peak Pricing Pilot,” presented at Demand Response Research Center Conference, Berkeley, California, 2006.

NEW JERSEY- GPU PILOT[16]

GPU offered a residential TOU pilot program with a critical peak price and enabling technology component in the summer of 1997. Rate design involved three price tiers (peak, shoulder, and off-peak) and a critical peak price that is only effective for a limited number of high-cost summer hours. Moreover, the pilot program tested the impacts from two sets of alternative rates by allocating treatment customers to two groups and subjecting each group to one of the two sets. Table 19 shows the control and treatment group rate designs.

Table 19. Experiment Rate Design

Group	Charge	Applicable
Control	Standard increasing-block residential tariff: $0.12/kWh if consumption <=600kWh per month $0.153/kWh if consumption >600kWh per month	All hours
Treatment Group 1 (High shoulder/peak design)	Off-peak: $0.065/kWh	1a.m.-8a.m. and 9p.m.-12p.m. weekdays; All day on weekends and holidays.
	Shoulder:$0.175/kWh	9a.m.-2p.m. and 7p.m.-8p.m. weekdays.
	Peak:$0.30/kWh	3p.m.-6p.m. weekdays
	Critical:$0.50/kWh	When called during peak period
Treatment Group 2 (Low shoulder/peak design)	Off-peak:$0.09/kWh	1a.m.-8a.m. and 9p.m.-12p.m. weekdays; All day on weekends and holidays.
	Shoulder:$0.125/kWh	9a.m.-2p.m. and 7p.m.-8p.m. weekdays.
	Peak:$0.25/kWh	3p.m.-6p.m. weekdays
	Critical:$0.50/kWh	When called during peak period

One important feature of this pilot is that the treatment customers were installed communication equipment that allowed them to preset their usage patterns in response to the time-varying rates and receive price signals from the utility during the critical hours.

Analysis of the hourly load data for each of the treatment and control group customers collected for the period of June through September 1997 revealed the following results:

- On non-critical weekdays, the largest usage reductions in the average hourly load were observed during the peak period and averaged to 0.53 KW or 26% relative to the control group. Load reductions were also observed during the late-morning shoulder period, but these reductions were limited compared to those during the peak period. The treatment

[16] Braithwait, S. 2000, "Residential TOU Price Response in the Presence of Interactive Communication Equipment," In *Pricing in Competitive Electricity Markets*, edited by Kelly Eakin and Ahmad Faruqui: Springer.

group with the high rate design reduced usage by roughly 50% more during each of peak and shoulder periods than the treatment group with the low-rate design.

- On CPP days, the results were similar to those on the non-CPP weekdays; though larger in magnitude, especially during the peak period. In the first hour of the peak period, average load reduction was 1.24 KW or a 50% reduction compared to the control group. During the next two peak hours, the reduction was around 1 KW, later falling to 0.59 KW on the last peak hour. Also, the treatment group usage was substantially larger than the control group during the shoulder and off-peak periods following the critical peak hours.
- On weekends, average usage was similar for the control and treatment customers, with slightly lower (though not statistically significant) levels for the treatment customers.
- Average usage over all days by the treatment group decreased compared to the control group, but the result was not statistically significant. A large portion of these reductions can be attributed to the changes in the weekday usage. Average daily usage on weekend, weekdays, and all days are presented in Table 20.

Table 20. Average Daily Usage for Summer 1997 (kWh)

	Control	Treatment	Usage Difference	% Difference
Weekdays	30.4	28.3	-2.1	-6.9%
Weekends	34.1	33.7	-0.4	-1.2%
All days	32.5	30.9	-1.6	-4.9%

Pilot results were also utilized for the estimation of the substitution elasticities. Elasticity estimates were based on two alternative demand models; the constant elasticity of substitution (CES) model and the generalized Leontief (GL) model.

- Substitution elasticity from the CES model is estimated to be -0.30 and shows the percentage change in usage ratio due to the change in price ratio between any two TOU-price periods. This estimate is larger than -0.17, the average of previous estimates from several other studies. Larger substitution elasticities from this pilot can be attributed to the presence of interactive communication equipments through which the customers preset their usage patterns of air conditioning (AC) and some other appliance.

- GL model allows substitution elasticity estimates to vary by the time-period. Substitution elasticity between peak and off-peak periods was estimated as -0.40 from the GL model. Substitution elasticities between other time-periods can be seen in Table 21.

Table 21. Elasticities of Substitution

Month	Time Period	CES	GL High Rate Tariff	GL Low Rate Tariff
1	Overall	-0.306	#N/A	#N/A
	Peak-shoulder	#N/A	-0.155	-0.166
	Peak-off-peak	#N/A	-0.395	-0.356
	Shoulder-off-peak	#N/A	-0.191	-0.187
2	Overall	-0.295	#N/A	#N/A
	Peak-shoulder	#N/A	-0.055	-0.06
	Peak-off-peak	#N/A	-0.407	-0.366
	Shoulder-off-peak	#N/A	-0.178	-0.176

NEW JERSEY- PSE&G RESIDENTIAL PILOT PROGRAM [17]

Public Service Electric and Gas Company (PSE&G) offered a residential TOU/CPP pilot pricing program in New Jersey during 2006 and 2007. The PSE&G pilot had two sub-programs. Under the first sub-program, *myPower Sense*, participants were educated about the TOU/CPP tariff and were notified of the CPP event on a day-ahead basis and the program assessed the reduction in energy use when a CPP event was called. Under the second sub-program, *myPower Connection*, also designed to assess the reduction in energy use when a CPP event was called, participants were given a free thermostat that received price signals from PSE&G and adjusted their air conditioning settings (CAC) based on previously programmed set points. A total of 1,148 customers participated in the pilot program; 450 in the control group, 379 in myPower Sense, and 319 in myPower Connection. PSE&G recruited the participants separately for each group through direct mail with follow-up telemarketing[18]. Customers didn't have the opportunity to choose the treatment they would be receiving. *myPower Sense* customers received a $25 incentive upon enrollment and another $75 to be paid upon the conclusion of the program.

[17] PSE&G and Summit Blue Consulting, "Final Report for the myPower Pricing Segments Evaluation" December 2007.

[18] PSE&G recruited pilot participants from Cherry Hill and Hamilton towns as they had high percentages of residents on standard rates and high predicted penetrations of CAC.

myPower Connection participants were provided free programmable thermostats and received $75 at the end of the program.

The TOU/CPP tariff included a night discount, a base rate, an on-peak adder, and a critical peak adder for the summer months as shown in Table 22.

Table 22. TOU/CPP Rate Design: Summer Months (June to September 2006 and 2007)

Period	Charge (June to September 2006)	Charge (June to September 2007)	Applicable
Base Price	$0.09/kWh	$0.087/kWh	All hours
Night Discount	-$0.05/kWh	-$0.05/kWh	10 p.m.-9 a.m. daily
On Peak Adder	$0.08/kWh	$0.15/kWh	1 p.m.-6 p.m. weekdays
Critical Peak Adder	$0.69/kWh	$1.37/kWh	1 p.m.-6 p.m. weekdays when called (Added to the base price when called)

PSE&G called two CPP events in Summer 2006 and five CPP events in Summer 2007. Table 23 summarizes the peak demand impacts on these 7 CPP event days. Results show that:

- *myPower Connection customers* reduced their peak demand by 21% due to TOU-only pricing. These customers reduced their peak load by an additional 26% on CPP event days.
- *myPower Sense* customers with CAC ownership reduced their peak demand by 3% on TOU-only days. On CPP event days, their peak load reductions reached to 17%. Interestingly, *myPower Sense* customers without CAC ownership achieved 6 % peak reductions on TOU-only days while the reductions reached 20% on CPP event days.
- *myPower Connection* customers reduced their peak-demand consistently more than *myPower Sense* customers. The larger reductions for *myPower Connection* customers were not surprising since these customers had an enabling technology (i.e., the smart thermostat) whereas the myPower Sense customers did not.

Table 23. Estimated Peak Demand Impacts on 2006 and 2007 Summer CPP Event Days (Average kW per Hour)

Impact Estimate	Base Average Peak Consumption (kW)	TOU Impact		CPP Impact		Total Impact	
		kW	%	kW	%	kW	%
myPower Connection	2.85	-0.59	-21%	-0.74	-26%	-1.33	-47%
myPower Sense with CAC	2.6	-0.07	-3%	-0.36	-14%	-0.43	-17%
myPower Sense without CAC	1.61	-0.09	-6%	-0.23	-14%	-0.32	-20%

Source: Summit Blue analysis of PSEG myPower data

Study also estimates summer substitution elasticities for *myPower Connection and myPower Sense* customers. Table 24 presents the elasticity estimates and the associated lower and upper bounds for 90% confidence level.

As expected, *myPower Connection* customers have the largest elasticity of substitution, followed respectively by *myPower Sense* customers with and without CAC ownership. A substitution elasticity of -0.125 implies that a 100% increase in the peak to off-peak price ratio leads to a 12.5% decrease in the peak to off-peak demand ratio for *myPower Connection* customers.

Table 24. Estimated Substitution Elasticity for Summers 2006 and 2007

Impact Estimate	Substitution Elasticity	90% Confidence Interval
myPower Connection	-0.125	-0.12 to -0.131
myPower Sense with CAC	-0.069	-0.063 to -0.075
myPower Sense without CAC	-0.063	-0.055 to -0.072

NEW SOUTH WALES/AUSTRALIA- ENERGY AUSTRALIA'S NETWORK TARIFF REFORM [19]

The Time of Use (TOU) pricing program is the largest demand management project by Energy Australia. Recent price elasticity estimates from the TOU tariffs are presented in Table 25.

[19] Harry Colebourn, "Network Price Reform," presented at BCSE Energy Infrastructure and Sustainability Conference, December 2006.

Table 25. TOU Price Elasticity Estimates

Type	Season	Peak Own Price Elasticity	Peak to Shoulder Cross Price Elasticity	Peak to Off-Peak Cross Price Elasticity
Residential	Summer 2006 Winter 2006	-0.30 to -0.38 -0.47	-0.07 -0.12	-0.04 #N/A
Business (less than 40 MWh)	Summer 2006 Winter 2006	-0.16 to -0.18 (ns) -0.2 (ns)	-0.03 #N/A	#N/A #N/A
Business (40 MWh to 160 MWh)	Summer 2006 Winter 2006	-0.03 to -0.13 (ns) -0.02 to -0.09 (ns)	#N/A #N/A	#N/A #N/A

Note: ns refers to "not statistically significant"

The TOU results show that:

- Slight energy conservation effects resulted from residential consumption under TOU rates (compared to residential consumption under the flat tariffs).
- Conservation effects were larger in winter than in summer for the residential customers.
- Business customer price elasticities are not statistically significant. Therefore, they should be interpreted with caution.

Energy Australia started the Strategic Pricing Study in 2005 which included 1,300 voluntary customers (50% business, 50% resident customers). The study tested seasonal, dynamic, and information only tariffs and involved the use of in-house displays and online access to data. Study participants received dynamic peak price signals through Short Message Service (SMS), telephone, email, or the display unit.

Preliminary results that are available from three dynamic peak pricing (DPP) events show that:

- Residential customers reduced their dynamic peak consumption by roughly 24% for DPP high rates (A$2+/kWh) and roughly 20% for DPP medium rates (A$1+/kWh).
- Response to the 2nd DPP event was greater than that to the 1st DPP event. This may be attributed to the day-ahead notification under the 2nd DPP event (versus day-of notification under the 1st DPP event) and/or temperature differences.
- Response to the 2nd event was also greater than to the 3rd DPP event. This may be explained by lower temperatures on the 3rd DPP event which may have led to less discretionary appliances to turn off.

ONTARIO/CANADA- ONTARIO ENERGY BOARD SMART PRICE PILOT[20]

The Ontario Energy Board operated the residential Ontario Smart Price Pilot (OSPP) between August 2006 and March 2007. The OSPP used a sample of Hydro Ottawa residential customers and tested the impacts from three different price structures:

- The existing Regulated Price Plan (RPP) TOU: The RPP TOU rates are shown in Table 26.
- RPP TOU rates with a CPP component (TOU CPP). The CPP was set at C$0.30 per kWh based on the average of the 93 highest hourly Ontario electricity prices in the previous year. The RPP TOU off-peak price was decreased to C$0.031 (from C$0.035) per kWh to offset the increase in the critical peak price. The maximum number of critical day events was set at 9 days, however only 7 CPP days were called during the pilot.
- RPP TOU rates with a critical peak rebate (TOU CPR): The CPR provided participants with a C$0.30 per kWh rebate for each kWh of reduction from estimated baseline consumption. The CPR baseline consumption was defined as the average usage during the same hours over the participants' last five non-event weekdays, increased by 25%.

Table 26. Regulated Price Plan (RPP) TOU Rate Design

Season	Time	Charge	Applicable
Summer (Aug 1- Oct 31)	Off-peak	C$0.035/kWh	10 p.m.- 7 a.m. weekdays; all day on weekends and holidays
Summer (Aug 1- Oct 31)	Mid-peak	C$0.075/kWh	7 a.m.- 11 a.m. and 5 p.m.- 10 p.m. weekdays
Summer (Aug 1- Oct 31)	On-peak	C$0.105/kWh	11 a.m.- 5 p.m. weekdays

A total of 373 customers participated in the pilot: 124 in TOU-only, 124 in TOU-CPP, and 125 in TOU-CPR. The control group included 125 participants who had smart meters installed but continued to pay non-TOU rates.

[20] Ontario Energy Board, "Ontario Energy Board Smart Price Pilot Final Report," 2007.

The OSPP results show that:

- The load shift during the critical hours of the four summer CPP events ranged between 5.7 % and 25.4 %. [21]
- The load shift during the entire peak period of the four summer CPP events ranged between 2.4% and 11.9%.

Table 27 shows the shift in load during the summer CPP events as a percentage of the load in critical peak hours and of the entire peak period. It is important to note that the percentage reductions for the TOU-only customers are not significant at the 90% confidence level.

Table 27. Percentage Shift in Load During the Four Summer CPP Events Under Different Rate Structures

Period	TOU- only	TOU- CPP	TOU- CPR
Shift as % of critical peak hours	5.7%	25.4%	17.5%
Shift as % of all peak hours	2.4%	11.9%	8.5%

This study also analyzed the total conservation impact during the full pilot period. The total reduction in electricity consumption due to program impacts is reported in Table 28. The average conservation impact across all customers was 6%.

Table 28. Total Conservation Effect for the Full Pilot Duration (Treatment Compared to Control Group)

Program	% Reduction in Total Electricity Usage
TOU-only	6.0%
TOU- CPP	4.7% (ns)
TOU- CPR	7.4%
Average Impact	6.0%

[21] Under the OSPP, 3 to 4 hours of the peak period were defined as critical on a CPP day.

SEATTLE SUBURBS- PUGET SOUND ENERGY (PSE)'S TOU PROGRAM[22]

PSE initiated a time-of-use (TOU) program for its residential and small commercial customers in 2001. Rate design involved four price tiers. Prices were most expensive during the morning and evening periods with mid-day and economy periods following these most expensive periods. 300,000 PSE customers were placed in the program and given the option to go back to the standard rates if they were not satisfied with the program. Peak price was roughly 15% higher than the average price prevailed before the program and the off-peak price was 15% lower. In 2002, the second year of the program, customers were charged a monthly fee of $1 per month for meter-reading costs. The results of PSE's quarterly report revealed that the 94% of the customers paid an extra $0.80 (the total of $0.20 power savings and $1 meter reading costs) by participating in the pilot. This was in contrast with the 1st year results where customers were not charged meter reading costs and around 55% of them experienced bill savings. As the result of customer dissatisfaction and negative media coverage, PSE ceased its TOU program. Following are several lessons that were derived from this experience:

- Modest price differentials between peak and off-peak may induce customers to shift their load if they are accompanied with unusual circumstances such as the energy crisis of 2000-2001 in the West. An independent analysis of the program found that the customers lowered peak usage by 5 % per month over a 15 month period.
- It is important to provide the customers with accurate expectations about their bill savings.
- It is essential to offer a pilot program before implementing a full-scale program.

WASHINGTON- THE OLYMPIC PENINSULA PROJECT[23]

The Olympic Peninsula Project was a component of the Pacific Northwest GridWise Testbed Demonstration that took place in Washington and was led by the Pacific Northwest National Laboratory (PNNL). The Peninsula Project tested whether automated two-way communication systems between grid and passive resources (i.e., end use loads and idle distributed generation) and the use of price signals as instruments would be effective in reducing the stress on the

---

[22] Faruqui, A., S. George. 2003. "Demise of PSE's TOU Program Imparts Lessons." Electric Light& Power Vol. 81.01:14-15.

[23] Pacific Northwest National Laboratory. "Pacific Northwest GridWise Testbed Demonstration Projects Part 1: Olympic Peninsula Project", 2007.

system. This review will focus on the residential response and will not cover the impacts associated with the distributed generation resources.

By the end of 2005, the project recruited 112 participants with the assistance of the local utility companies. Project received a mailing list from the utilities of the potential participants who had high-speed internet, electric HVAC systems, electric water heater, and electric dryer and mailed recruiting letters to these potential participants. At the end of the recruiting process, 112 residential homes were installed with the two-way communication equipments that allowed utilities to send the market price signals to the consumers and allowed consumers to pre-program their demand response preferences. These 112 residential participants were then evenly divided into three treatment groups and a control group. Control group homes were also installed the equipments, but these customers had no program accounts, program contacts or program bills.

Each treatment group was assigned to one of the three electricity contracts:

- Fixed-price program contract: prices remained constant at all times.
- Time-of-use/critical peak price (TOU/CPP) program contract: prices differed between peak and off-peak time periods. Peak price were much higher during critical peak days.
- Real time contract: prices under this contract were unpredictable and varied every five minutes. Participants of this contract responded to real time prices by pre-setting their appliance controls for their preferences through the web but they still had the option to override their preferences at any time.

Table 29 shows the prices that prevailed under fixed price and TOU/CPP contracts.

Table 29. Experimental Rate Design

Contract	Season	Period	Charge	Applicable
Time-of-Use/ CPP	Spring (1 Apr-24 Jul) and Fall/Winter (1 Oct-31 Mar)	Off-peak	$0.04119/kWh	9 am-6pm and 9pm-6am
		On-peak	$0.1215/kWh	6am-9am and 6pm-9pm
		Critical	$0.35/kWh	Not called
	Summer (25 Jul- 30 Sep)	Off-peak	$0.05/kWh	9am-3pm
		On-peak	$0.135/kWh	3pm-9pm
		Critical	$0.35/kWh	When called
Fixed-Price	All seasons	All day	$0.081/kWh	All hours

Results from the pilot for the residential participants are as follows:

- The fixed-price group saved 2% on their average monthly bill compared to the control group; time-of-use group saved 30%, and real time group saved 27%.
- Differences in average energy consumption between the contract groups were small but statistically significant. The time-of-use group consumed 21% less energy and achieved conservation benefits from time-of-use pricing. The real time group consumed as much as the control group. The fixed-price group used 4% more energy than the control group. The usage comparison across the contract groups is presented in Table 30.

Table 30. Average Daily Energy Consumption per Home (April 06- December 06)

Contract Type	Average Daily Energy Consumption (kWh)	Standard Deviation(kWh)	Percentage Difference (compared to the control)
Control	47	24	0%
Fixed	49	22	4%
Time-of-Use	39	29	-21%
Real-Time	47	26	0%

- Examination of the residential load shapes by contract and season revealed that the time-of-use/CPP contract was the most effective design at reducing the peak-demand.
- On average, the real-time contract doesn't bring the lowest average peak demand. This is explained by the fact that the real-time pricing induces the response when it is most needed, during a relatively small portion of all hours. Nevertheless, real-time price control was effective at reducing congestion peaks when that was most needed.

CONCLUSIONS

This article reviews the most recent evidence on the effectiveness of residential demand response dynamic pricing programs in the United States and elsewhere. Our review of the fourteen recent experiments points to demand impacts that vary from modest to substantial, largely depending on the time-varying rates used in the experiments and the availability of enabling technologies integrated into the experiment designs. We observe that, on average, treatment customers with TOU rates reduce their peak period consumption by approximately 5%. When TOU rates are paired with enabling technologies, peak load reductions reach to 25% on average.

Complementing a TOU rate design with a critical peak price component increases the program effectiveness and leads to peak load reductions in the order of 20% on CPP event days. Finally, the largest peak load reductions can be attributed to the CPP programs with enabling technologies. Under these programs, treatment customers reduce their peak period consumption on CPP days by approximately 30%, on average. These observations reveal that the residential dynamic pricing designs can be effective demand side resources in reducing peak electrical consumption. This has essential implications for the reliability and least cost operation of an electric power system facing ever increasing demand for power and surging capacity costs. A demand response program that blends together the customer education initiatives, enabling technology investments, and carefully designed time-varying rates can achieve demand impacts that can alleviate the pressure on the power system.

SUMMARY EXHIBITS

Table 31. Central Air Conditioning (CAC) Saturations from the Studies Reviewed

Pilot	Program	CAC Saturation
PSE&G Residential Pilot Program	CPP CPP w/ Tech	62% 100%
Ontario Energy Board Smart Price Pilot	TOU, CPP, and PTR	85%
California Statewide Pricing Pilot	TOU, CPP-F, and CPP-V	Average= 38 % CAC= 100 % No-CAC= 0 %

Table 32. Summary of the Experimental Tariffs from the Studies Reviewed

Study	Control Group Tariff	Applicable Period	Treatment Group Tariff	Applicable Period
California- Anaheim Peak Time Rebate Pricing Experiment	\$0.0675/kWh \$0.1102/kWh	Usage<=240kWh per month Usage>240kWh per month	**PTR/** Control group tariff **PTR/** \$0.35/kWh rebate for each kWh reduction from baseline	All hours except 12a.m.- 6p.m. on CPP days. 12a.m.- 6p.m. on CPP days.
California- Statewide Pricing Pilot	\$0.13/kWh.	All hours	**TOU/** Off-peak: \$0.09/kWh **TOU/** Peak: \$0.22/kWh **CPP-F/** Off-peak: \$0.09/kWh **CPP-F/** Peak: \$0.22/kWh **CPP-F/** CPP: \$0.59/kWh **CPP-V/** Off-peak: \$0.10/kWh **CPP-V/** Peak: \$0.22/kWh **CPP-V/** CPP: \$0.65 /kWh	12a.m.- 2 p.m. and from 7 p.m. until 12a.m. weekdays, all day on weekends. 2 p.m. to 7 p.m. weekdays. 12a.m.- 2 p.m. and from 7 p.m. until 12a.m. weekdays, all day on weekends. 2 p.m. to 7 p.m. weekdays. 2 p.m. to 7 p.m. weekdays when called. 12a.m.- 2 p.m. and from 7 p.m. until 12a.m. weekdays, all day on weekends. 2 p.m. to 7 p.m. weekdays. 2 or 5 hours during 2 p.m. to 7 p.m., weekdays when called.
Florida- The Gulf Power Select Program	\$0.057/kWh	All hours	**RST/** Off-peak: \$0.027/kWh **RST/** Peak: \$0.104/kWh **RSVP/** Off-peak: \$0.035/kWh **RSVP/** Mid-peak: \$0.046 /kWh **RSVP/** Peak: \$0.093/kWh **RSVP/** CPP: \$0.29/kWh	12 a.m.-12p.m. and 9p.m.-12a.m. 12p.m.- 9p.m. 12a.m.-6a.m. and 11p.m.-12a.m. 6a.m.-11a.m. and 8p.m.-11p.m. 11a.m.-8p.m. Assigned hours on CPP days.
Idaho- Idaho Residential Pilot Program	\$0.054/kWh \$0.061/kWh	Usage<= 300 kWh per month Usage>300 kWh per month	**TOU/** Off-peak: \$0.045/kWh **TOU/** Mid-peak: \$0.061 /kWh **TOU/** On-peak: \$ 0.083/kWh **CPP/** Non-CPP hours: \$0.054/kWh **CPP/** CPP: \$0.20/kWh	9p.m. to 7a.m. weekdays, all day on weekends. 7a.m. to 1p.m. weekdays. 1p.m. to 9p.m. weekdays. All hours except CPP hours. 5 p.m. to 9 p.m. on CPP days.
Missouri- AmerenUE Residential TOU Pilot Study	#N/A	#N/A	**TOU/** Off-peak: \$0.048/kWh **TOU/** Mid-peak: \$0.075/kWh **TOU/** On-peak: \$0.1831/kWh **CPP/** same as TOU except that there is a CPP component set at \$0.30/kWh and peak price is decreased to \$0.1675 /kWh	10p.m.–10a.m. weekdays, all day on weekends. 10a.m.– 3p.m. and 7p.m.-10p.m. weekdays. 3p.m. – 7p.m. weekdays. CPP days when called, otherwise same as TOU.

Table 32. (Cont'd) Summary of the Experimental Tariffs from the Studies Reviewed

Study	Control Group Tariff	Applicable Period	Treatment Group Tariff	Applicable Period
New Jersey- GPU Pilot	$0.12/kWh $0.153/kWh	Usage<=600kWh Usage>600kWh	**High-rate Design** **CPP/** Off-peak: $0.065/kWh **CPP/** Shoulder:$0.175/kWh **CPP/** Peak:$0.30/kWh **CPP/** Critical:$0.50/kWh **Low-rate Design** **CPP/** Off-peak:$0.09/kWh **CPP/** Shoulder:$0.125/kWh **CPP/** Peak:$0.25/kWh **CPP/** Critical:$0.50/kWh	 1a.m.-8a.m. and 9p.m.-12p.m. weekdays, all day on weekends and holidays. 9a.m.-2p.m. and 7p.m.-8p.m. weekdays. 3p.m.-6p.m. weekdays When called during peak period 1a.m.-8a.m. and 9p.m.-12p.m. weekdays, all day on weekends and holidays. 9a.m.-2p.m. and 7p.m.-8p.m. weekdays. 3p.m.-6p.m. weekdays When called during peak period
New Jersey- PSE&G Residential Pilot Program	$0.087/kWh	All hours	**CPP/** Night: $0.037/kWh **CPP/** Peak: $0.24/kWh **CPP/** CPP: $1.46/kWh	10 p.m.-9a.m. daily. 1p.m.-6p.m. weekdays. 1p.m.-6p.m. weekdays when called.
Ontario/ Canada- Ontario Energy Board Smart Price Pilot	$0.058/kWh $0.067/kWh	Usage<= 600 kWh per month Usage>600 kWh per month	**TOU/** Off-peak: $0.035/kWh **TOU/** Mid-peak: $0.075/kWh **TOU/** On-peak: $0.105/kWh **CPP/** same as TOU except that there is a CPP component set at $0.30/kWh and off-peak price is decreased to $0.031/kWh **PTR/** same as TOU with PTR at $0.30/kWh for each kWh reduction from the baseline	10 p.m.- 7 a.m. weekdays, all day on weekends and holidays. 7 a.m.- 11 a.m. and 5 p.m.- 10 p.m. weekdays. 11 a.m.- 5 p.m. weekdays. CPP days when called, otherwise same as TOU. CPP days when called, otherwise same as TOU.
Washington - Olympic Peninsula Project	#N/A	#N/A	**Summer** **CPP/** Off-peak:$0.05/kWh **CPP/** On-peak:$0.135/kWh **CPP/** Critical:$0.35/kWh **Fall/ Spring/ Winter** **CPP/** Off-peak:$0.04119/kWh **CPP/** On-peak:$0.1215/kWh **CPP/** Critical:$0.35/kWh **Fixed Price/** All hours:$0.081/kWh	 9 am-6pm and 9pm-6am 6am-9am and 6pm-9pm Not called 9am-3pm 3pm-9pm When called All hours

Table 33. Summary of the Experimental Elasticities from the Studies Reviewed

Pilot	Program	Substitution Elasticity	Own Price Elasticity	Cross Price Elasticity
New Jersey- PSE&G Residential Pilot Program	CPP w/ CAC	-0.069	#N/A	#N/A
	CPP w/o CAC	-0.063		
	CPP w/ Tech.	-0.125	#N/A	#N/A
Illinois- The Community Energy Cooperative's Energy-Smart Pricing Plan	RTP	#N/A	-0.047 (Overall)	#N/A
	RTP	#N/A	-0.069 (Overall with AC cycling)	#N/A
	RTP	#N/A	-0.015 (Daytime)	#N/A
	RTP	#N/A	-0.026 (Late daytime/evening)	#N/A
	RTP	#N/A	-0.02 (Daytime+high price notification)	#N/A
	RTP	#N/A	-0.048 (Late daytime/evening+high price notification)	#N/A
New South Wales/ Australia- Energy Australia's Network Tariff Reform	TOU	#N/A	-0.30 to -0.38	-0.07 (Peak to shoulder)
	TOU	#N/A	#N/A	-0.04 (Peak to off-peak)
California- Statewide Pricing Pilot	CPP-F	-0.087	-0.054 (daily)	#N/A
	CPP-V/ Track A	-0.111	-0.027 (daily)	#N/A
	CPP-V/ Track A	#N/A	-0.043 (weekend daily)	#N/A
	CPP-V/ Track C	-0.154 (*)	-0.044 (daily)	#N/A
	CPP-V/ Track C	#N/A	-0.041 (weekend daily)	#N/A
New Jersey- GPU Pilot		**1st Month**		
	CPP w/ Tech.	-0.306 (Overall)	#N/A	#N/A
	CPP w/ Tech.	-0.155, -0.166 (Peak-shoulder)	#N/A	#N/A
	CPP w/ Tech.	-0.395, -0.356 (Peak-off-peak)	#N/A	#N/A
	CPP w/ Tech.	-0.191, -0.187 (Shoulder-off-peak)	#N/A	#N/A
		2nd Month		
	CPP w/ Tech.	-0.295 (Overall)	#N/A	#N/A
	CPP w/ Tech.	-0.055, -0.06 (Peak-shoulder)	#N/A	#N/A
	CPP w/ Tech.	-0.407, -0.366 (Peak-off-peak)	#N/A	#N/A
	CPP w/ Tech.	-0.178, -0.176 (Shoulder-off-peak)	#N/A	#N/A

(*) Elasticity of substitution for CPP-Track C customers is estimated to be -0.077 and excludes the impact of technology (-0.214).
We calculated substitution elasticity including the impact of technology as -0.154 through simulation.

BIBLIOGRAPHY

Borenstein, S., M. Jaske, and A. Rosenfeld. 2002. "Dynamic Pricing, Advanced Metering and Demand Response in Electricity Markets." UCEI.

Braithwait, S. 2000. Residential TOU Price Response in the Presence of Interactive Communication Equipment. In *Pricing in Competitive Electricity Markets*, edited by K. E. Ahmad Faruqui: Springer.

Caves, D. W., L. R. Christensen, and J. A. Herriges. 1984. "Consistency of Residential Customer Response in Time-of-Use Electricity Pricing Experiments." *Journal of Econometrics* 26:179-203.

CRA International. 2005. "Impact Evaluation of the California Statewide Pricing Pilot." March, 2005.

Colebourn H. 2006. "Network Price Reform." presented at BCSE Energy Infrastructure& Sustainability Conference. December, 2006.

Faruqui, A and J. R. Malko. 1983. "The Residential Demand for Electricity by Time-of-Use: A Survey of Twelve Experiments with Peak Load Pricing." *Energy* Vol. 8: 781-795.

Faruqui, A., R. Hledik, S. Newell, and J. Pfeifenberger. 2007. "The Power of Five Percent." The Electricity Journal Vol. 20, Issue 8:68-77.

Faruqui, A., S. George. 2002. "The Value of Dynamic Pricing in Mass Markets." *Electricity Journal* Vol.15.6: 45-55.

Faruqui, A., S. George. 2003. "Demise of PSE's TOU Program Imparts Lessons." *Electric Light& Power* Vol. 81.01:14-15.

Idaho Power Company. 2006. "Analysis of the Residential Time-of-Day and Energy Watch Pilot Programs: Final Report." December, 2006.

Ontario Energy Board. 2007. "Ontario Energy Board Smart Price Pilot Final Report." July, 2007.

Pacific Northwest National Laboratory. 2007. "Pacific Northwest GridWise Testbed Demonstration Projects Part 1: Olympic Peninsula Project." October, 2007.

PSE&G and Summit Blue Consulting. 2007. "Final Report for the Mypower Pricing Segments Evaluation." December, 2007.

RLW Analytics. 2004. "AmerenUE Residential TOU Pilot Study Load Research Analysis: First Look Results." February, 2004.

Rocky Mountain Institute. 2006. "Automated Demand Response System Pilot, Final Report." March, 2006.

Summit Blue Consulting, LLC. 2006. "Evaluation of the 2005 Energy-Smart Pricing Plan-Final Report." August, 2006.

U.S. Department of Energy (DOE). 2006. "Benefits of Demand Response in Electricity Markets and Recommendations for Achieving Them: A Report to the United States Congress Pursuant to Section 1252 of the Energy Policy Act of 2005." February, 2006.

Voytas. R. 2006. "AmerenUE Critical Peak Pricing Pilot." presented at Demand Response Resource Center Conference, June 2006.

Wolak, F. A. 2007. "Residential Customer Response to Real-Time Pricing: Anaheim Critical Peak Pricing Experiment." UCEI and Department of Economics, Stanford and NBER.