The Brattle Group

The Zen of PRISMetrics

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San Diego, CA
September 24, 2009

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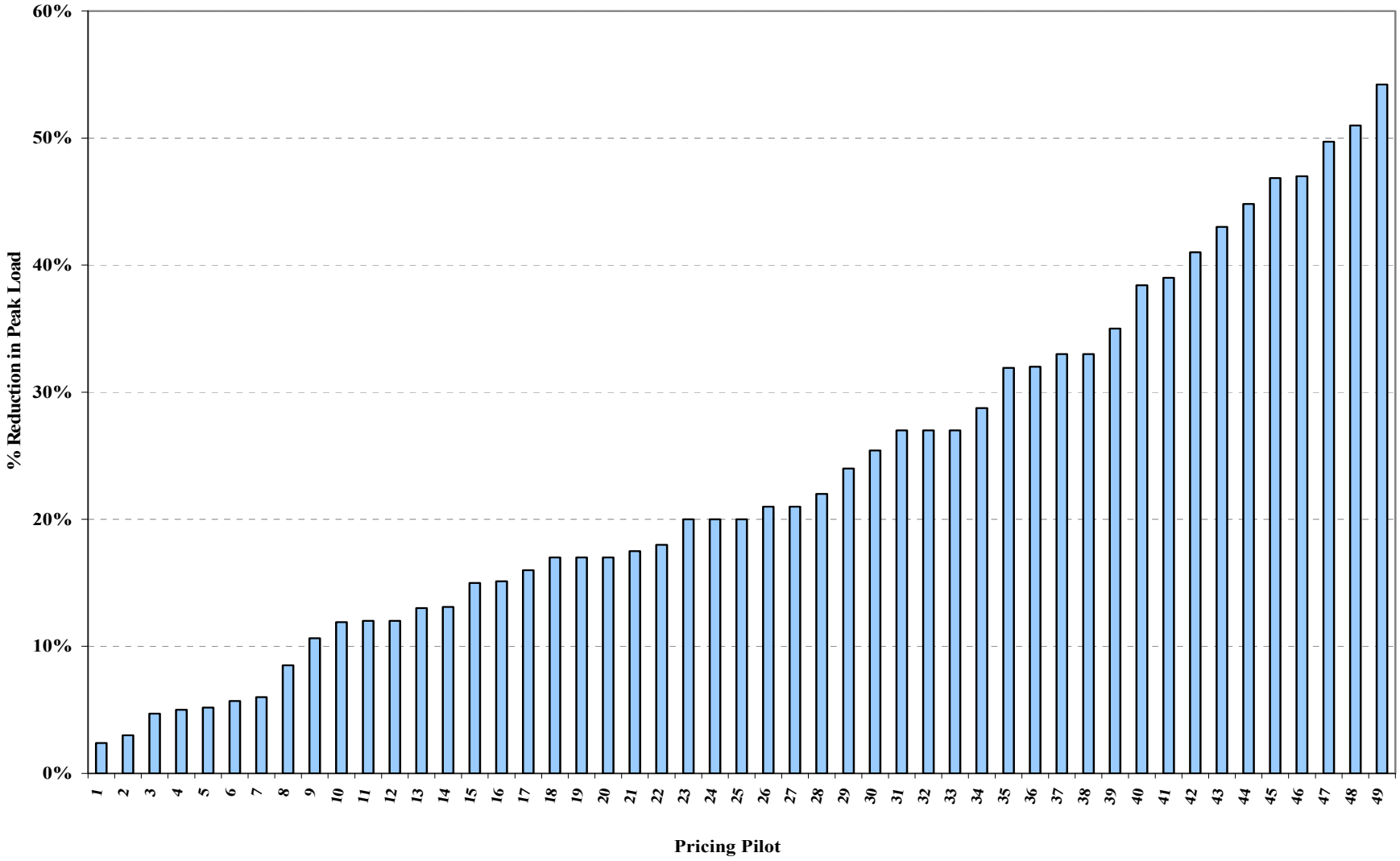
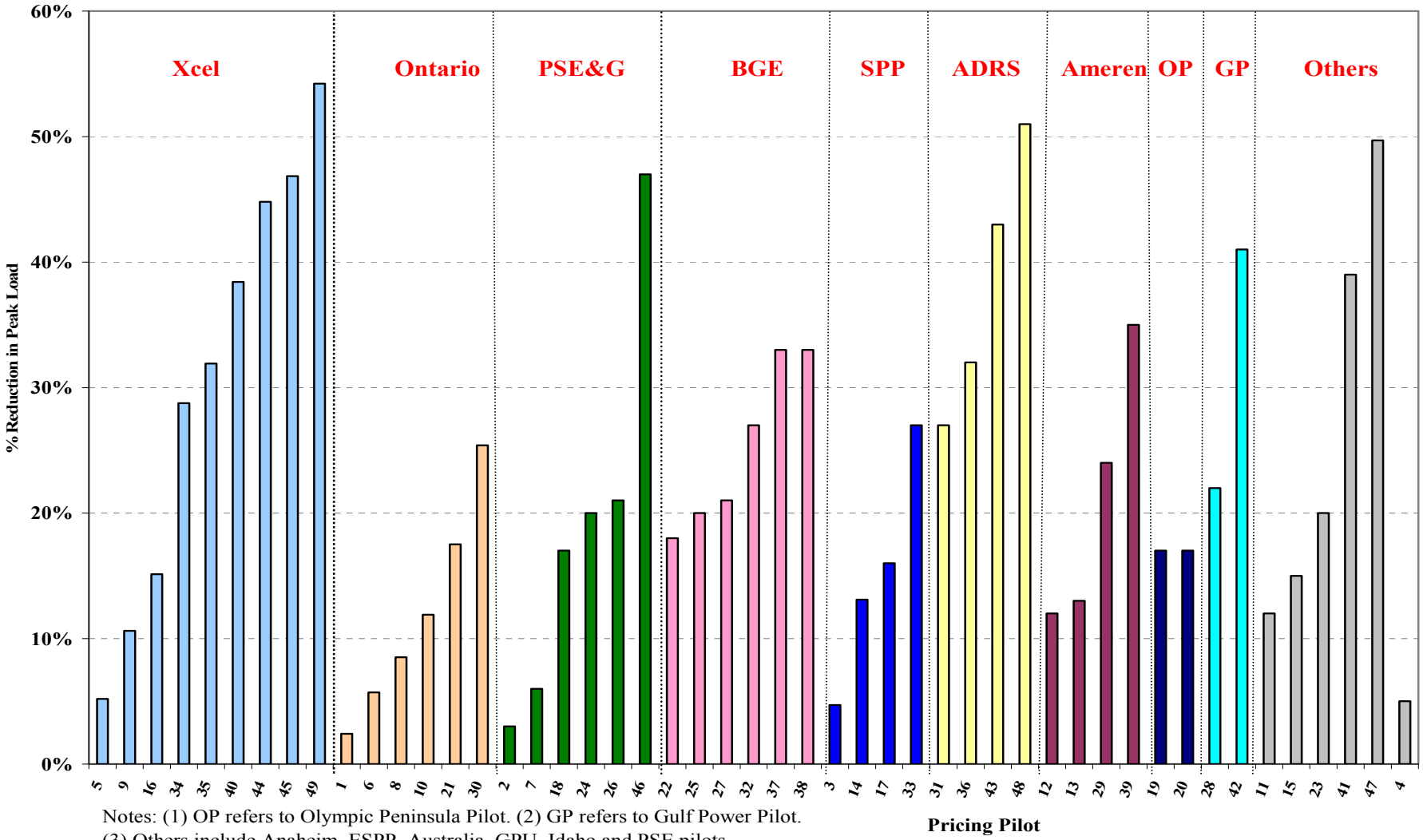
49 tests with dynamic pricing have yielded 49 different estimates of demand response

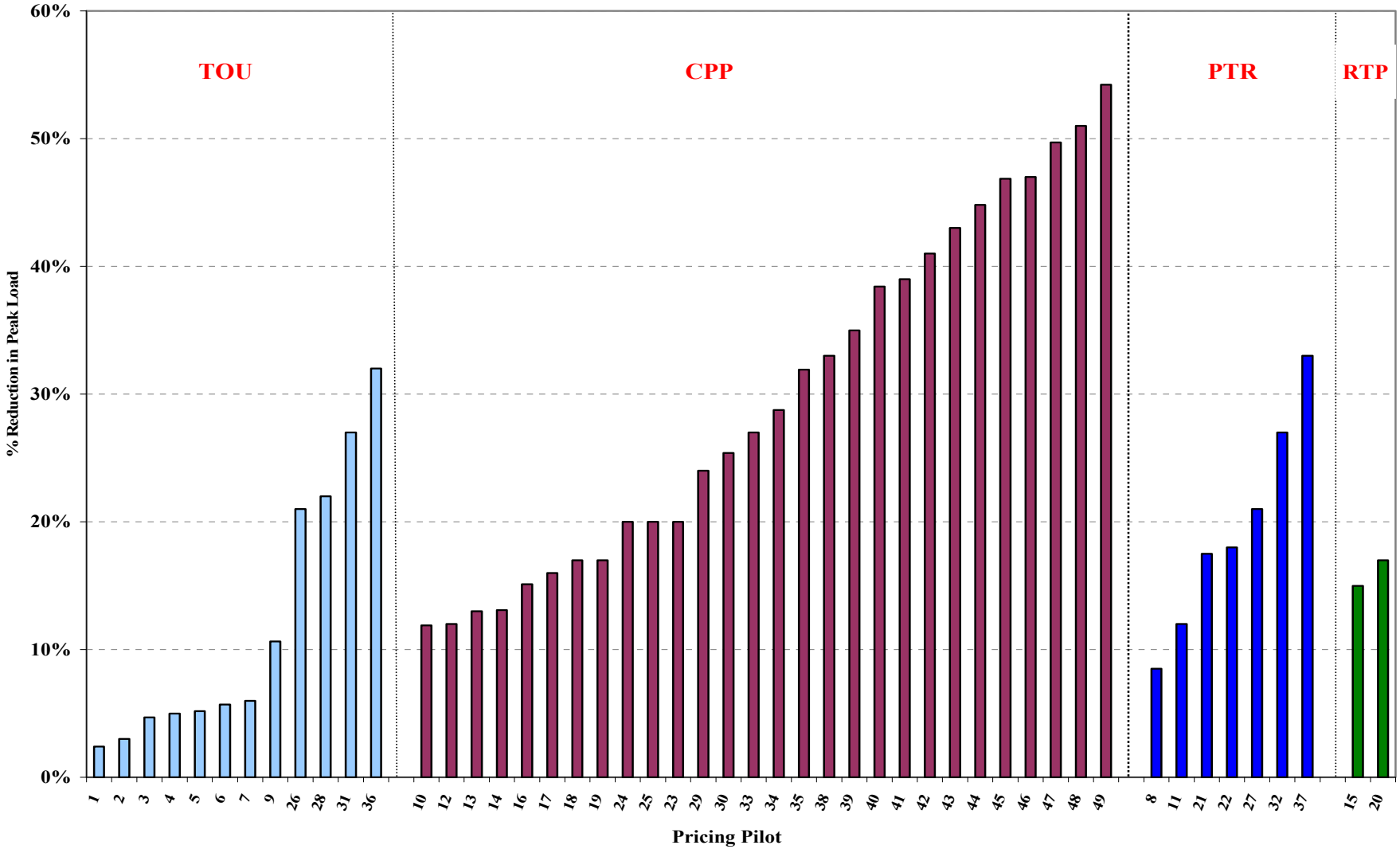


The picture sharpens if we group results by pilot

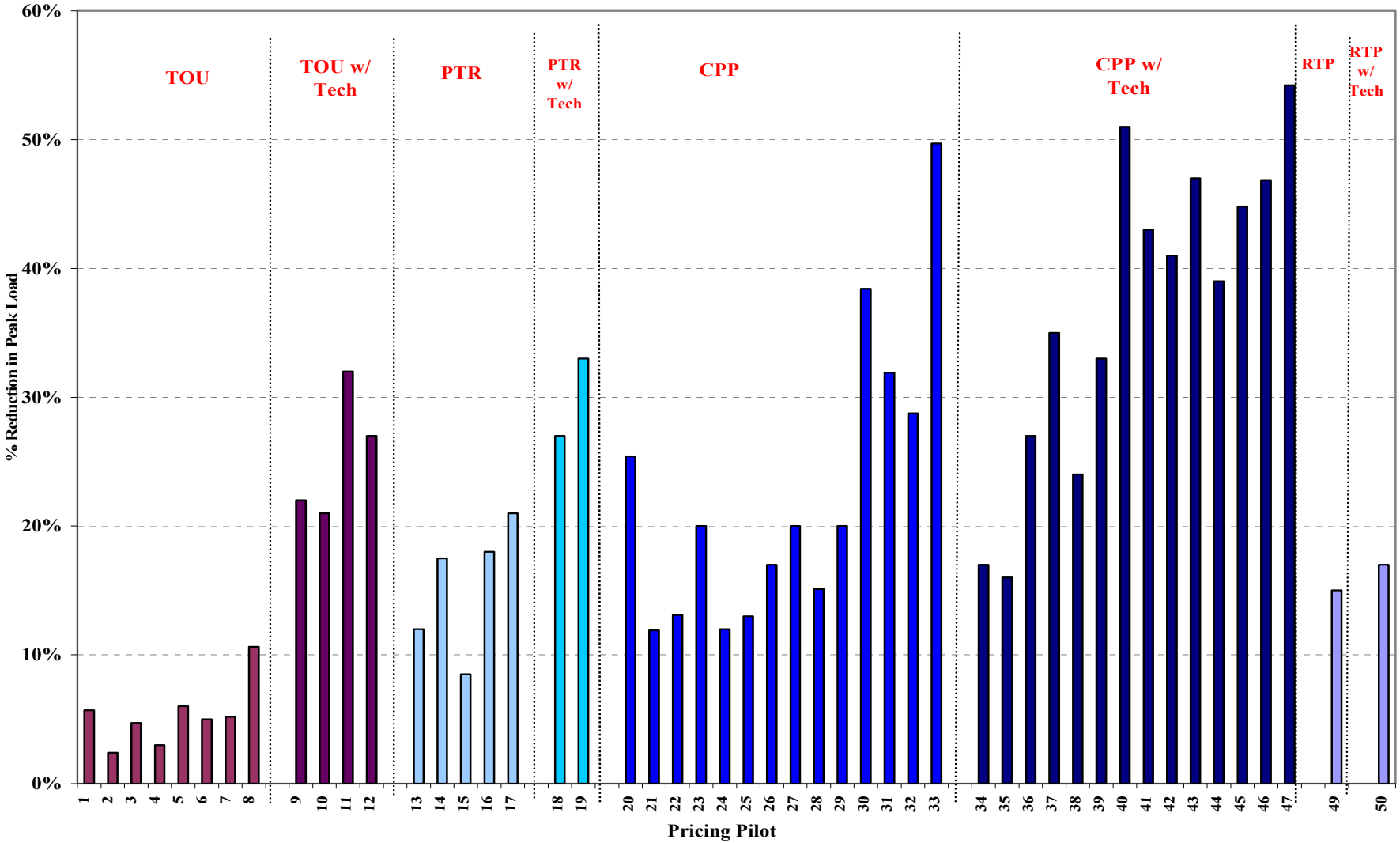


Notes: (1) OP refers to Olympic Peninsula Pilot. (2) GP refers to Gulf Power Pilot.
(3) Others include Anaheim, ESPP, Australia, GPU, Idaho and PSE pilots.

It sharpens further if we group results by rate type



And it sharpens even further when we introduce enabling technology as an explanatory variable



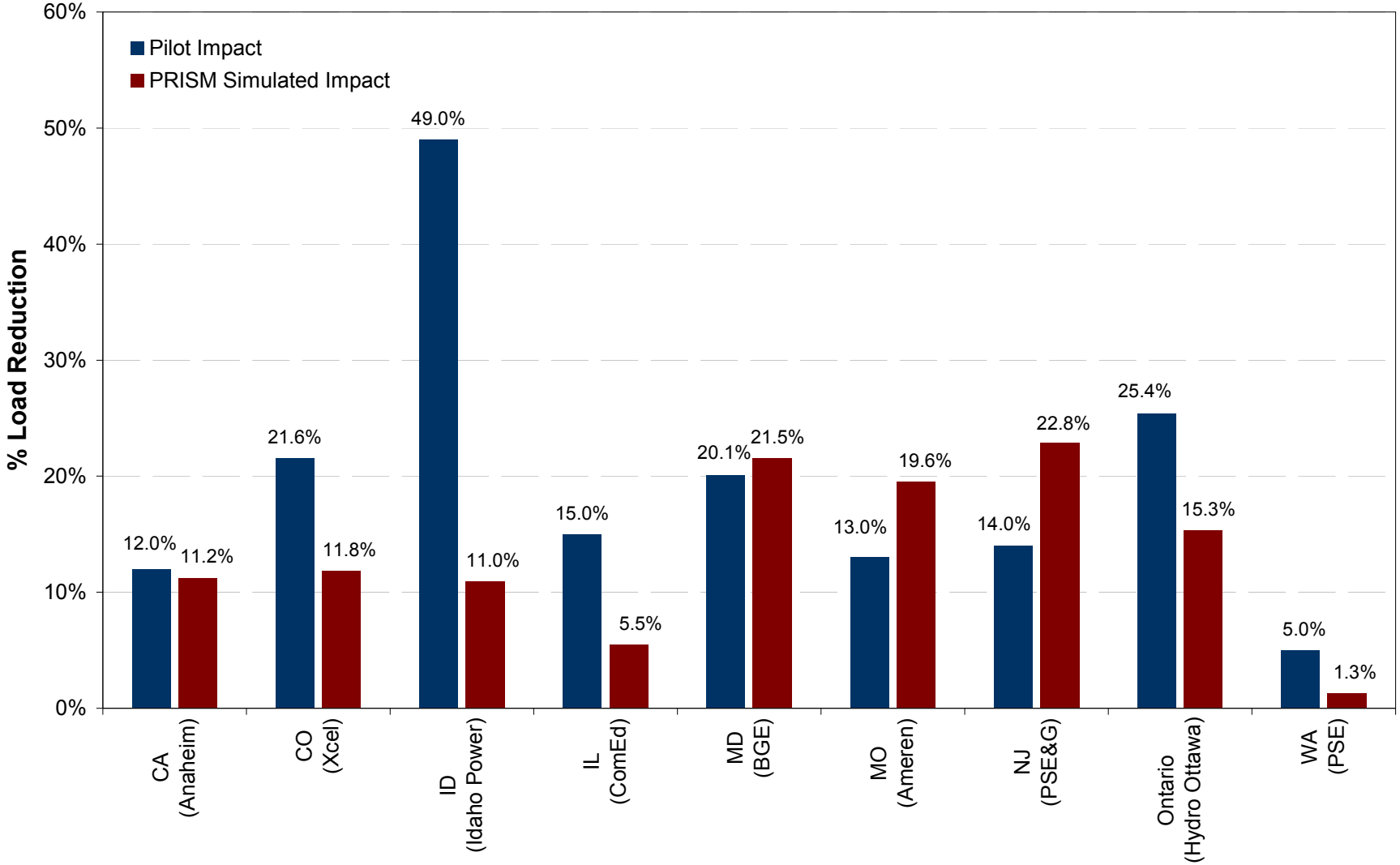
However, there is still far too much unexplained variation

This can be probed further by using a common modeling framework, such as that provided by the Price Impact Simulation Model (PRISM), which grew out of California's Statewide Pricing Pilot (SPP)

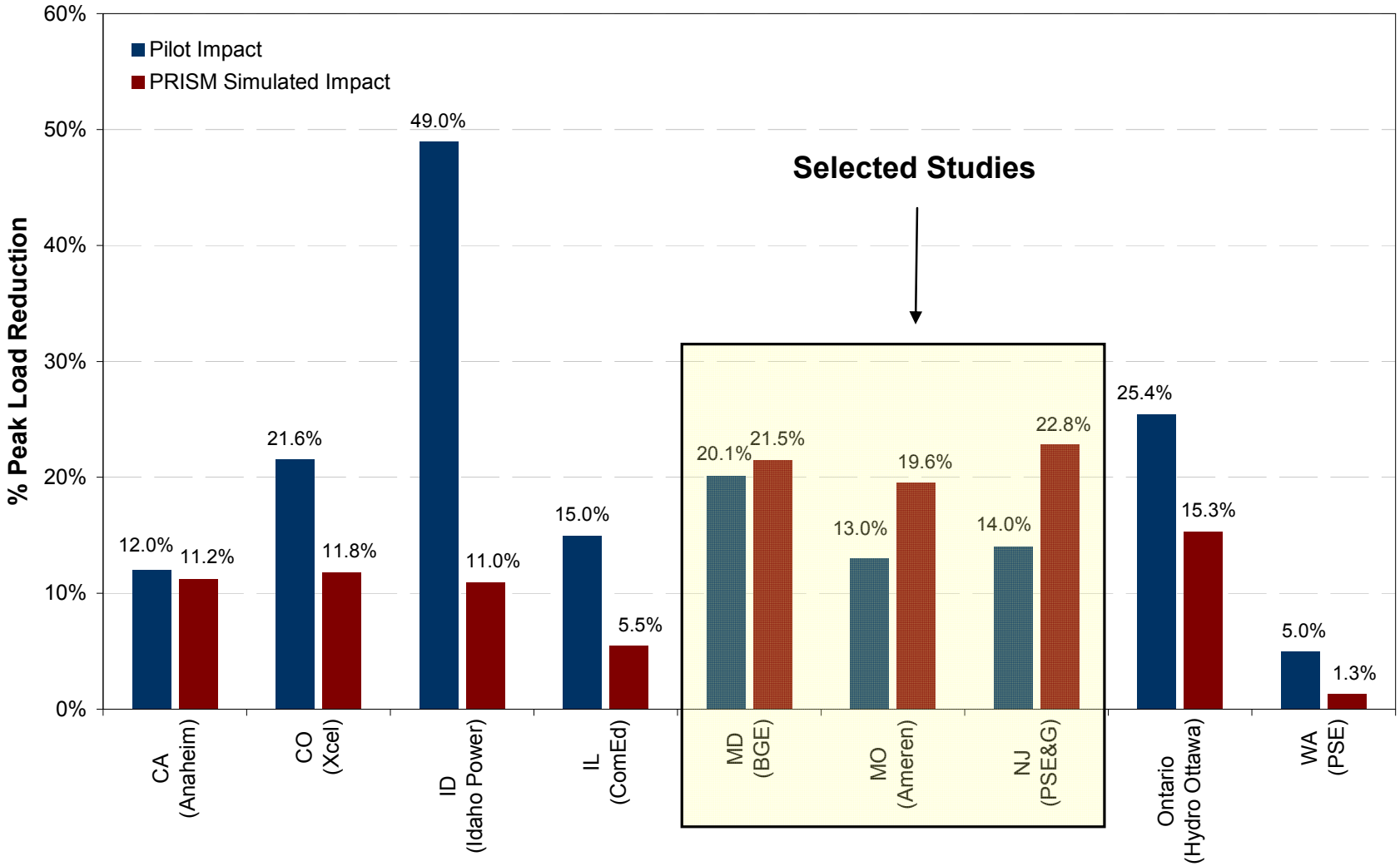
The architecture of PRISM revolves around two fundamental equations, one of which models changes in load shapes that are induced by time-varying rates and one of which models changes in energy consumption that are induced by changes in rate levels

But even then the explanation is far from complete, as seen in the next two slides

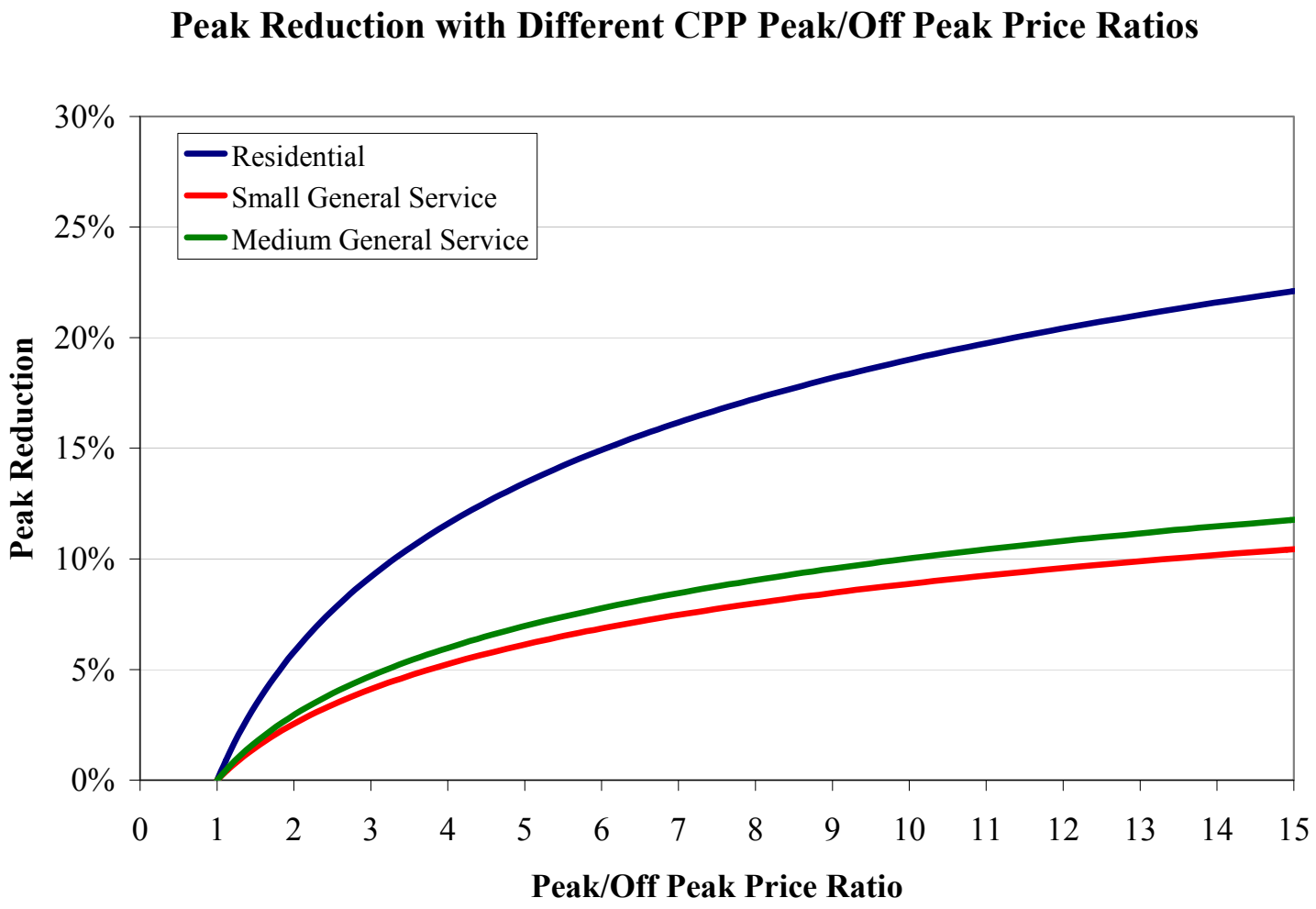
PRISM over-predicts the impacts of some pilots and under-predicts others



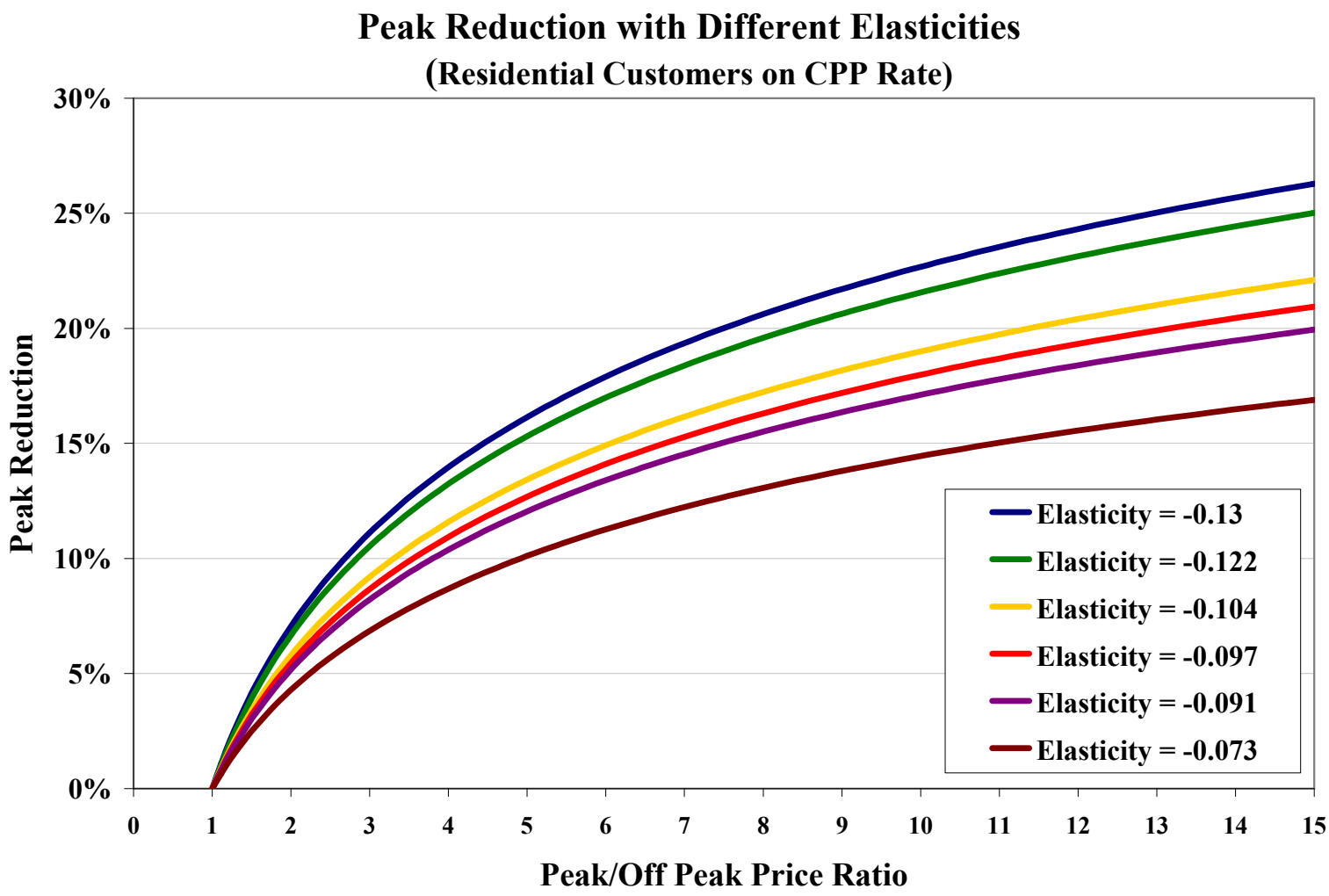
Limiting the sample to the most valid comparisons suggests that PRISM over-predicts impacts for more humid regions



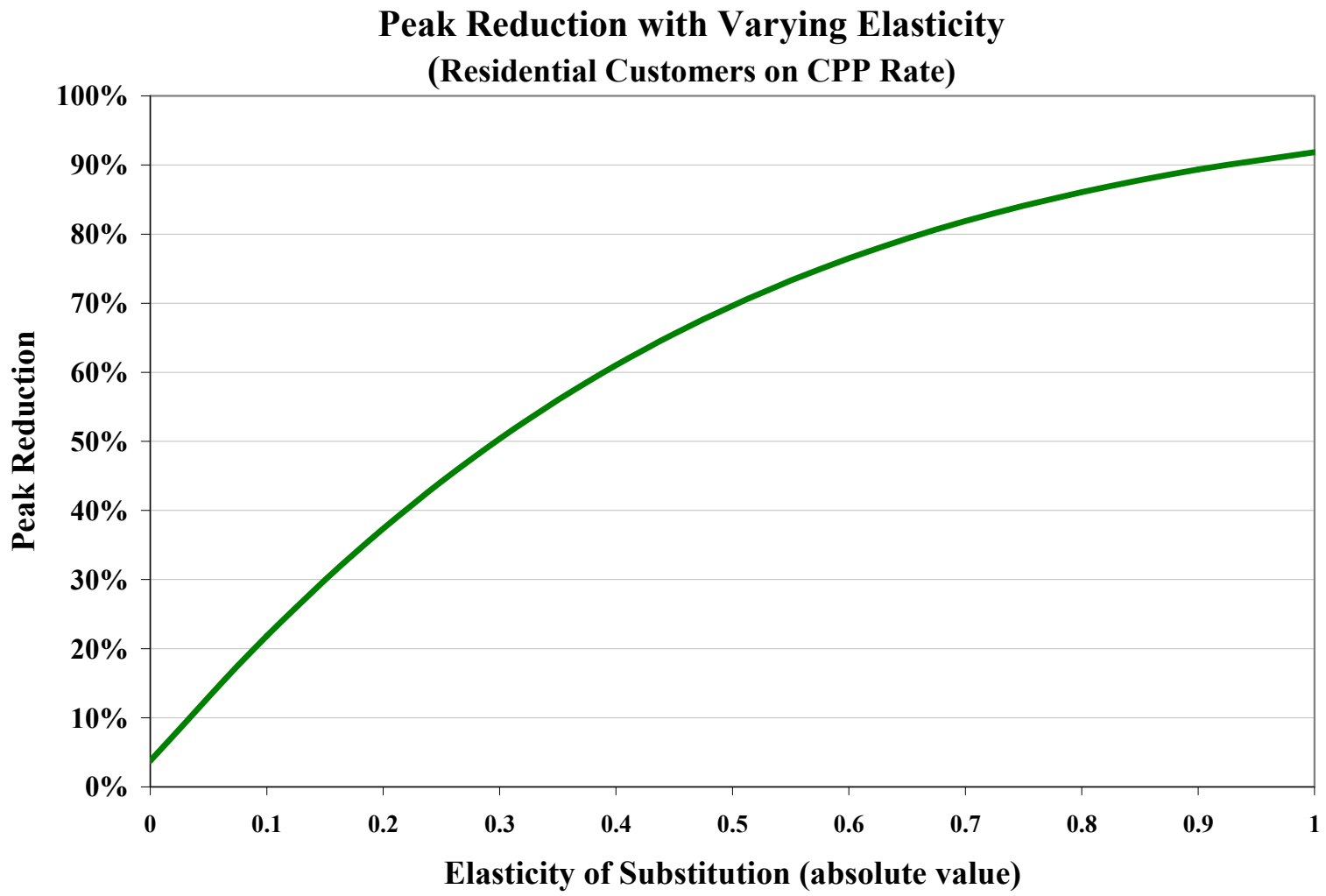
For a given elasticity of substitution, demand response rises with the peak-to-off peak price ratio



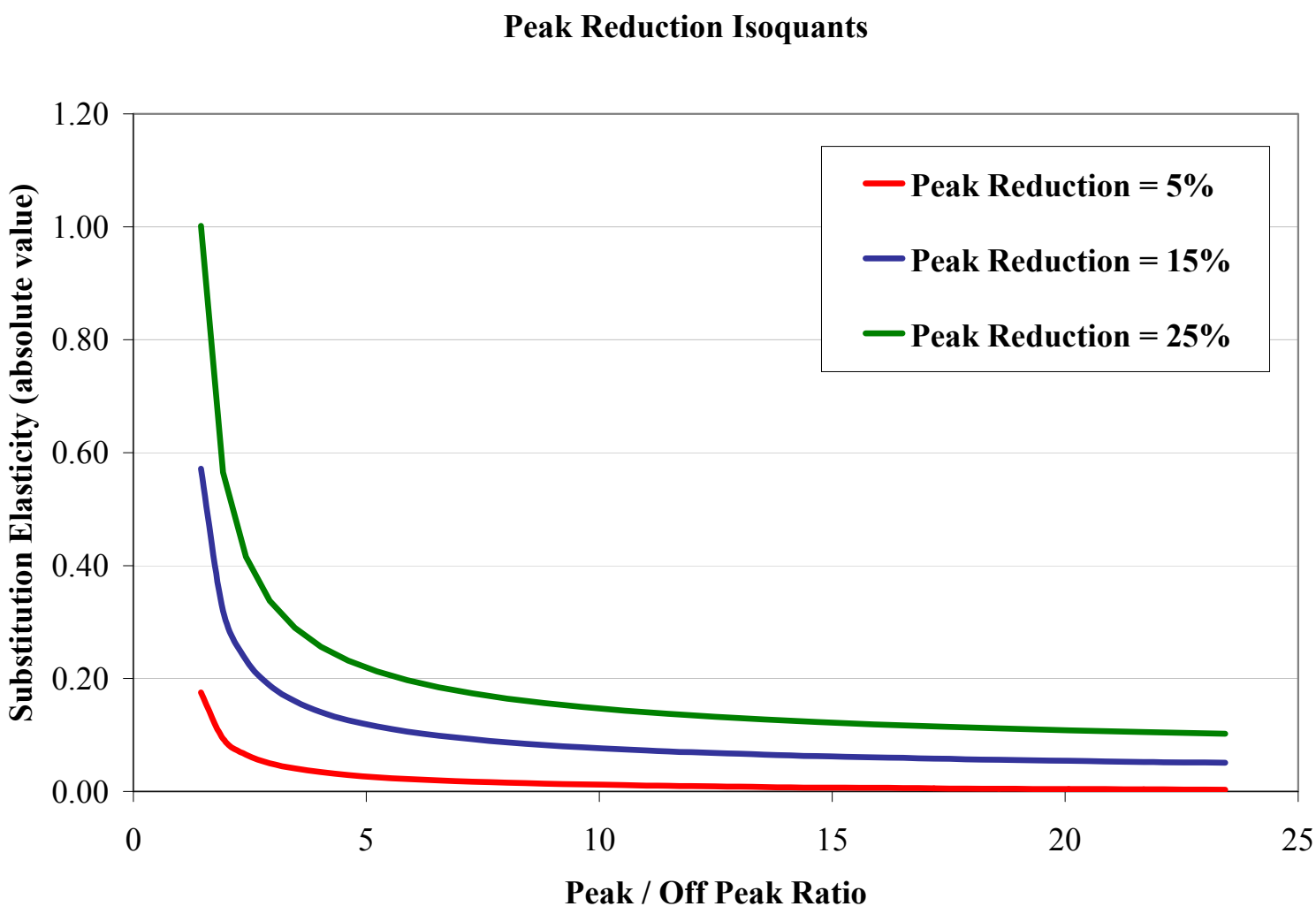
But there is much cross-pilot uncertainty about the elasticity of substitution



As the elasticity of substitution rises, the magnitude of demand response increases but at a decreasing rate



Demand response "indifference curves" can be used to model the impact of irreducible uncertainty



There are four ways of dealing with uncertainty

Live with it – but can you afford to make a big mistake in your AMI business case or your load forecast?

Borrow estimates from a "neighboring" pilot and reduce the uncertainty

Develop a pooled model that explains cross-experimental variation and further reduce the uncertainty

Do your own pilot and get custom-tailored estimates for your service area

BGE chose to do its own pilot with smart energy pricing (SEP)

The pilot ran from June 1, 2008 through September 30, 2008 (and is being repeated this summer with some changes)

It involved some 1,375 residential customers of whom 1,021 were exposed to some type of dynamic pricing and the rest were in a control group. Data on both groups were collected during the pre-treatment and treatment periods

The SEP pilot featured three dynamic pricing rate designs, a critical peak rate design (called dynamic peak pricing or DPP) and two variations of a peak time rebate (PTR) rate design- one testing a low rebate level and the other testing a high rebate level

The SEP pilot featured two enabling technologies, the Energy Orb and a switch for cycling central air conditioners (A/C Switch)

Rate and Technology Combinations Tested by BGE

Rate Design	Enabling Technology	Abbreviation
DPP	None	DPP
DPP	Energy Orb and A/C Switch	DPP_ET_ORB
PTRL	None	PTRL
PTRL	Energy Orb Only	PTRL_ORB
PTRL	Energy Orb and A/C Switch	PTRL_ET_ORB
PTRH	None	PTRH
PTRH	Energy Orb Only	PTRH_ORB
PTRH	Energy Orb and A/C Switch	PTRH_ET_ORB

The pilot featured the following "all-in" rates

SEP Program All-in Rates ($/kWh)

	Original	Critical	Peak	Off-Peak
DPP	0.153	1.309	0.149	0.099
DPP_ET_ORB	0.153	1.309	0.149	0.099
PTRL	0.153	1.313	0.153	0.153
PTRL_ORB	0.153	1.313	0.153	0.153
PTRL_ET_ORB	0.153	1.313	0.153	0.153
PTRH	0.153	1.903	0.153	0.153
PTRH_ORB	0.153	1.903	0.153	0.153
PTRH_ET_ORB	0.153	1.903	0.153	0.153

Notes:

1- SEP DPP rates include electric supply, transmission, and distribution charges.Therefore, they are converted to all-in rates by adding the customer charges.

2- SEP PTRH and PTRL rates include electric supply charges only. They are converted to all-in rates by adding transmission, distribution and customer charges.

3- Critical PTRL price is calculated by adding peak time rebate to peak price (i.e. 1.16 plus 0.153)

4- Critical PTRH price is calculated by adding peak time rebate to peak price (i.e. 1.75 plus 0.153)

5- Original prices are calculated by taking the average prices across the pilot period

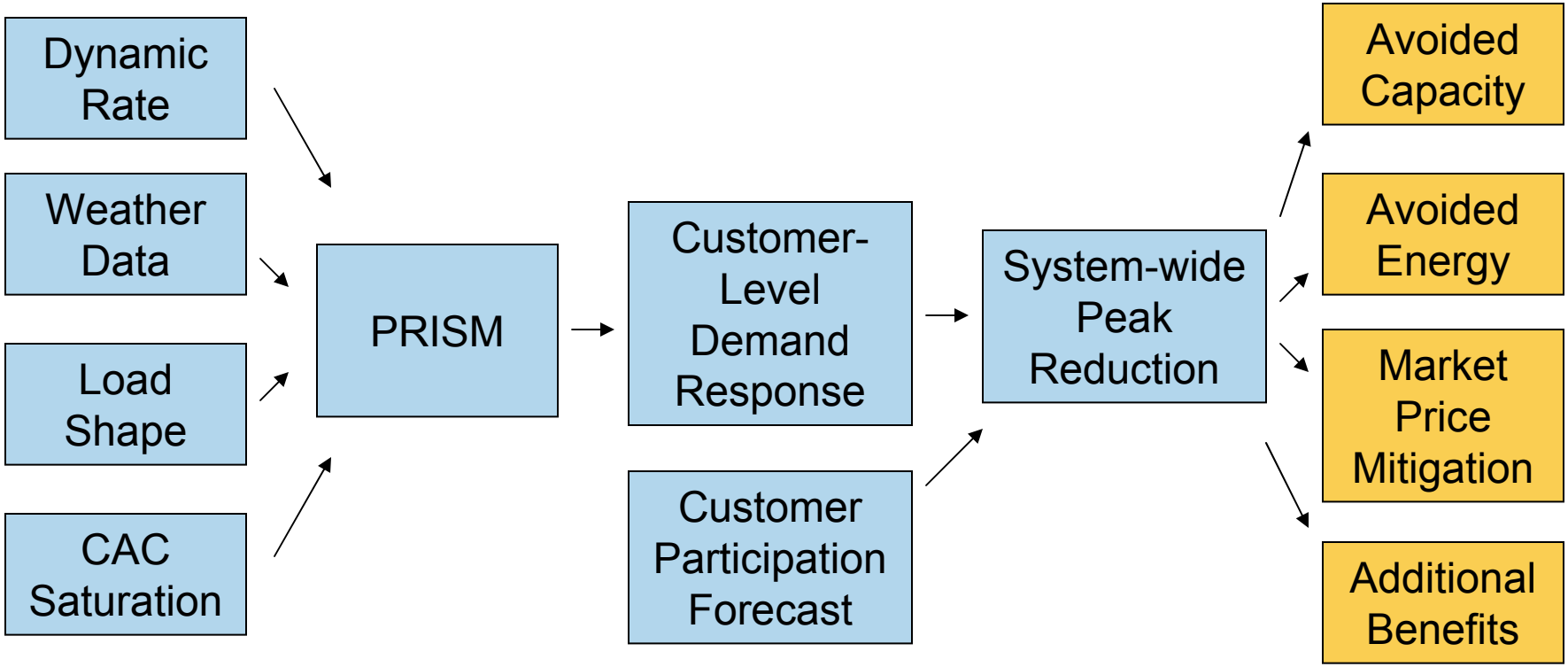
Estimation of Demand Equations

In order to predict consumption under new rate designs, we estimated a constant elasticity of substitution (CES) demand system that consists of two equations (algebra lovers will enjoy the appendix)

- The Substitution Equation models changes in load shape caused by changing peak-to-off peak prices
- The Daily Equation models changes in daily average consumption caused by changing daily prices

Using elasticities estimated by this system of two equations, we predict consumption by rate period using PRISMetrics

The Zen of PRISMetrics



Steps in estimating demand response

1- We converted unbundled BGE rates into an "all-in" rates

2- We estimated BGE substitution and daily elasticities using pretreatment and treatment period data on the treatment and control group customers

3- We developed PRISM-MD by incorporating the BGE elasticities and the typical BGE residential customer load profile

4- We estimated the demand response and total consumption impacts

Weather has a strong impact on price responsiveness

We employ two variables to capture the impact of weather in our analyses:

1- THI : Temperature humidity index

2- THI_DIFF: Difference between average peak and off-peak THI values

Since the elasticities are based on the weather term, we identified three different levels for the weather variables to arrive at the elasticity values used in the PRISM model

1- Based on the Average Weather

- Uses the value of the weather term averaged over 10 Critical Peak Pricing (CPP) days (excludes 2 CPP days with low weather terms)

2- Based on the Minimum Weather

- Uses the value from the CPP day with the minimum THI_DIFF value (CPP 11 ~ 9/23/2008)

3- Based on the Maximum Weather

- Uses the value from the CPP day with the maximum THI_DIFF value (CPP 9 ~ 9/3/2008)

Substitution and daily price elasticities

BGE Substitution & Daily Elasticities

	Based on Minimum Weather	Based on Average Weather	Based on Maximum Weather
Price Only	-0.073	-0.096	-0.109
Price + ORB	-0.113	-0.136	-0.149
Price + ET_ORB	-0.157	-0.180	-0.193
Daily	-0.019	-0.039	-0.034

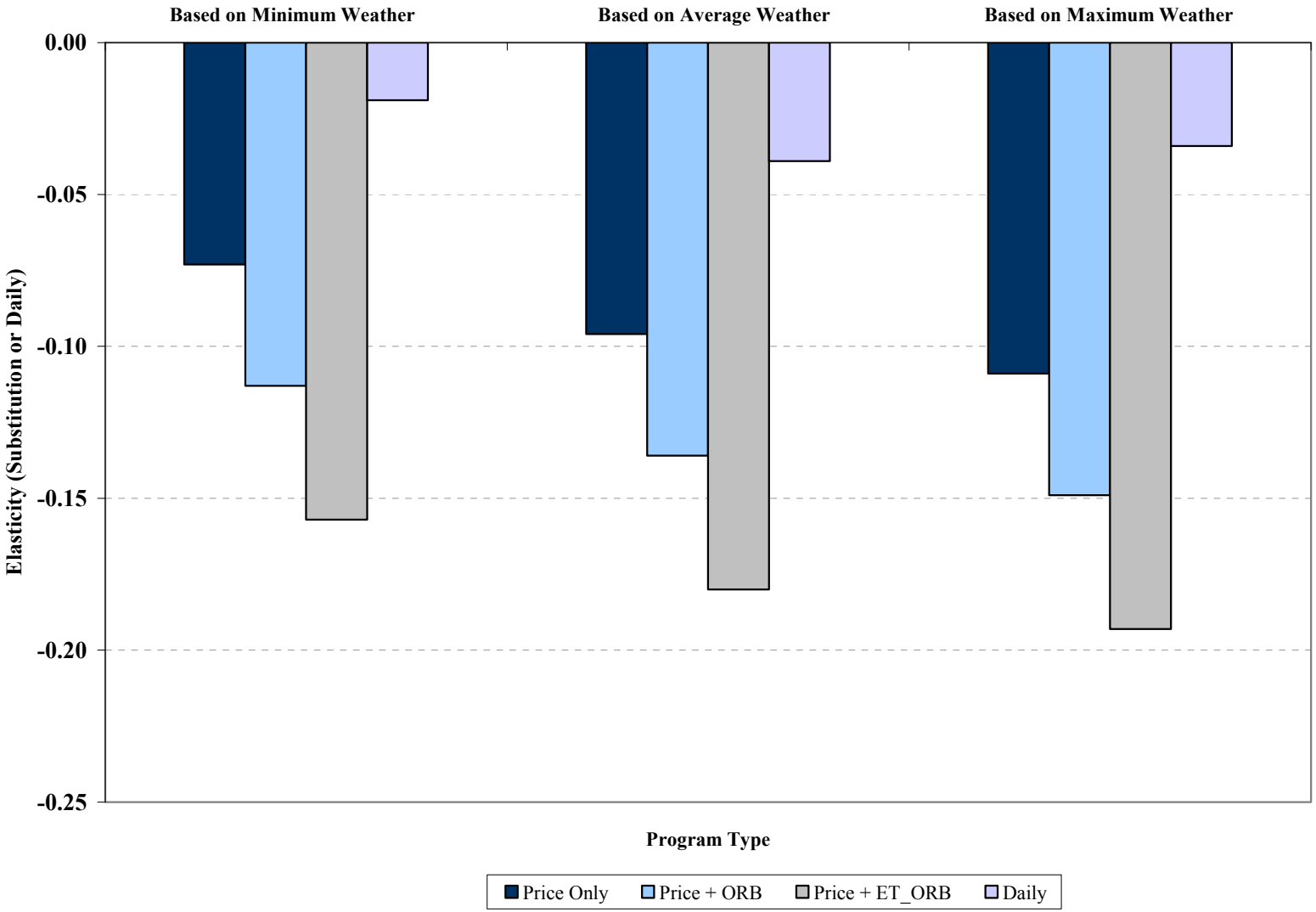
Substitution elasticity

- One percent increase in the ratio of peak to off-peak prices results in 0.096 percent decrease in the ratio of peak to off-peak consumption

Daily (price) elasticity

- One percent increase in the daily average price results in 0.039 percent decrease in the daily average consumption

The elasticities rise with technology and hot weather



The SEP Pilot showed that customers on the DPP and PTR rates exhibited similar price responsiveness

The price elasticities for customers on these different rates were statistically indistinguishable from each other

- This implies that the customers perceive similar incentives from critical peak pricing and peak time rebate programs
- They respond to *carrot* and *stick* in the same fashion

However, the resulting load impacts may be (and are) different from each other because the underlying rate levels are not identical

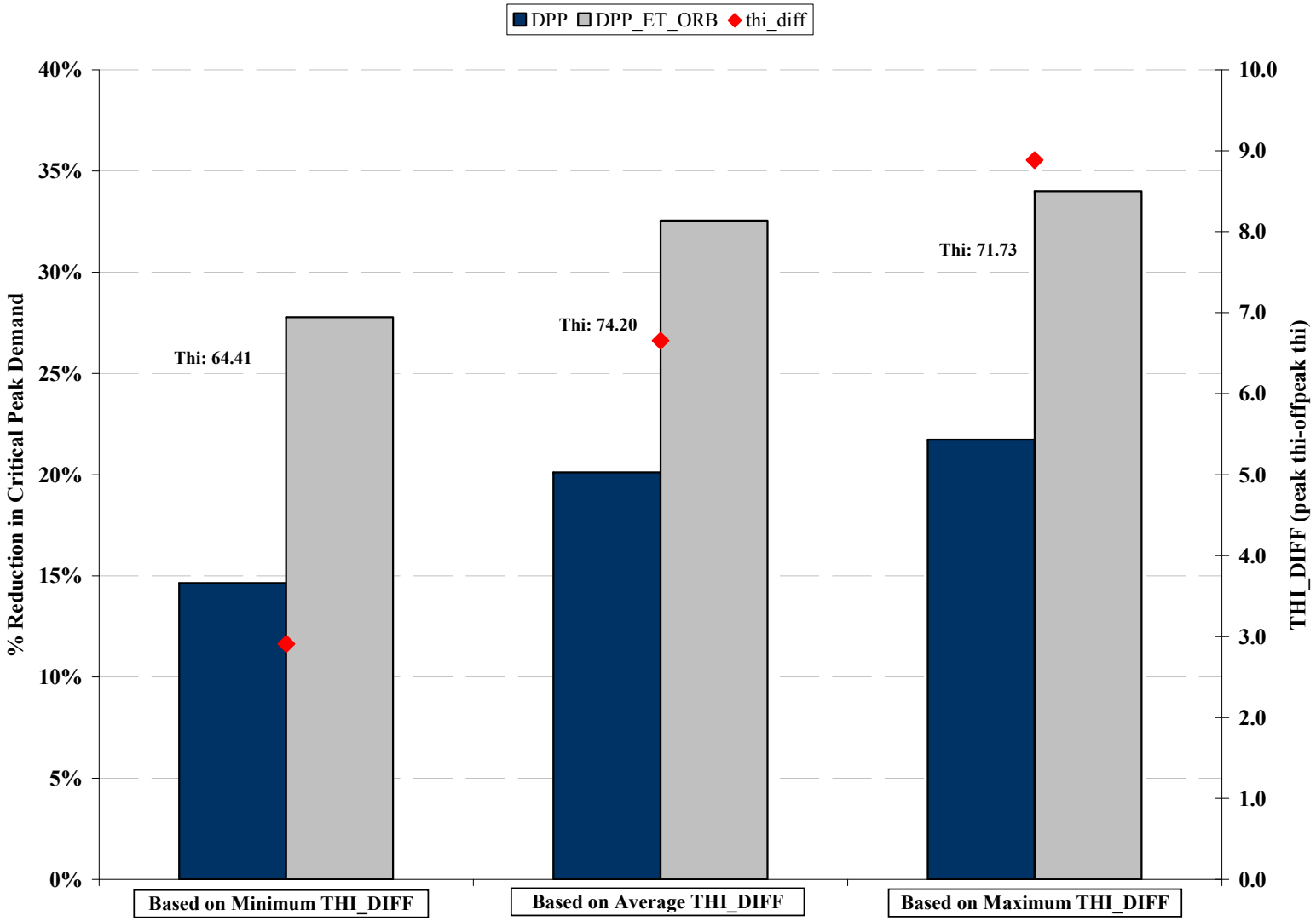
In the following slides, we report the average impacts achieved in the programs tested in the SEP pilot

For the average CPP day weather, the average reduction in critical peak period usage ranges from 18 to 33 percent

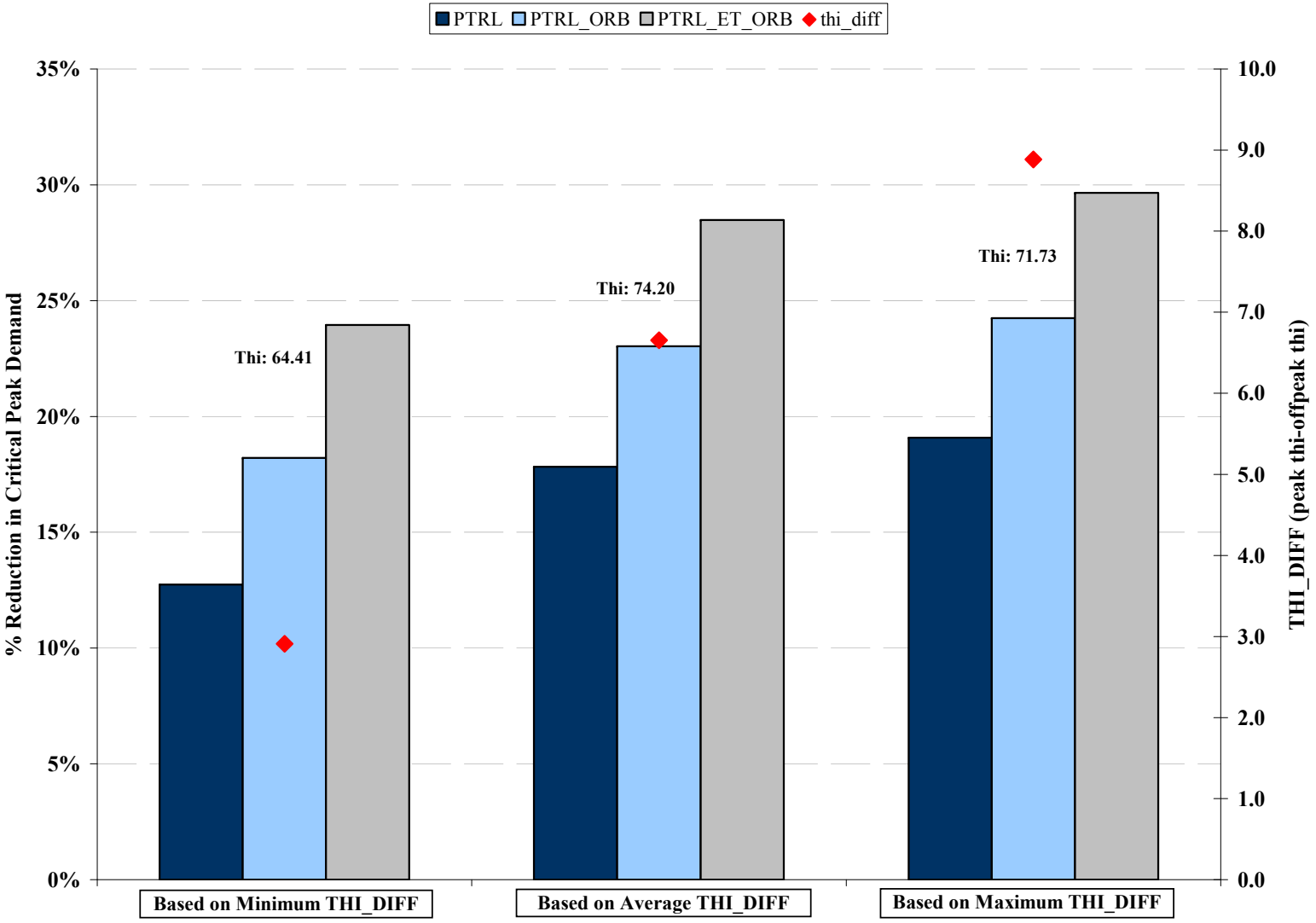
- DPP, PTRL, and PTRH programs *without enhancing technologies* yield impacts in the range of 18 to 21 percent
- DPP, PTRL, and PTRH programs *with orb technology* yields impacts in the range of 23 to 27 percent
- Presence of *both A/C switch and orb* almost doubles the impacts that are obtained from the rates alone and yields impacts in the range of 28 to 33 percent

Unless otherwise is noted, percent reductions are the averages over critical peak hours

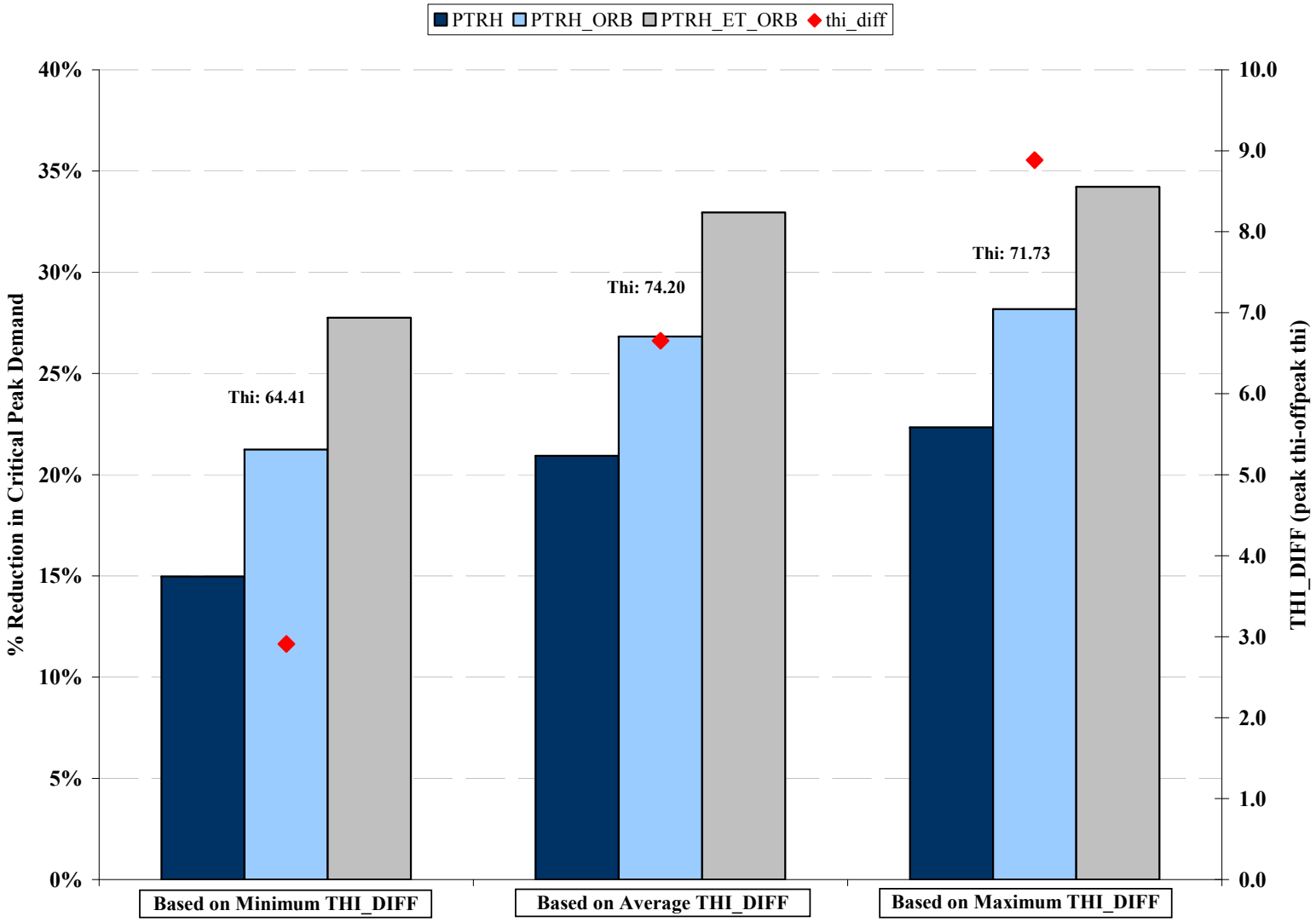
DPP Program- Critical Peak Demand Impacts



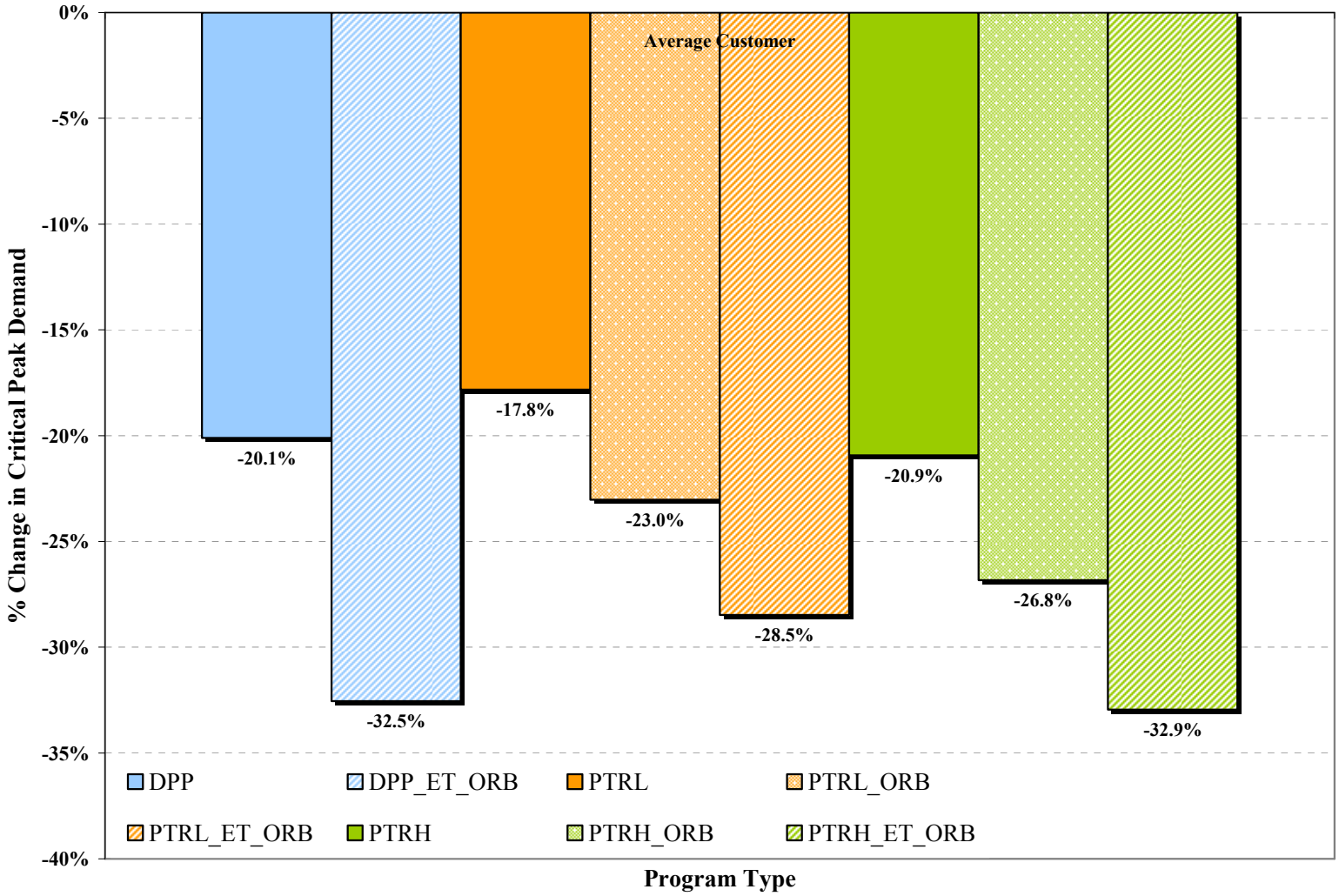
PTRL Program- Critical Peak Demand Impacts



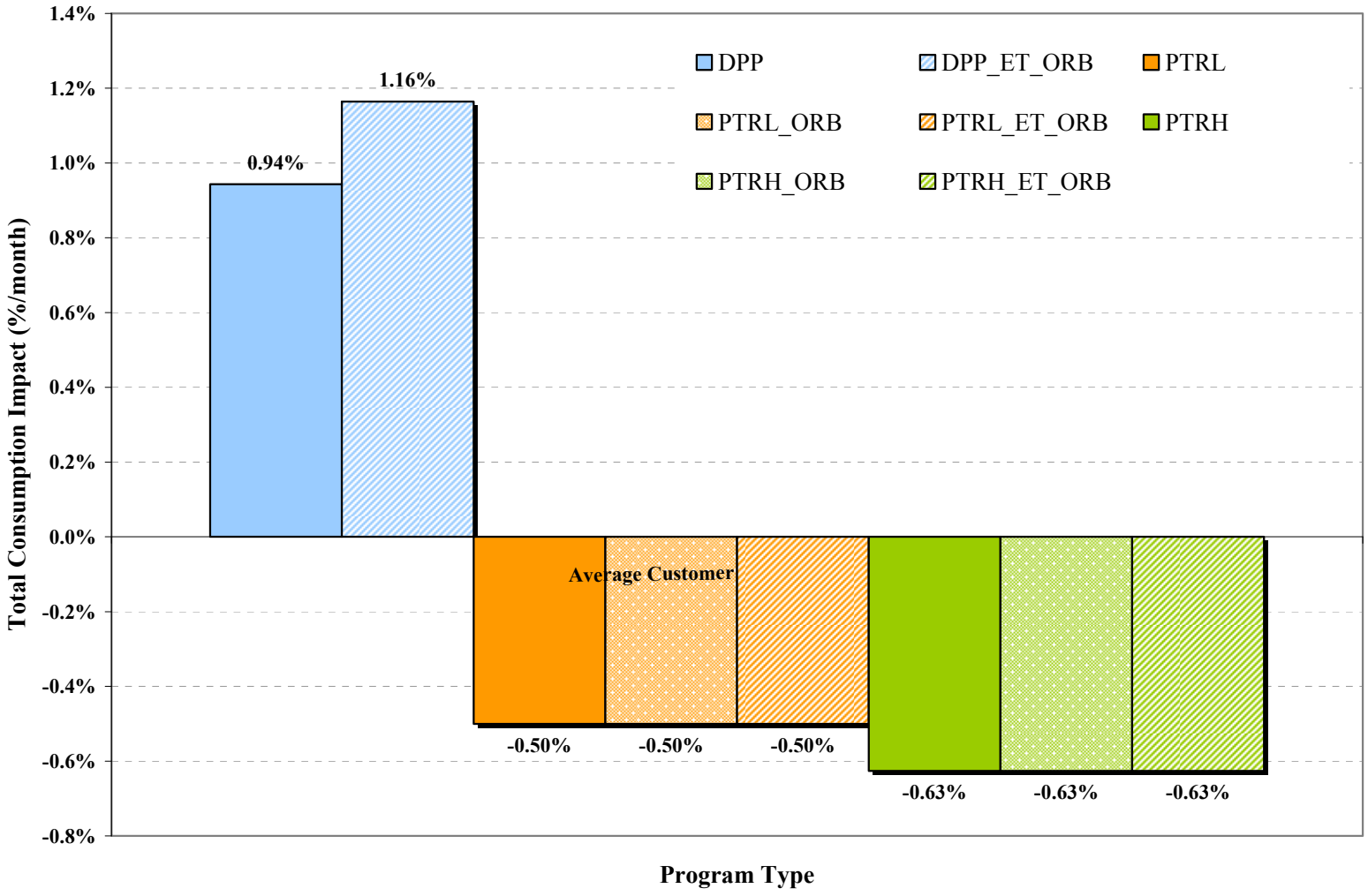
PTRH Program- Critical Peak Demand Impacts



Demand Response Impact Summary (Based on Average Critical Peak Day Weather)



Total Monthly Consumption Impact Summary (Based on Average Critical Peak Day Weather)



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Summary of SEP Impacts

1- Customers show the same price responsiveness to dynamic pricing on the DPP and PTR rates

2- The average reduction in critical peak period usage ranges from 18 to 33 percent

- DPP, PTRL, and PTRH programs without enhancing technologies yield impacts in the range of 18 to 21 percent
- The Energy Orb significantly boosts the extent of demand response
- The presence of both A/C switch and the Energy Orb almost doubles the impacts that are obtained from the rates alone

3- Total monthly consumption increases by at about one percent for DPP and decreases by about half percent for PTRL and 0.6 percent for PTRH

Comparison of results with California's SPP

1- The results from the SEP are qualitatively similar to those from the SPP

- Customers respond to dynamic prices by reducing their peak period usage
- Automating technologies increase the extent of the demand response (PCTs in SPP and A/C switch in the case of BGE)

2- The range of the impact estimates from the two pilots is also comparable

- The SEP yielded impacts in the range of 18 to 33 percent
- The SPP yielded impacts in the range of 13 to 27 percent

3- However, with identical prices, the SPP over-estimates the impacts achieved in the SEP pilot by a couple of percentage points

References

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Faruqui, Ahmad and Sanem Sergici, "Household response to dynamic pricing of electricity–a survey of the experimental evidence," January 10, 2009. http://www.hks.harvard.edu/hepg/

FERC, "A National Assessment of Demand Response Potential," Filed with Congress, June 2009.

Biography

Ahmad Faruqui, a Principal with The Brattle Group, has led FERC's state-by-state assessment of the potential for demand response, provided significant input to EPRI's national assessment of the potential for energy efficiency and written a report on quantifying the benefits of dynamic pricing for EEI. He has assessed the benefits of dynamic pricing for the New York Independent System Operator, worked on fostering economic demand response for the Midwest ISO and ISO New England and assisted the California Energy Commission in developing load management standards. And he has assisting several utilities and commissions assess the economics of dynamic pricing, demand response and advanced metering. This has often involved the design and evaluation of innovative pilot programs. His early work on time-of-use pricing experiments is cited in Bonbright's canon. The author, co-author or editor of four books and more than a hundred articles and papers, he holds a doctoral degree in economics from the University of California at Davis.

APPENDIX

The algebra of peak-to-off peak substitution

$$\ln\left(\frac{Peak_kWh}{OffPeak_kWh}\right)_{it} = \alpha_0 + \alpha_1 THI_DIFF_{it} + \alpha_2 \ln\left(\frac{Peak_Price}{OffPeak_Price}\right)_{it} + \alpha_3 \ln\left(\frac{Peak_Price}{OffPeak_Price}\right)_{it} xTHI_DIFF_{it}$$

$$+ \alpha_4 \ln\left(\frac{Peak_Price}{OffPeak_Price}\right)_{it} xORB + \alpha_5 \ln\left(\frac{Peak_Price}{OffPeak_Price}\right)_{it} xET_ORB + \sum_{k=1}^{6} \delta_k (THI_DIFFxD_Month_k)_{it}$$

$$+ \alpha_6 D_TreatPeriod_t + \alpha_7 D_TreatPeriodxTreatCustomer_{it} + \sum_{k=1}^{6} \beta_k D_Month_k + \sum_{k=1}^{12} \gamma_k D_CPP_k$$

$$+ \alpha_8 D_WEEKEND + v_i + u_{it}$$

$\ln\left(\frac{Peak_kWh}{OffPeak_kWh}\right)_{it}$	: Logarithm of the ratio of peak to off-peak load for a given day
THI_DIFF_{it}	:The difference between peak and off-peak THI. THI is defined as follows: THI= 0.55 x Drybulb Temperature + 0.20 x Dewpoint + 17.5
$\ln\left(\frac{Peak_Price}{OffPeak_Price}\right)_{it}$	:Logarithm of the ratio of peak to off-peak prices for a given day
$\ln\left(\frac{Peak_Price}{OffPeak_Price}\right)xTHI_DIFF_{it}$	:Interaction of ratio of peak to off-peak prices and THI_DIFF for a given day
$\ln\left(\frac{Peak_Price}{OffPeak_Price}\right)xORB_{it}$	:Interaction of ratio of peak to off-peak prices and ORB for a given day
$\ln\left(\frac{Peak_Price}{OffPeak_Price}\right)xET_ORB_{it}$	:Interaction of ratio of peak to off-peak prices and ET_ORB for a given day
THI_DIFFxD_Month	:Interaction of THI_DIFF variable with monthly dummies
$D_TreatPeriod$	:Dummy variable is equal to 1 when the period is June 2008 through September 30, 2008
$D_TreatPeriodxTreatCustomer$	: Interaction of $D_TreatPeriod$ with treatment customer dummy
D_Month_k	: Dummy variable that is equal to 1 when the month is k
D_CPP	: Dummy variable that is equal to 1 on CPP days
$D_WEEKEND$	: Dummy variable that is equal to 1 on weekends

The algebra of daily energy consumption

$$\ln(kWh)_{it} = \alpha_0 + \alpha_1 \ln(THI)_{it} + \alpha_2 \ln(Price)_{it} + \alpha_3 \ln(Price)_{it} x \ln(THI)_{it} + \sum_{k=1}^{6} \delta_k (\ln(THI) x D_Month_k)_{it}$$

$$+ \alpha_4 D_TreatPeriod_t + \alpha_5 D_TreatPeriodxTreatCustomer_{it} + \sum_{k=1}^{6} \beta_k D_Month_k + \sum_{k=1}^{12} \gamma_k D_CPP_k$$

$$+ \alpha_6 D_WEEKEND + v_i + u_{it}$$

$\ln(kWh)_{it}$	: Logarithm of the daily average of the hourly load
$\ln(THI)_{it}$	: Logarithm of the daily average of the hourly THI
$\ln(Price)_{it}$	: Logarithm of the daily average of the hourly Price
$\ln(Price) x \ln(THI)_{it}$	: Interaction of price with ln (THI)
$\ln(THI) x D_Month$	: Interaction of $\ln(THI)$ variable with monthly dummies
$D_TreatPeriod$	: Dummy variable is equal to 1 when the period is June 2008 through September 30, 2008
$D_TreatPeriodxTreatCustomer$	: Interaction of $D_TreatPeriod$ with treatment customer dummy
D_Month_k	: Dummy variable that is equal to 1 when the month is k
D_CPP	: Dummy variable that is equal to 1 on CPP days
$D_WEEKEND$	: Dummy variable that is equal to 1 on weekends

The parameters of the substitution equation

	All Grps, Period Beginning 4/08
thi_diff	-0.012**
	(0.001)
thi_diff_april	0.000
	(0.000)
thi_diff_may	0.008**
	(0.001)
thi_diff_june	0.037**
	(0.002)
thi_diff_july	0.047**
	(0.002)
thi_diff_august	0.051**
	(0.002)
thi_diff_september	0.029**
	(0.001)
ln_price_ratio	-0.056**
	(0.014)
ln_price_ratio_thi_diff	-0.006**
	(0.002)
ln_price_ratio_orb	-0.040**
	(0.012)
ln_price_ratio_et_orb	-0.084**
	(0.012)
weekend	0.096**
	(0.005)
Constant	-0.007
	(0.008)
Observations	232169
R-squared	0.099
Number of customerid	1375

Robust standard errors in parentheses
** p<0.01, * p<0.05

Note: Other variables are also controlled for but suppressed here due to limited space.

The parameters of the daily energy equation

	All Grps, Period Beginning 4/08
ln_thi	-0.816**
	(0.034)
ln_thi_april	
ln_thi_may	0.806**
	(0.033)
ln_thi_june	4.077**
	(0.050)
ln_thi_july	4.306**
	(0.070)
ln_thi_august	3.708**
	(0.056)
ln_thi_september	3.160**
	(0.043)
ln_price	0.577**
	(0.055)
ln_price_ln_thi	-0.143**
	(0.013)
weekend	0.046**
	(0.001)
Constant	-0.031
	(0.019)
Observations	231236
Number of customerid	1375
R-squared	0.136
rho	0.595

Standard errors in parentheses
** p<0.01, * p<0.05

Note: Other variables are also controlled for but suppressed here due to limited space.

Estimation results from differentiating substitution elasticities across program types

VARIABLES	All Grps, Period Beginning 4/08
thi_diff	-0.012**
	(0.001)
ln_price_ratio	-0.070**
	(0.014)
ln_price_ratio_thi_diff	-0.001
	(0.001)
ln_price_ratio_ptrl	-0.001
	(0.019)
ln_price_ratio_ptrh	-0.016
	(0.017)
ln_price_ratio_dpp_et	-0.085**
	(0.020)
ln_price_ratio_ptrl_et	-0.101**
	(0.021)
ln_price_ratio_ptrh_et	-0.087**
	(0.018)
ln_price_ratio_ptrl_orb	-0.043*
	(0.020)
ln_price_ratio_ptrh_orb	-0.047**
	(0.018)
weekend	0.096**
	(0.005)
Constant	-0.007
	(0.008)
Observations	232169
R-squared	0.098
Number of customerid	1375

** p<0.01, * p<0.05
Robust standard errors in parentheses

Note: Other variables are also controlled for but suppressed here due to limited space.