Dynamic Electricity Pricing in California: Do Customers Respond?
The next 40 minutes...

1. The Problem
   - 25% generating capacity used less than 100 hours/year

2. The Proposed Solution
   - Dynamic peak pricing

3. The Rollout
   - Business case for advanced metering
1. THE PROBLEM
The Problem: California’s Electric System Hits New Peaks Annually

California System Peak Load – August 2004 (Source: Cal ISO)

Days above 40kMW
One quarter of capacity used less than 100 hours/year

CA Load Duration Curve

Planning Reserve Margin: 64,132 MW
Spinning Reserve Required: 56,364 MW
Peak Demand: 52,568 MW
1% of Time Demand greater than 48,528 MW
5% of Time Demand greater than 42,813 MW
10% of Time Demand greater than 39,244 MW
Related Problem

• Retail/wholesale price disconnect
→ Allocative efficiency losses
2. THE PROPOSED SOLUTION
One Proposed Solution: “Manage the Peak” with Dynamic Pricing

- Critical peak pricing (CPP)
CPP Pricing

Source: Larsh Johnson, “California’s Statewide Pricing Pilot” (presentation), 25 March 2004
Constraints on CPP

- Peak is random
- Technical constraints: new meters are needed
- Uncertainty: will consumers respond?
Statewide Pricing Pilot (SPP)

- Controlled experiment
- 2,500 customers
- Residential and small business only
SPP Objectives

• Will customers shift or reduce load in response to time-varying price signals?

• Are these changes sustained over successive days and successive summers?

• Key policy issues:
  
  Will demand reductions from dynamic pricing offset the cost of new meters?

  Can the price mechanism be used to manage demand-supply imbalances?
Experiment Design 1/3

• Four rate structures:
  – CPP-F
  – CPP-V
  – TOU
  + Information Only

• Control groups for each sample

• Sample sizes determined using pre-experimental data
CPP-F Price Settings

- Normal Weekday:
  - Peak: $0.22
  - Off-Peak: $0.09
  - Control: $0.13

- Critical Day:
  - Peak: $0.59
  - Off-Peak: $0.09
  - Control: $0.13
Experiment Design 2/3

- July 2003-December 2004
- Total of 27 critical days declared in this period
- Three groups of customers
  - Track A: representative
  - Track B: low-income customers
  - Track C: customers from a smart thermostat pilot
SPP sample segmented across four climate zones

Air Conditioning
- Zone 1 – 6%
- Zone 2 – 29%
- Zone 3 – 69%
- Zone 4 – 73%

CPP Weather
- Zone 1 – 73 °
- Zone 2 – 79 °
- Zone 3 – 88 °
- Zone 4 – 99 °
Experiment Design 3/3

Experiment Constraints

• 15 critical days/year
• Revenue neutral for the average customer
• Maximum +/- 5% change in costs for unchanged behaviour
• Customers have opportunity to reduce bills by 10% if reduced peak usage by 30%
Sample Sizes

<table>
<thead>
<tr>
<th>Track A - Representative Population Sample</th>
<th>Control</th>
<th>CPP-F</th>
<th>Info Only</th>
<th>CPP-V</th>
<th>TOU</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>470</td>
<td>542</td>
<td>126</td>
<td>125</td>
<td>200</td>
<td>1463</td>
</tr>
<tr>
<td>Commercial &lt;20kW</td>
<td>88</td>
<td>0</td>
<td>0</td>
<td>58</td>
<td>50</td>
<td>196</td>
</tr>
<tr>
<td>Commercial 20-200kW</td>
<td>88</td>
<td>0</td>
<td>0</td>
<td>80</td>
<td>50</td>
<td>218</td>
</tr>
<tr>
<td>Track B - San Francisco Co-Operative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>0</td>
<td>64</td>
<td>189</td>
<td>0</td>
<td>0</td>
<td>253</td>
</tr>
<tr>
<td>Track C - Smart Thermostat (AB970) Pilot</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>20</td>
<td>0</td>
<td>0</td>
<td>125</td>
<td>0</td>
<td>145</td>
</tr>
<tr>
<td>Commercial &lt;20kW</td>
<td>42</td>
<td>0</td>
<td>0</td>
<td>56</td>
<td>0</td>
<td>98</td>
</tr>
<tr>
<td>Commercial 20-200kW</td>
<td>42</td>
<td>0</td>
<td>0</td>
<td>76</td>
<td>0</td>
<td>118</td>
</tr>
<tr>
<td>Total Participants</td>
<td>750</td>
<td>606</td>
<td>315</td>
<td>520</td>
<td>300</td>
<td>2491</td>
</tr>
</tbody>
</table>
CES demand system used to predict the change in electricity use caused by dynamic pricing

Daily: $\ln(Q_d) = \alpha + \eta_d \ln(P_d) + \delta(CDH_d) + \sum_{i=1}^{N} \theta_i D_i + \varepsilon$

Substitution: $\ln\left(\frac{Q_p}{Q_{op}}\right) = \alpha + \sigma \ln\left(\frac{P_p}{P_{op}}\right) + \delta(CDH_p - CDH_{op}) + \sum_{i=1}^{N} \theta_i D_i + \varepsilon$

Temperature
Estimation Methodology 2/2

\[
\ln \left( Q_d \right) = a + b_d \ln \left( P_d \right) + c(\text{CDH}_d) + d \left( P_d \times \text{CDH}_d \right) + e(\text{P}_d \times \text{CAC}) + \varepsilon
\]

\[
\ln \left( \frac{Q_p}{Q_{op}} \right) = a + b \ln \left( \frac{P_p}{P_{op}} \right) + c(\text{CDH}_{p-op}) + d(\text{CAC}) \times \ln \left( \frac{P_p}{P_{op}} \right) + e(\text{CDH}_{p-op}) \times \ln \left( \frac{P_p}{P_{op}} \right) + \varepsilon
\]

- The two-equation system estimated using daily observations
- Estimated in first differences to eliminate or reduce autocorrelation in error terms
RESULTS
CPP Produces A Significant Residential Response

• The statewide summer impact on critical days was 13.1 percent
• Higher response in warmer climates
CPP Produces Consumer Response

- Expressed in absolute terms, electricity reduction is more pronounced in hot climates

Change in Residential Peak-Period kW

<table>
<thead>
<tr>
<th>Zone</th>
<th>Change in kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>-0.04</td>
</tr>
<tr>
<td>Zone 2</td>
<td>-0.09</td>
</tr>
<tr>
<td>Zone 3</td>
<td>-0.26</td>
</tr>
<tr>
<td>Zone 4</td>
<td>-0.36</td>
</tr>
<tr>
<td>All</td>
<td>-0.15</td>
</tr>
</tbody>
</table>
Critical Peak Period Response By Hour

Figure 2
Hourly % Impacts - Complex Period Share Model

- Zone 1
- Zone 2
- Zone 3
- Zone 4
- Zonal Average

Off 11 12 13 14 15 16 17 18 19 20 21
Distribution of Customer Responses

30% of residential customers provided 80% of demand response

High Responders
- Monthly kWh 775
- CAC Saturation 66%
- 75% single family
- High price elasticity

Low Responders
- Monthly kWh 453
- CAC Saturation 29%
- 52% single family
- Low price elasticity

30% of residential customers provided 80% of demand response
Econometric results can be used to produce demand curves

- CRA’s pricing impact simulation (PRISM) model predicts the change in load shapes that are likely to be induced by time-varying rates
- PRISM results can be summarized as demand curves and impact curves
The demand curve for peak period usage shows small but significant price responsiveness.

The graph illustrates the relationship between peak period usage (in kWh/hour) and peak price ($/kWh). The demand curve is downward sloping, indicating that as peak period usage increases, the peak price decreases. The graph includes three key points:

- **Average CPP Price = $0.58**
- **Average Non-CPP Price = $0.22**
- **Average Control Price = $0.13**

The data points on the graph are marked, showing the relationship between peak period usage and peak price.
PRISM can be used to simulate the impact of a variety of prices

Percent Reduction in Peak-Period Energy Use on Critical Days
Average Summer, 2003/04

<table>
<thead>
<tr>
<th>Peak Price ($/kWh)</th>
<th>Zone 1</th>
<th>Zone 2</th>
<th>Zone 3</th>
<th>Zone 4</th>
<th>Statewide</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>0.10</td>
<td>2.00</td>
<td>1.80</td>
<td>1.60</td>
<td>1.40</td>
<td>1.50</td>
</tr>
<tr>
<td>0.20</td>
<td>3.50</td>
<td>3.30</td>
<td>3.10</td>
<td>2.90</td>
<td>3.00</td>
</tr>
<tr>
<td>0.30</td>
<td>5.00</td>
<td>4.80</td>
<td>4.60</td>
<td>4.40</td>
<td>4.50</td>
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<td>0.40</td>
<td>6.50</td>
<td>6.30</td>
<td>6.10</td>
<td>5.90</td>
<td>6.00</td>
</tr>
<tr>
<td>0.50</td>
<td>8.00</td>
<td>7.80</td>
<td>7.60</td>
<td>7.40</td>
<td>7.50</td>
</tr>
<tr>
<td>0.60</td>
<td>9.50</td>
<td>9.30</td>
<td>9.10</td>
<td>8.90</td>
<td>9.00</td>
</tr>
<tr>
<td>0.70</td>
<td>11.0</td>
<td>10.8</td>
<td>10.6</td>
<td>10.4</td>
<td>10.5</td>
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<tr>
<td>0.80</td>
<td>12.5</td>
<td>12.3</td>
<td>12.1</td>
<td>11.9</td>
<td>12.0</td>
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<tr>
<td>0.90</td>
<td>14.0</td>
<td>13.8</td>
<td>13.6</td>
<td>13.4</td>
<td>13.5</td>
</tr>
<tr>
<td>1.00</td>
<td>15.5</td>
<td>15.3</td>
<td>15.1</td>
<td>14.9</td>
<td>15.0</td>
</tr>
</tbody>
</table>

SPP average price = 59 ¢/kWh
## Drivers of % Impact on Critical Peak Energy Use

<table>
<thead>
<tr>
<th>Variable</th>
<th>Customer Characteristic</th>
<th>Peak Period</th>
<th>Off-Peak Period</th>
<th>Daily Period</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Average</td>
<td>-13.06</td>
<td>2.04</td>
<td>-2.37</td>
</tr>
<tr>
<td>Central A/C</td>
<td>Yes</td>
<td>-17.43</td>
<td>3.21</td>
<td>-2.82</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>-8.05</td>
<td>0.68</td>
<td>-1.87</td>
</tr>
<tr>
<td>Average Daily Use</td>
<td>200% of Average</td>
<td>-14.70</td>
<td>1.77</td>
<td>-3.04</td>
</tr>
<tr>
<td></td>
<td>50% of Average</td>
<td>-12.15</td>
<td>2.21</td>
<td>-1.99</td>
</tr>
<tr>
<td>Spa</td>
<td>Yes</td>
<td>-15.84</td>
<td>3.53</td>
<td>-2.13</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>-12.94</td>
<td>1.93</td>
<td>-2.41</td>
</tr>
<tr>
<td>Electric Cooking</td>
<td>Yes</td>
<td>-11.53</td>
<td>0.32</td>
<td>-3.14</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>-14.09</td>
<td>3.16</td>
<td>-1.87</td>
</tr>
<tr>
<td>Persons Per Household</td>
<td>Four</td>
<td>-12.13</td>
<td>1.51</td>
<td>-2.47</td>
</tr>
<tr>
<td></td>
<td>Two</td>
<td>-13.99</td>
<td>2.46</td>
<td>-2.35</td>
</tr>
<tr>
<td>Annual Income</td>
<td>$100,000</td>
<td>-16.15</td>
<td>2.99</td>
<td>-2.60</td>
</tr>
<tr>
<td></td>
<td>$40,000</td>
<td>-10.92</td>
<td>1.68</td>
<td>-2.00</td>
</tr>
<tr>
<td>Housing Type</td>
<td>Single Family</td>
<td>-13.98</td>
<td>2.72</td>
<td>-2.16</td>
</tr>
<tr>
<td></td>
<td>Multi-Family</td>
<td>-11.78</td>
<td>0.43</td>
<td>-3.14</td>
</tr>
<tr>
<td># Bedrooms</td>
<td>Four</td>
<td>-15.67</td>
<td>2.12</td>
<td>-3.07</td>
</tr>
<tr>
<td></td>
<td>Two</td>
<td>-11.59</td>
<td>2.01</td>
<td>-1.96</td>
</tr>
<tr>
<td>College Education</td>
<td>Graduate</td>
<td>-18.52</td>
<td>3.69</td>
<td>-2.79</td>
</tr>
<tr>
<td></td>
<td>Did Not Graduate</td>
<td>-8.56</td>
<td>0.93</td>
<td>-1.84</td>
</tr>
<tr>
<td>CARE Discount</td>
<td>Yes</td>
<td>-2.87</td>
<td>0.00</td>
<td>-0.84</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>-15.56</td>
<td>4.04</td>
<td>-1.68</td>
</tr>
</tbody>
</table>

Winter Results

- Winter defined as 1 November 2003 to 30 April 2004
- CPP-F: Winter demand response (DR) one third of summer

Critical Peak

-4.7%

Normal Peak

-4.7%

-1.8%

-13.1%

-14%

-12%

-10%

-8%

-6%

-4%

-2%

0%
Winter CPP Impact By Zone

% Change in Residential Peak Energy Use

<table>
<thead>
<tr>
<th>Zone</th>
<th>Critical Weekdays</th>
<th>Normal Weekdays</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zone 1</td>
<td>-4.3%</td>
<td>-1.6%</td>
</tr>
<tr>
<td>Zone 2</td>
<td>-4.1%</td>
<td>-1.4%</td>
</tr>
<tr>
<td>Zone 3</td>
<td>-3.7%</td>
<td>-1.4%</td>
</tr>
<tr>
<td>Zone 4</td>
<td>-3.4%</td>
<td>-1.3%</td>
</tr>
<tr>
<td>All Zones Winter</td>
<td>-3.9%</td>
<td>-1.4%</td>
</tr>
<tr>
<td>All Zones Summer</td>
<td>-13.1%</td>
<td>-4.7%</td>
</tr>
</tbody>
</table>

- Critical Weekdays
- Normal Weekdays
Other key findings for the CPP-F rate

• Peak-period demand reduction persisted into second summer – TOU did not

• Peak-period demand reduction persisted on 2\textsuperscript{nd} or 3\textsuperscript{rd} days of multi-day critical events

• Critical-day impacts were greatest in mid summer (-14.4\%) than cooler shoulder months (-8.1\%)

• Overall annual energy use unchanged
CPP-V Results

• 50% of customers on CPP-V is business
• Stronger critical peak reduction due to a) higher use of CAC in this sample, b) greater use of enabling technology
  – Track A: 16% reduction in critical peak period (vs. 13% for CPP-F)
  – Track C: 27% reduction

• Allowed the effect of enabling technology to be isolated

• Conclusion: Enabling technology matters
CPP-V Results: The Effect Of Enabling Technology

(Hot Day, August 15, 2003, Average Peak Temperature 88.5°F)

Information Only Results

• Some response in 2003 to Information Only, especially in one zone
• No response at all in 2004
• Customers were confused – most thought they were still on the high rates – they weren’t! This confusion increased over time

→ Financial incentives do matter
Most Customers Saw Bill Reductions

Customer Response Is Positive

Customer Response Is Positive

Should dynamic rates be offered to all customers?

<table>
<thead>
<tr>
<th></th>
<th>Definitely</th>
<th>Probably</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>69%</td>
<td>22%</td>
</tr>
<tr>
<td>TOU</td>
<td>65%</td>
<td>30%</td>
</tr>
<tr>
<td>CPP-F</td>
<td>73%</td>
<td>20%</td>
</tr>
<tr>
<td>CPP-V</td>
<td>61%</td>
<td>26%</td>
</tr>
<tr>
<td>Info Only</td>
<td>69%</td>
<td>17%</td>
</tr>
</tbody>
</table>

Should all customers be placed on a dynamic rate and given an option to switch to another rate?

<table>
<thead>
<tr>
<th></th>
<th>Definitely</th>
<th>Probably</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>43%</td>
<td>21%</td>
</tr>
<tr>
<td>TOU</td>
<td>39%</td>
<td>28%</td>
</tr>
<tr>
<td>CPP-F</td>
<td>46%</td>
<td>17%</td>
</tr>
<tr>
<td>CPP-V</td>
<td>41%</td>
<td>23%</td>
</tr>
<tr>
<td>Info Only</td>
<td>41%</td>
<td>22%</td>
</tr>
</tbody>
</table>

Summing Up: Seven Surprises...

1. That customers responded at all
2. People understood the rates enough to respond
3. CPP response persisted across years and across multi-day critical events
4. TOU response not sustained
5. Not everyone will take a free enabling technology
6. Significant impacts are achievable without enabling technology
7. Customers liked the rates and most chose to stay on them
Not so surprising...

- Price matters
- The magnitude of customer response varies with customer characteristics
  - Central air conditioning the key driver
  - High users (that have more appliances) have more load to shift
- The CPP-F tariff did not have a measurable effect on overall, annual energy use
  - Encouraged by off-peak price reductions, customers’ total energy consumption unchanged.
3. ROLLOUT
Demand Response and AMI – Advanced Metering Infrastructure

• In December 2002, California Public Utilities Commission asks Pacific Gas & Electric to investigate AMI
Benefits of Demand Response

- Lowers peak capacity requirements, raises system reliability
- Reserve margin multiplies avoided capacity costs
- Connects retail prices to cost, increasing demand elasticity and producing allocative efficiency benefits
- DR is a check on market power of suppliers
The AMI Business Case (PG&E Only)

- PV Cost of rolling out AMI: $2.265 billion
- PV Operational benefits of AMI (excluding DR): $2.024 billion
  
  Gap: $241 million
- Can DR via dynamic pricing cover this cost? Yes
- Avoided peak capacity costs $270 million
  + avoided transmission and distribution capacity $68 million
  
  = total DR savings of $338 million
- Assumes one third of customers with CAC adopt, 5% of customers without CAC
- PG&E has requested that it begin deployment in 2006
Conclusion

• The SPP has shown conclusively that small customers respond to time-varying prices
• Residential responses significantly higher in warmer climate zones and for customers with central air conditioning
• Estimated peak load reduction of 1,500 to 3,000 MW over 5 years
• A voluntary, opt-in critical pricing rate offered to residential customers with central air conditioning has the potential to add value
Further Information

• Full SPP data set available for research purposes from CEC. Contact Mike Messenger mmesseng@energy.state.ca.us

  Requires statement of purpose and signing non-disclosure

• CRA contact: Ahmad Faruqui afaruqui@crai.com

• Comprehensive documentation of SPP available from http://www.energy.ca.gov/demandresponse/documents/

  Recommended reading: March 24, 2005 CRA report