Optimal Retail Choice in Modern Power Sectors

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University of California at Berkeley

September, 2015
A challenging economic sector
A challenging economic sector
A challenging economic sector
A challenging economic sector
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A challenging economic sector
Rates, rates, rates!

My Rate Plan Choices

PG&E offers several **Base Plan** choices.

**Tiered Base Plan**
PG&E’s standard **Tiered rate plan** is based on usage tiers. As you use more electricity during your monthly bill period, the price goes up with each tier.

**Electric Vehicle Base Plan**
The **Plug-in Electric Vehicles rate plan** is also Time of Use, just without usage tiers. This plan is environmentally friendly and energy efficient, just like your vehicle.

**Time of Use Base Plan**
An alternative to the Tiered Plan, the **Time of Use plan** pricing varies depending on when you use during the day, week, and season. This puts you in control.

On top of your Base Plan, PG&E also offers **Add-ons** to help you save.

**SmartRate™ Add-on**
The **SmartRate Plan** helps you save up to 20% on your summer electric bill. Receive a discount for reducing your electricity usage up to 15 days a year.

**Net Energy Metering Add-on**
The **Net Energy Metering Add-on** allows customers with an eligible power generator like solar panels to earn a credit for power exported to the grid.
It won’t be easy…”
Where to start? The peak-load pricing theory

(Steiner, 1957)  (Boitzeux, 1960)  (Turvey, 1968)
(Panzar, 1976)  (Crew & Kleindorfer, 1976)
Where to start? The Peak-Load Pricing theory

\[ ICAP = q_{\text{day}} \]

(Steiner, 1957)  (Boitzeux, 1960)  (Turvey, 1968)

\[ p_{\text{day}} = c_{\text{ICAP}} + c_e \]

(Panzar, 1976)  (Crew & Kleindorfer, 1976)

\[ p_{\text{night}} = c_e \]

Where to start? The peak-load pricing theory

\[ ICAP = q_{\text{day}} \]

\[ p_{\text{day}} = c_{ICAP} + c_e \]

\[ p_{\text{night}} = c_e \]

\[ q_{\text{night}} \]

\[ q_{\text{day}} \]
Advanced versions

State of nature: Day, week, year, etc.
The retail model

Regulator

LSE

Supervises LSE

Wholesale market

Tariffs

Consumption
The retail model

Regulator

Supervises LSE

Wholesale market

Maximize customer surplus

Subject to

Revenue sufficiency of LSE

LSE offers a portfolio of tariffs

Regulator internalizes impacts on long-run customers’ decisions
Long-run decisions

Retail customers

Array of technologies

Smart meter

Smart meter + PV panel

Storage system

Back-up generation

Tariffs

Residential

Industrial

Flat rate

Time-of-Use
Long-run decisions

- Retail customers
  - Array of technologies
    - Smart meter
      - Segment
        - Flat rate
        - Tariffs
        - Time-of-Use
        - Industrial
        - Back-up generation
The tariffs

Two-part tariffs

Fixed charge (e.g. $/meter) \quad \quad l_\tau \in \mathbb{R}

Variable charge (e.g. c$/kWh) \quad \quad p_\tau \in \mathbb{R}_+^{\left|\Omega\right| \times T}

Variable charge feasible region \quad \quad \mathcal{P}_\tau \subset \mathbb{R}_+^{\left|\Omega\right| \times T}
Flat rate

\[ p(t, \omega) \]
Flat rate

Constraints \( p(t_1, \omega_1) = p(t_1, \omega_1) = \cdots = p(T(|\Omega|)) \)
Time-of-Use

$p(t, \omega)$

Winter day

Summer day

$t$
\[ p(t, \omega) = p(\text{off-peak}_1)(\text{Summer}) = p(\text{off-peak}_2)(\text{Summer}) = \cdots \]

\[ p(\text{peak}_1)(\text{Summer}) = p(\text{peak}_2)(\text{Summer}) = \cdots \]

\[ \vdots \]
Real time pricing

$p(t, \omega)$

Day 1
Day 2
Day 3
Real time pricing

\[ p(t, \omega) \]

No constraints
Long-run equilibrium

\[
\max E \left\{ \sum_h \alpha_h [S_h(p_h) - k_h] - c(y, x) \right\}
\]

\[
\sum_{h \in H} \alpha_h D_h(p_h) = \sum_{i \in I} y_i
\]

\((y, x) \in Q\)

\(p^h \in \mathcal{P}^h\)

\(\alpha \in \mathcal{A}\)
Normative implications

No additional structure

- Proposition 1 (No switching)

Additional structure

- Proposition 1 (Sufficiency + easy)

- Corollary 1 (Eq. welfare maximizing)

- Corollary 2 (Opt. tariff → Opt. outcomes)
The structure of the analysis

- **AMI cost**
  - [(2014)$/month]

- **RPS targets**
  - 1.00
  - 1.50
  - 2.00

- **Flat rate + TOU v/s Flat rate + TOU + RTP**

- **Load and weather patterns**
  - California
  - Denmark

- **Automation technology upfront cost**
  - [(2014)$]
The structure of the analysis

- AMI cost $[(2014)\$/month]$
- RPS targets
- Load and weather patterns
- Flat rate + TOU v/s Flat rate + TOU + RTP
- California
- Denmark
- Automation technology upfront cost $[(2014)\$]$
The structure of the analysis

RPS targets

Load and weather patterns

California

Denmark

Flat rate + TOU

v/s

Flat rate + TOU + RTP

AMI cost

[(2014)$/month]

Automation technology upfront cost

[(2014)$]

15%

35%

55%

75%

1.00

1.50

2.00

113

170

226
The structure of the analysis

- **AMI cost**
  - [(2014)$/month]

- **RPS targets**
  - 1.00
  - 1.50
  - 2.00

- **Load and weather patterns**
  - California
  - Denmark

- **Flat rate + TOU v/s Flat rate + TOU + RTP**

- **Automation technology upfront cost**
  - [(2014)$]
The structure of the analysis

RPS targets

Load and weather patterns

California

Denmark

Flat rate + TOU
v/s
Flat rate + TOU + RTP

AMI cost
[(2014)$/month]

Automation technology
upfront cost
[(2014)$]
Recall

- **AMI cost**: [(2014)$/month]
  - 35%
  - 15%

- **RPS targets**: 1.00, 1.50, 2.00

- **Automation technology upfront cost**: [(2014)$]
  - 113, 170, 226

- **Load and weather patterns**
  - California
  - Denmark

- **Flat rate + TOU v/s Flat rate + TOU + RTP**
2 Tariffs

- Standard meter
- AMI
- AMI + Automation
- Flat rate
- TOU

Representative costumer
Demand assumptions

3 Tariffs

Representative costumer

- Standard meter
- AMI
- AMI + Automation

- Flat rate
- TOU
- RTP
Welfare difference (3Tar - 2Tar)

Incremental cost AMI [$/month]

Avg. Absolute difference [$/year]

Avg. Relative difference [%]

Capital cost automation [$]

113 170 226

1.0

1.5

2.0

0M

50M

100M

150M

200M
Welfare difference (3Tar - 2Tar)
## Demand mix

<table>
<thead>
<tr>
<th># Tariffs</th>
<th>Customer type</th>
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<th>Incremental cost AMI [$/month]</th>
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Supply mix

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<tr>
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<th>Avg. Installed capacity [MW-year]</th>
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15% RPS
Supply mix

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<tr>
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<td>Peak</td>
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<td>High-peak</td>
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<td></td>
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30% RPS
## Supply mix

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<tr>
<td>Mid-merit</td>
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<td>High-peak</td>
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</tr>
<tr>
<td>Wind</td>
<td><img src="image" alt="Bar Graph" /></td>
<td>45K</td>
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<tr>
<td><strong>3 Tariffs</strong></td>
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<tr>
<td>Mid-merit</td>
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<tr>
<td>Wind</td>
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</table>

50% RPS
## Supply mix

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<tr>
<td></td>
<td>Wind</td>
<td><img src="image" alt="Wind Capacity" /></td>
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75% RPS
Final thoughts and future work

• The problem of rate design is far from simple yet very important in the current stage of the electricity sector.

• Normative guidelines could involve more complex analysis specially with the current computational power and algorithmic techniques.

• Analysis of rate design should contemplate not only effects on supply of a given rate offering but also on the long-run demand decisions.

• Next: An application to an analysis of residential rates in California.
Thank you!
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Welfare analysis by tech. costs: Denmark

\[ \Delta W = \Delta GS - \Delta C = C_{\text{reduction}} + GS_{\text{increase}} \]
Welfare analysis by RPS: Denmark

Welfare comparison by RPS

Welfare composition by RPS

Elasticity
- high
- medium
- low

Graphs showing welfare analysis with RPS for Denmark.
## Technology mix: Denmark

### Demand mix

<table>
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<tr>
<th># Tariffs</th>
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</thead>
<tbody>
<tr>
<td>2 Tariffs</td>
<td>Standard meter</td>
<td>Flat rate</td>
<td>113 170 226</td>
<td>113 170 226</td>
</tr>
<tr>
<td></td>
<td>AMI only</td>
<td>TOU</td>
<td>●●●</td>
<td>●●●</td>
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<tr>
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<td>AMI + automation</td>
<td>TOU</td>
<td>●●●</td>
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### Supply mix

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<tr>
<td></td>
<td>High-peak</td>
<td>1,747 1,778 1,779</td>
<td>1,841 1,872 1,873</td>
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<td>Wind</td>
<td>4,978 4,978 4,978</td>
<td>4,978 4,978 4,978</td>
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<td>2,158 2,159 2,159</td>
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<tr>
<td></td>
<td>High-peak</td>
<td>1,233 1,249 1,256</td>
<td>1,283 1,299 1,307</td>
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<tr>
<td></td>
<td>Wind</td>
<td>4,979 4,979 4,979</td>
<td>4,979 4,979 4,979</td>
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</table>

### Avg. Installed capacity [MW-year]

- 1,233
- 4,979
The regulator problem

\[
\max_{(\alpha_h, l_h, p^\tau)} \mathbb{E} \left[ \sum_{\tau} \sum_h \alpha_h [S_h(p^\tau) - p^\tau D_h(p^\tau) - k_h - l_h] \right]
\]

\[
\mathbb{E} \left[ \sum_{\tau} \sum_h \alpha_h [(p^\tau - \lambda) D_h(p^\tau) + l_h] \right] - \Pi \geq 0
\]

\[p^\tau \in \mathcal{P}^\tau\]

\[\alpha \in \mathcal{A}\]

**Proposition 1** At the optimal retail allocation, no customer enrolled in a program has negative net surplus and no customer has incentives to change to a different retail tariff.
Long-run equilibrium

\[
\max E \left\{ \sum_h \alpha_h [S_h(p_h) - k_h] - c(y, x) \right\}
\]

\[
\sum_{h \in H} \alpha_h D_h(p_h) = \sum_{i \in I} y_i
\]

\((y, x) \in Q\)

\(p^h \in \mathcal{P}^h\)

\(\alpha \in \mathcal{A}\)
Long-run equilibrium

$$\max E \left\{ \sum_h \alpha_h [S_h(p_h) - k_h] - c(y, x) \right\}$$

$$\sum_{h \in H} \alpha_h D_h(p_h) = \sum_{i \in I} y_i$$

$$(y, x) \in Q$$

$$p^h \in P^h$$

$$\alpha \in A$$
Long-run equilibrium

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\max E \left\{ \sum_h \alpha_h [S_h(p_h) - k_h] - c(y, x) \right\}
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\((y, x) \in Q\)

\(p^h \in \mathcal{P}^h\)

\(\alpha \in \mathcal{A}\)
Long-run equilibrium

\[ \max E \left\{ \sum_h \alpha_h [S_h(p_h) - k_h] - c(y, x) \right\} \]

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\((y, x) \in Q\)

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\(\alpha \in \mathcal{A}\)
Long-run equilibrium

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\((y, x) \in Q\)

\(p^h \in P^h\)

\(\alpha \in A\)
Long-run equilibrium

\[ \max E \left\{ \sum_h \alpha_h [S_h(p_h) - k_h] - c(y, x) \right\} \]

\[ \sum_{h \in H} \alpha_h D_h(p_h) = \sum_{i \in I} y_i \]

\[ (y, x) \in Q \]

\[ p^h \in P^h \]

\[ \alpha \in \mathcal{A} \]
Supply assumptions

\[
\max_{y,x} E[(\lambda - c)^T y] - x \cdot k
\]

subject to

\[
0 \leq y \leq x \cdot \rho
\]
Supply assumptions

\[
\max_{y,x} E[(\lambda - c)^\top y] - x \cdot k
\]

subject to

\[
0 \leq y \leq x \cdot \rho
\]
Supply assumptions

$$\max_{y,x} E[(\lambda - c)^T y] - x \cdot k$$

subject to

$$0 \leq y \leq x \cdot \rho$$
Supply assumptions

\[
\max_{y,x} E[(\lambda - c)^T y] - x \cdot k
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Supply assumptions

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Supply assumptions

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\max_{y,x} E[ (\lambda - c)^\top y ] - x \cdot k
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0 \leq y \leq x \cdot \rho
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Supply assumptions

\[
\max_{y,x} E[(\lambda - c)^T y] - x \cdot k
\]

subject to

\[
0 \leq y \leq x \cdot \rho
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## Demand mix

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