A Price-based Approach to Demand Side Management

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Outline

1. Approach to measuring efficacy risk
2. PJM case study
3. Approach to improving efficacy risk

Background

- Fixed load (d): must be consumed at that time by that amount.
- Flexible load (Δd): can be shifted earlier or later within the day. Examples include: recharging electric vehicles, air conditioning, dish washing, laundry, irrigating, etc.
- Flexible load is the main target of demand side management
- Price based demand side management strategies include
  - Flat rates
  - Time-of-use (TOU) rates
  - Real-time (RT) rates

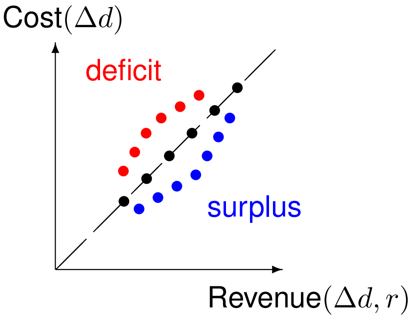
Efficacy assessment of an electric rate

For a given power system, a given fixed load d, a given flexible load Δd, and a given electric rate r, the efficacy of an electric rate is assessed by these values:

- $\text{Cost}(\Delta d) = c(d + \Delta d) - c(d)$
  - $c(d + \Delta d)$ is the cost to serve the total load (fixed and flexible)
  - $c(d)$ is the cost to serve the fixed load only
  - $\text{Cost}(\Delta d)$ is power system's cost to serve the flexible load
- $\text{Revenue}(\Delta d, r) = \sum_{t,n} r_{n,t} \Delta d_{n,t}$
  - n and t represent location and time, respectively
  - $\text{Revenue}(\Delta d, r)$ is power system's revenue from flexible load consumers

A revenue-cost space

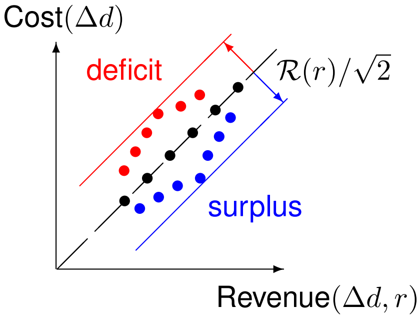
- Any $(\Delta d, r)$ can be mapped onto the revenue-cost space as a point.
- Ideally, all points should be on the 45 degree line.
- If revenue $<$ cost, then power system has a deficit.
- If revenue $>$ cost, then power system has a surplus.



Efficacy measure

For a given electric rate r, we define its efficacy risk as

$$\mathcal{R}(r) = \max_{\Delta d \in \mathcal{P}} \{\text{Cost}(\Delta d) - \text{Revenue}(\Delta d, r)\} + \max_{\Delta d \in \mathcal{P}} \{\text{Revenue}(\Delta d, r) - \text{Cost}(\Delta d)\}$$



A heuristic algorithm for computing $\mathcal{R}$(TOU)

Step 1 Start with an arbitrary Δd, and then obtain the resulting LMPs $p_{n,t}, \forall n, t$.

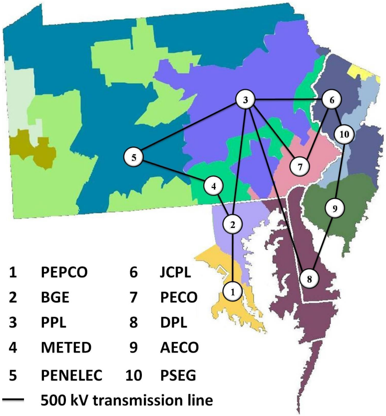
Step 2 To increase deficit, reallocate $\Delta d_{n,t}$ towards where $(p_{n,t} - r_{n,t})$ is large. Do the opposite to increase surplus.

Step 3 Recalculate LMPs for the new Δd and repeat Step 2 until no improvement can be made.

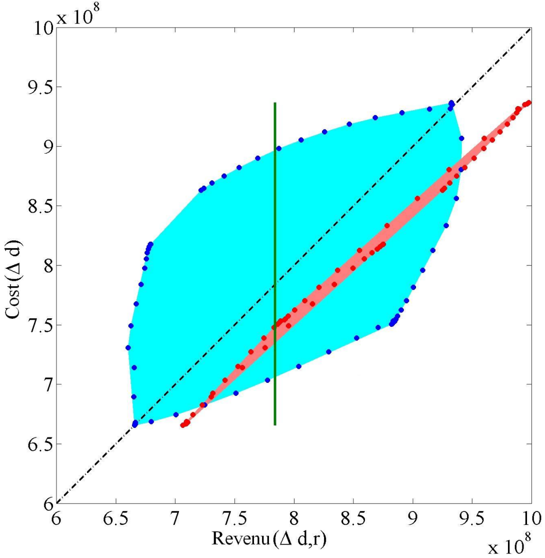
Outline

A PJM example

- A simplified test system for part of the PJM region.
- Historical load and supply data from 6/1/2005 to 5/30/2006 with modification.
- Average fixed and flexible loads are 790 and 33 GWh per day, respectively.
- Fixed daily energy consumption: $\sum_{t \text{ in a day}} \Delta d_{n,t} = 33$ GWh, $\forall n$.



Efficacy risk



- $\mathcal{R}$(flat) $\geq$ \$271M
  - 65 cent/kWh
- $\mathcal{R}$(TOU) $\geq$ \$273M
  - 81 cent/kWh from 11 am to 10 pm
  - 54 cent/kWh from 11 pm to 10 am
- $\mathcal{R}$(RT) $\geq$ \$27M

Outline

Reducing $\mathcal{R}(r)$

- RT rates have a much lower efficacy risk ($27M/year) than flat rates ($271M/year) and TOU rates ($273M/year).
- TOU rates have several advantages over RT rates
  - do not require realtime rate display devices
  - hedge consumers from prices uncertainties
  - help consumers develop habitual consumption pattern.
- TOU rates can be optimized to reduce the efficacy risk.

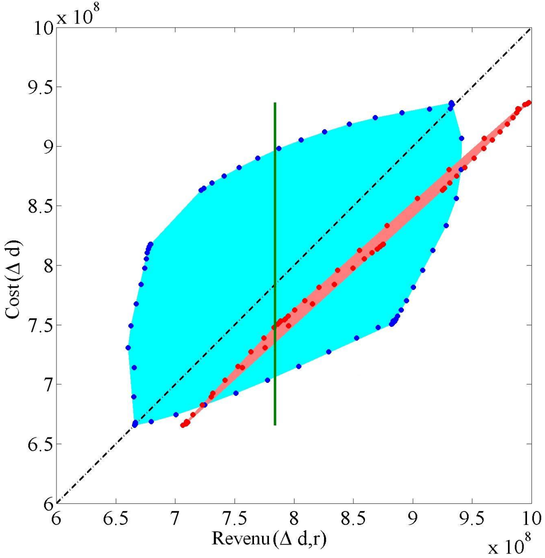
A heuristic algorithm for minimizing $\mathcal{R}$(TOU)

- If we replace $\mathcal{P}$ with a known set $\mathcal{P}^0 \subseteq \mathcal{P}$, then the problem reduces to a linear program:

$$\begin{aligned} \min_{r_{n,t},y_H,y_L} \quad & y_H + y_L \\ \text{s.t.} \quad & \delta(\Delta d) - \textstyle\sum_{n,t} r_{n,t}\Delta d_{n,t} \le y_H, \forall \Delta d \in \mathcal{P}^0 \\ & \textstyle\sum_{n,t} r_{n,t}\Delta d_{n,t} - \delta(\Delta d) \le y_L, \forall \Delta d \in \mathcal{P}^0 \\ & y_H, y_L \ge 0; r \in \mathcal{R}. \end{aligned}$$

- The set $\mathcal{P}^0$ can be updated iteratively using the heuristic algorithm for computing $\mathcal{R}$(TOU).

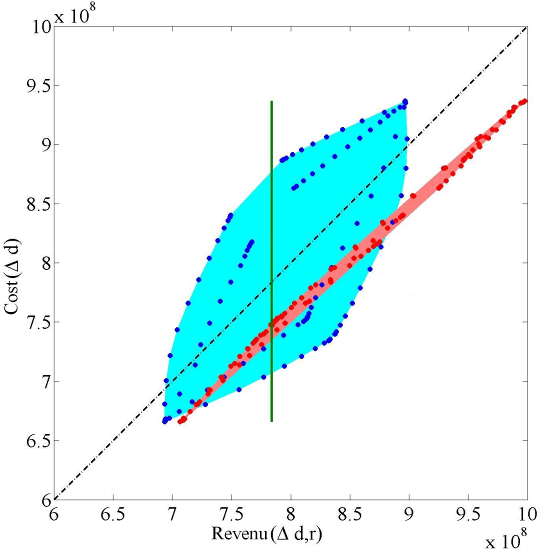
Mitigating $\mathcal{R}$(TOU)



Iteration 0

- $\mathcal{R}$(flat) $\geq$ \$271M
- $\mathcal{R}$(TOU) $\geq$ \$273M
- $\mathcal{R}$(RT) $\geq$ \$27M

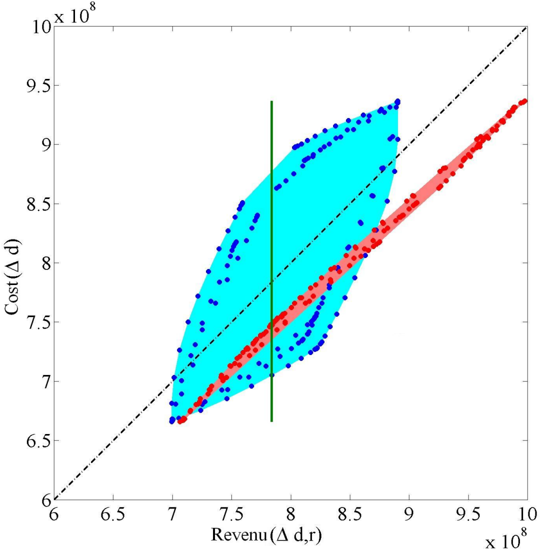
Mitigating $\mathcal{R}$(TOU)



Iteration 1

- $\mathcal{R}$(flat) $\geq$ \$271M
- $\mathcal{R}$(TOU) $\geq$ \$192M
- $\mathcal{R}$(RT) $\geq$ \$27M

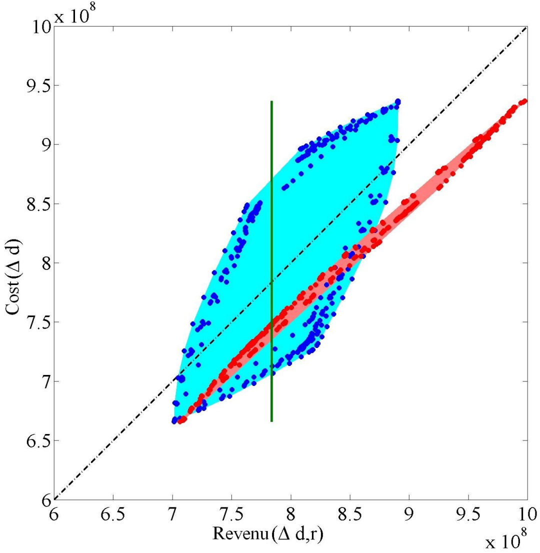
Mitigating $\mathcal{R}$(TOU)



Iteration 2

- $\mathcal{R}(\text{flat}) \geq \$271\text{M}$
- $\mathcal{R}(\text{TOU}) \geq \$188\text{M}$
- $\mathcal{R}(\text{RT}) \geq \$27\text{M}$

Mitigating $\mathcal{R}$(TOU)



Iteration 25

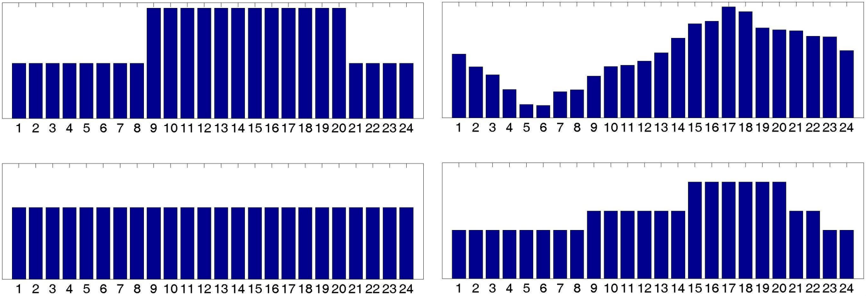
- $\mathcal{R}$(flat) $\geq$ \$271M
- $\mathcal{R}$(TOU) $\geq$ \$180M
- $\mathcal{R}$(RT) $\geq$ \$27M

Concluding remarks

- We defined an efficacy risk measure for price based demand side management strategies.
- Flat rates ($271M/year) and TOU rates ($273M/year) have high risk, and RT rates have low risk ($27M/year).
- We proposed heuristic algorithms to compute and minimize the efficacy risk ($180M/year) of TOU rates through better rate design.

Future directions

- Exact or advanced heuristic algorithm for computing $\mathcal{R}(\text{TOU})$ and $\mathcal{R}(\text{RT})$
- Consumer response to electric rate signal
- Customized rate design



Thank you

Load profiles