Self-Reported Baseline Mechanism for Demand Response

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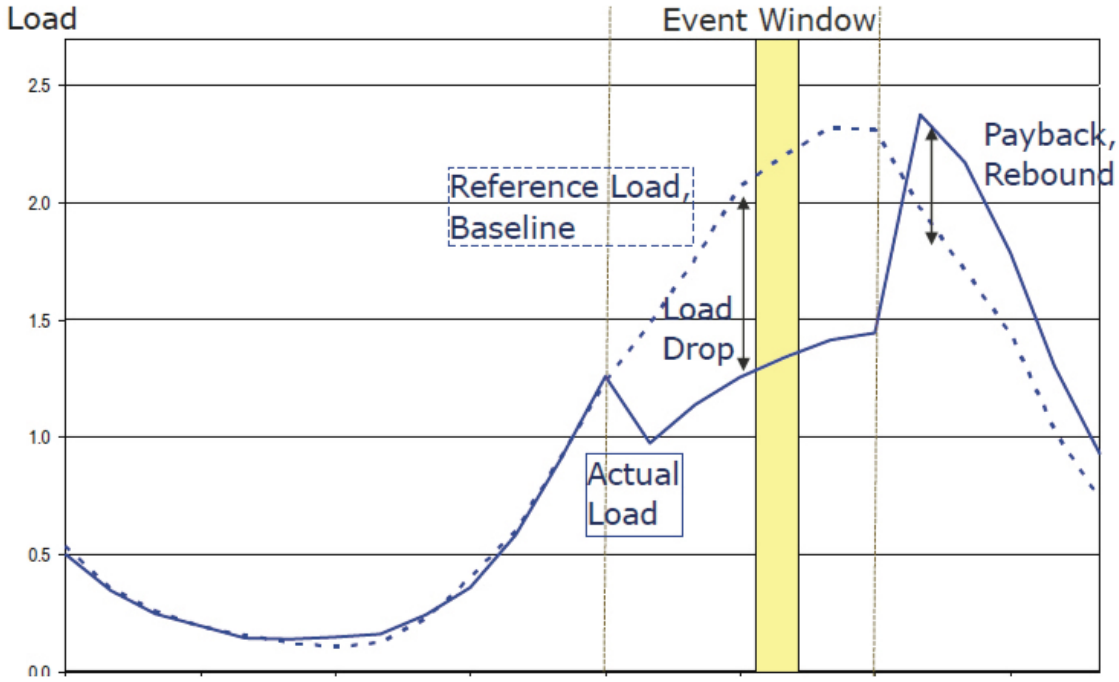
Cornell University

Demand Response (DR)

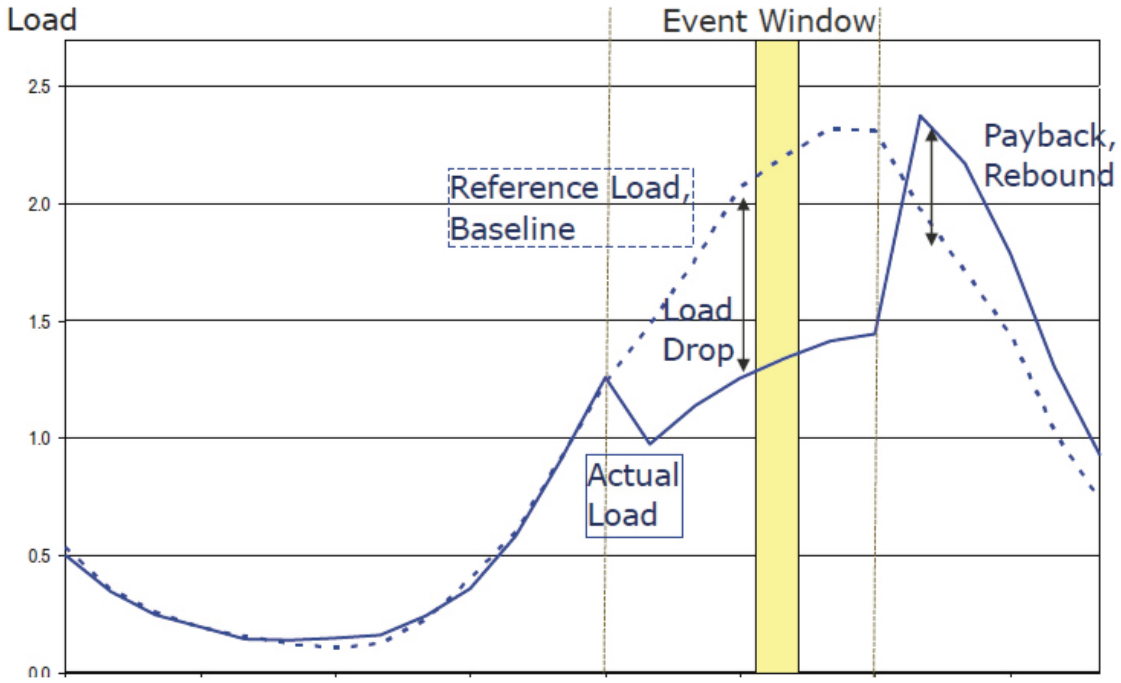
Consumers *reduce load* in response to *incentives* or *price signals*



Source: Miriam Goldberg, DMV GL

Baseline for Demand Response

- **Compensation for DR**:
  - Payment = (Reduction) × (Reward/kWh)
  - Reduction in Consumption = *Baseline* - *Observed*



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  - Ex: CAISO's 10/10 method

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- Current Method: Averaging
  - Baseline estimate is the *average consumption* of *similar non-event days*
  - Ex: CAISO's 10/10 method
- Problem?
  - Inadequate consumer response
  - Under payments and over payments (Chao '11)
  - **Baseline Manipulation** (Chao '11, Wolak '07)

Manipulation Example

- Camden Yards Stadium, Baltimore
  - Turned the lights on (during day time) *before* power emergency when no game was taking place
  - **Inflated Baseline estimate!**
  - Fine: $\$780,000$

Source: http://www.theenergyfix.com/2013/07/25/two-ferc-settlements-illustrate-attempts-to-game-demand-response-programs/

Self-Reported Baselines

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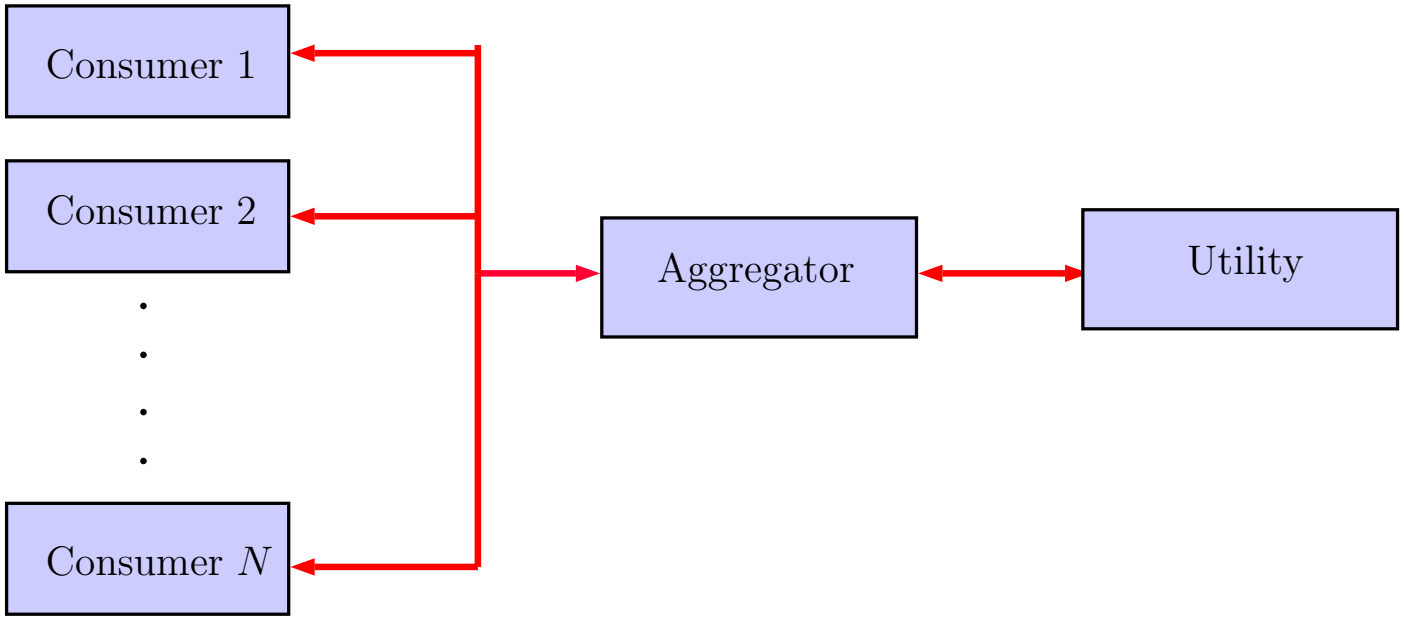
- Intuition:
  - Penalty can avoid baseline manipulation
  - Payment: incentive to reduce

Problem Setting



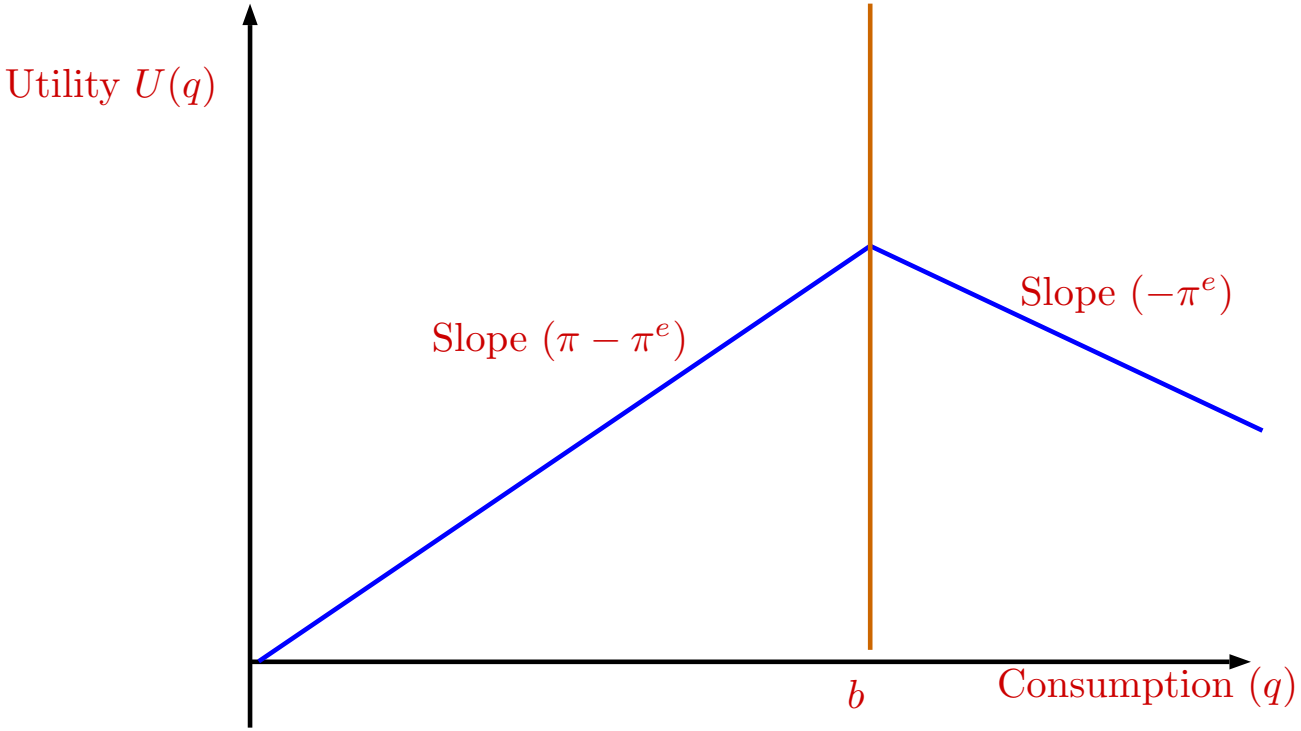
- **Load Reduction Requirement**: D
- **Probability of DR event**: $\mathbb{P}(D > 0) = \alpha$, Peak load scenarios

Consumer Model

- Net-Utility of consumer for consuming q units of energy

$$U(q) = \begin{cases} \pi q - \pi^e q & \text{if } q < b \\ \pi b - \pi^e q & \text{if } q \geq b \end{cases}$$

π marginal utility of consumer
π^e energy cost
b maximum (useful) consumption



We use index k for a particular consumer from now on

Self-Reported Baseline Mechanism (SRBM)

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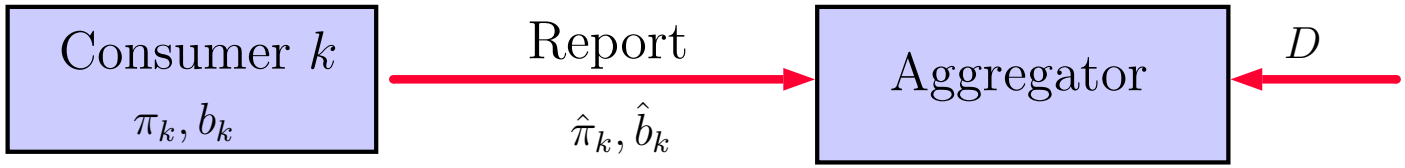

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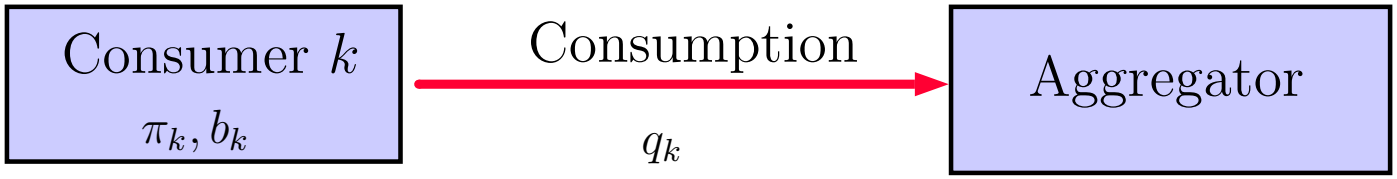

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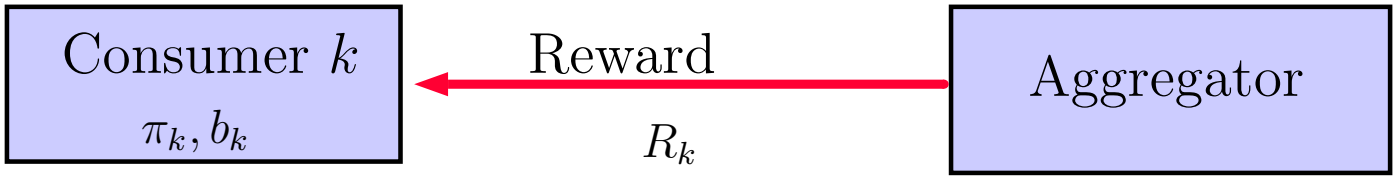

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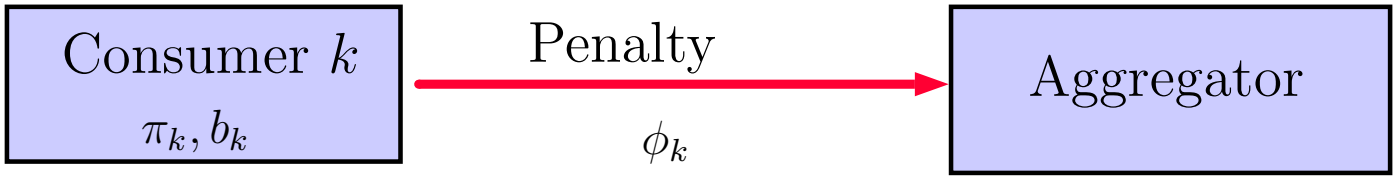
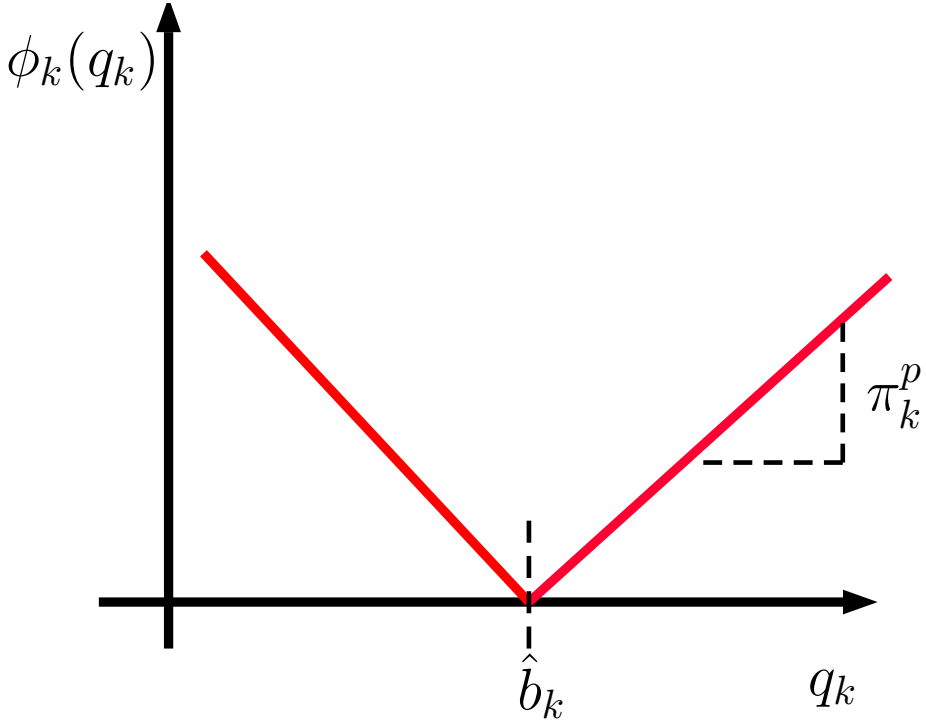
7. Impose penalty on the other consumers for deviating from $\hat{b}_k$



Reward and Penalty Design

When consumer k is not selected



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Note: Consumer pays $\pi^e q_k$ (retail cost)

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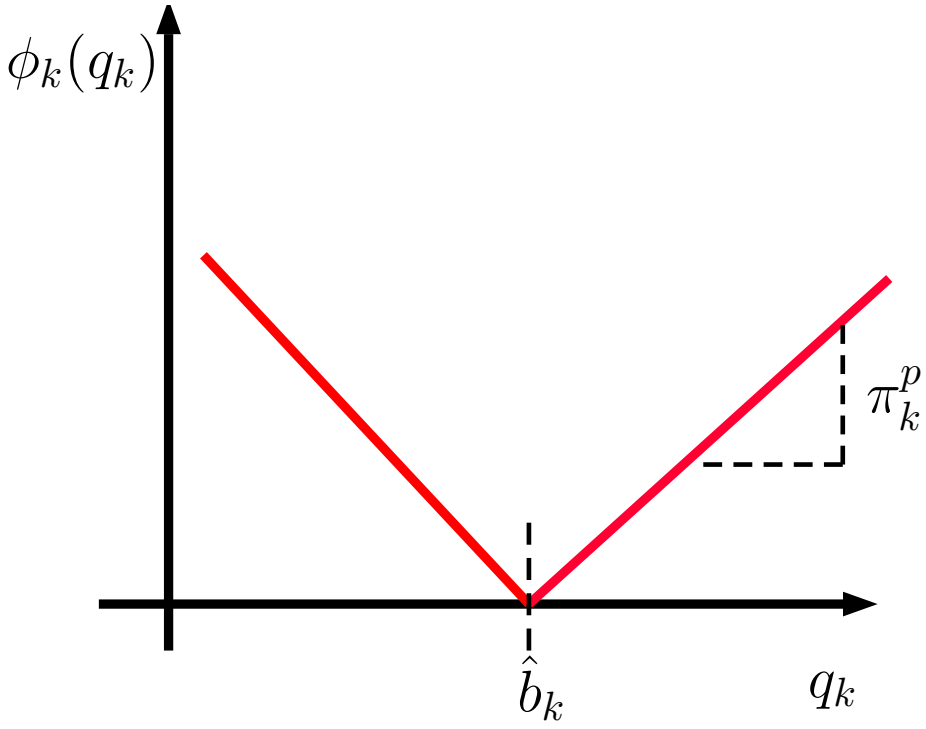

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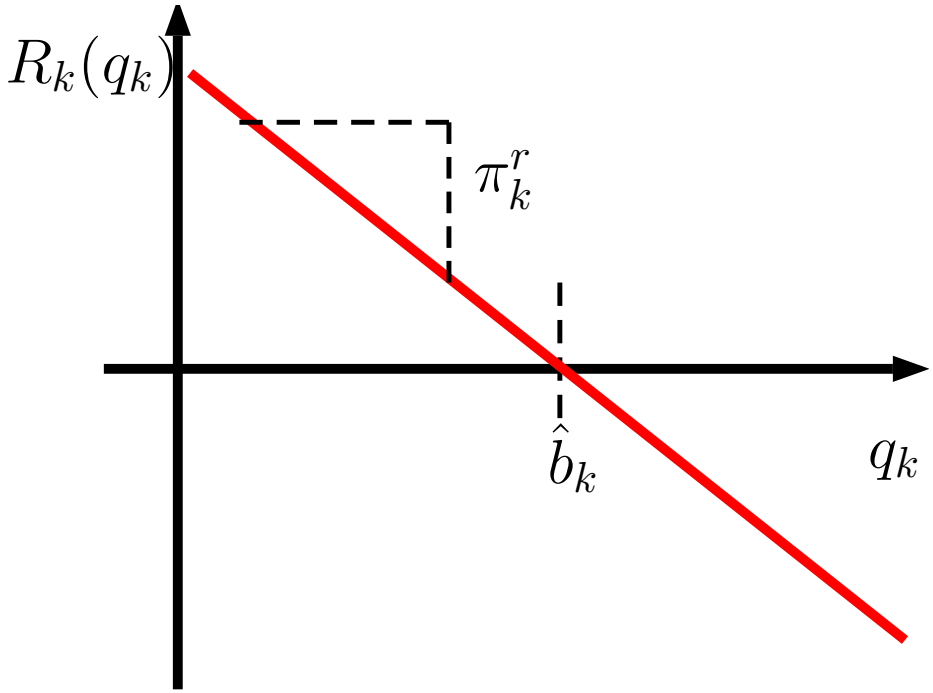


$$\pi_k^r = \max_j\{\hat{\pi}_j\} - \pi^e, \quad j \in S_{-k}$$

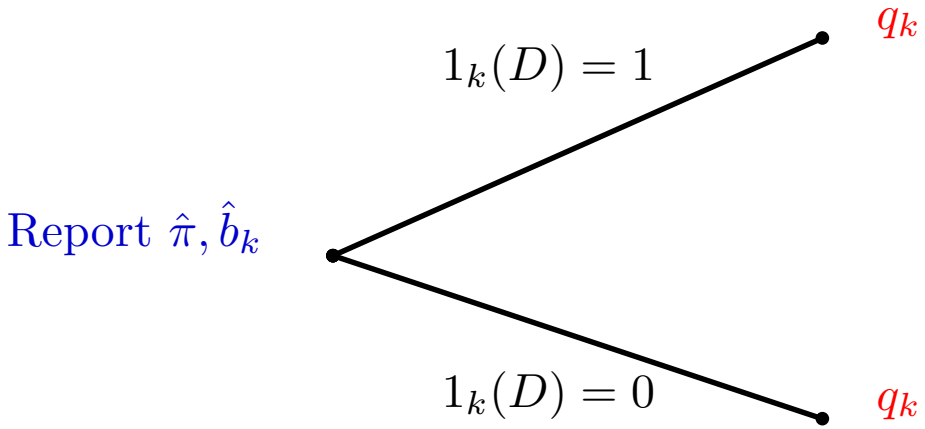
S_{-k}: Set of selected consumers when k is excluded

note: π_k^r is not uniform

Consumer's Decision Problem

- Two stage decision problem
  - First stage: Report baseline consumption $\hat{b}_k$ and marginal utility $\hat{\pi}_k$
  - Second stage: Decide the consumption q_k
  - Notation: $1_k(D) = \begin{cases} 0 & k \text{ is not selected}|D \\ 1 & k \text{ is selected}|D \end{cases}$

$$\max_{\hat{b}_k, \hat{\pi}_k} \mathop{\mathbb{E}}_{D, \hat{b}_{-k}, \hat{\pi}_{-k}} \left[\max_{q_k} \left(U_k(q_k) + \pi_k^r(\hat{\pi}_{-k}) \times (\hat{b}_k - q_k) 1_k(D) - \Phi_k(q_k) \overline{1_k(D)} \right) \right]$$



Optimal Consumer Decision

Theorem

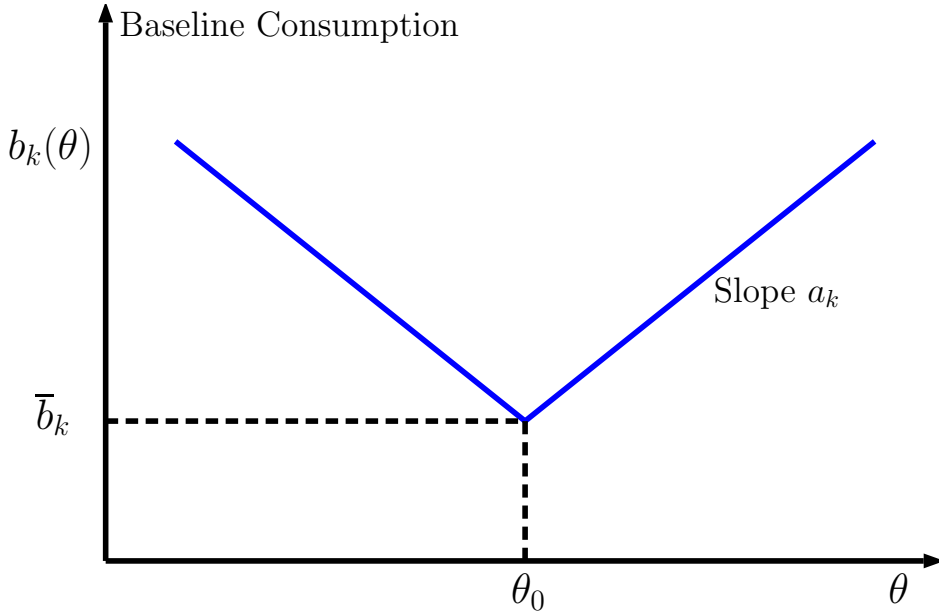
- *Reporting the true baseline and true marginal utility, i.e.* $(\hat{b}_k, \hat{\pi}_k) = (b_k, \pi_k)$ *is a* **dominant strategy equilibrium**
- *The second stage consumption decision is* $q_k = b_k \mathbb{I}\{k \text{ not selected}\}$

Remarks:

1. Baseline report is accurate
2. The mechanism meets the Utility's request D
3. Mechanism is simple
4. It is individiually rational (IR) for the consumers to participate

Extension - Uncertain Future Baseline

- Baseline consumption may depend on temperature
- $b_k(\theta) = \overline{b}_k + a_k|\theta - \theta_0|$
- Each consumers reports $(\hat{\overline{b}}_k, \hat{a}_k)$ and $\hat{\pi}_k$
- Appropriate reward function R_k and penalty function ϕ_k
- Truthful reporting is a dominant strategy for each consumer



Uniform Payment Mechanism

Is there a mechanism that rewards the consumers uniformly?

Uniform Reward/kWh:

- $\pi_k^r = \hat{\pi}_{k^*+1} - \pi_e$

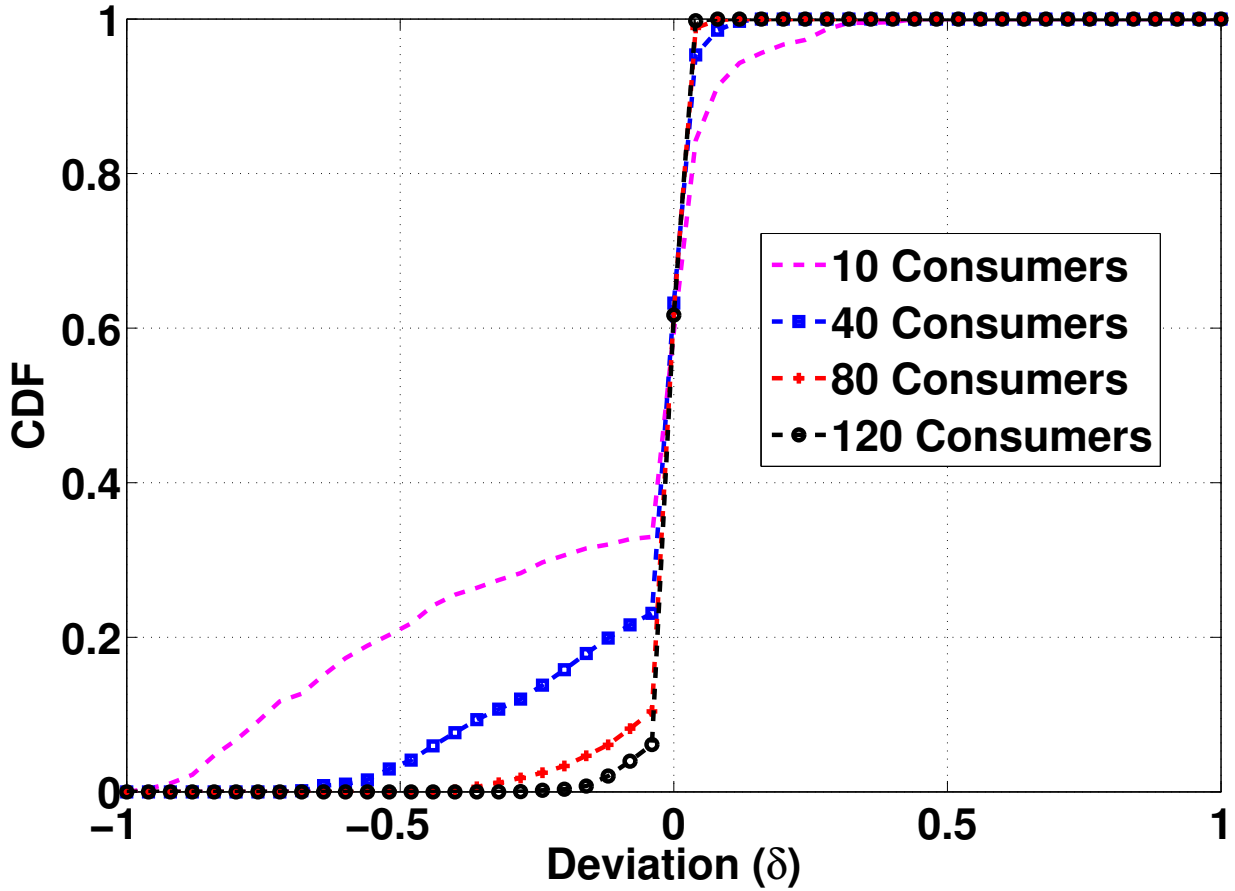
Assumption*: Smaller baseline consumers have smaller marginal utility

Theorem

- *Reporting true baseline and true marginal utility is a* **pure strategy Nash Equilibrium** *(uniqueness not guaranteed)*
- *The second stage consumption decision is* $q_k = b_k \mathbb{I}\{k \text{ not selected}\}$

Uniform Payment Mechanism

For large N, *Nash-Equilibrium* holds without Assumption*



CDF(δ): Fraction of consumers whose deviation from reporting true baseline is $\leq \delta$

CAISO Baseline

- CAISO: California Independent System Operator
- Raw Baseline = *Average consmuption* of *10 similar non-event days* prior to the event day (window of 45 days prior to the event day)
- A load adjustment ratio (LAR) accounts for *variation* in the event day consumption from the past
- Baseline Estimate = Raw Baseline x LAR

CAISO vs SRBM

- CAISO mechanism: No penalty, fixed Reward/kWh: π^r
- Note: we consider a stylized model

Theorem

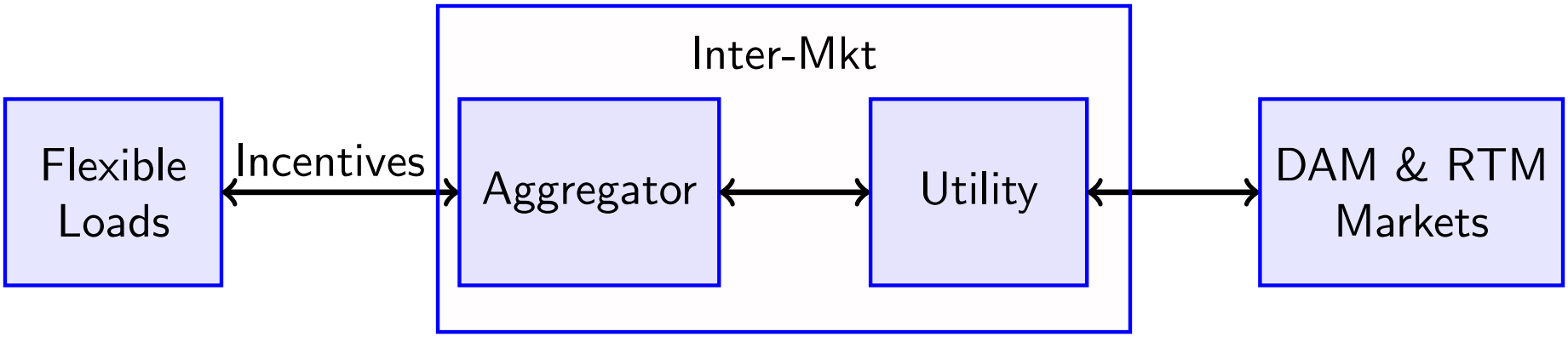
Under the CAISO Mechanism,

(i) When $\pi^r < \pi_{max}$: aggregate reduction may not be sufficient

(ii) When $\pi^r \geq \pi_{max}$: CAISO Payment > SRBM Payment

(iii) Consumers are signaled couple of hours ahead: baseline estimate is inflated

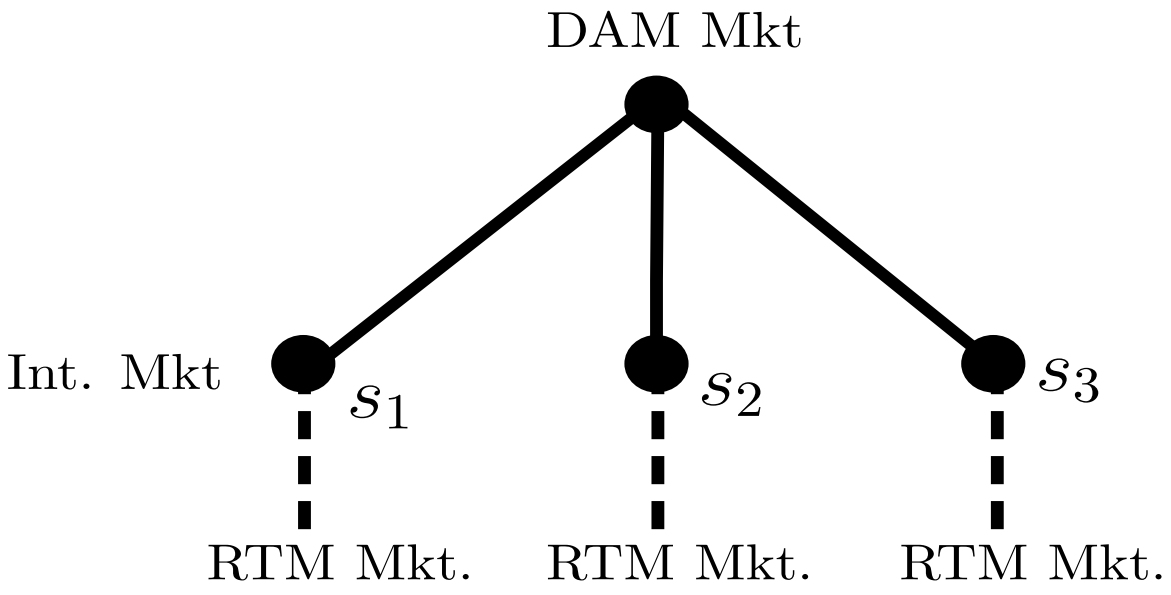
Future Work - Intermediate Market for Selling DR



DAM: Day Ahead Market

RTM: Real Time Market

Preliminary Results - Intermediate Spot Market



Intermediate Spot Market: Contingent Market Prices

Theorem

- *There exists a competitive equilibrium with contingent market prices*
- *All competitive equilibria are socially optimal*

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- By varying Reward/kWh Aggregator learns consumer's response
- Aggregator's objective: maximize savings over a period of time
- Aggregator's design: baseline mechanism and pricing policy (Reward/kWh as a function observed consumer response)

Preliminary Results - Sub-Linear Regret Mechanism

Simplified setting: DR events are exogenous and $\mathbb{P}\{\text{DR event}\} = \alpha$

Consumer model: linear demand function with uncertain baseline

Theorem

For a given α, $\exists$ a Baseline Mechanism and Pricing Policy that achieves sub-linear regret. In particular, Regret $\leq O\left(\sqrt{T}\right)$.

The baseline mechanism and pricing policy are given by,

- *Baseline Mechanism: Consumer's self-report before every day with the possibility of a DR event*
- *Pricing Policy: Optimal price for the learnt behavior plus a perturbation that decreases with time.*

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- Self-Reported Baseline Mechanism (SRBM)
  - Mechanism is reliable and requires less payments (vs. CAISO scheme)
- Future work - Intermediate Market for Selling DR and learning DR

References

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