Approximately Stable Pricing for Coordinated Purchasing of Electricity

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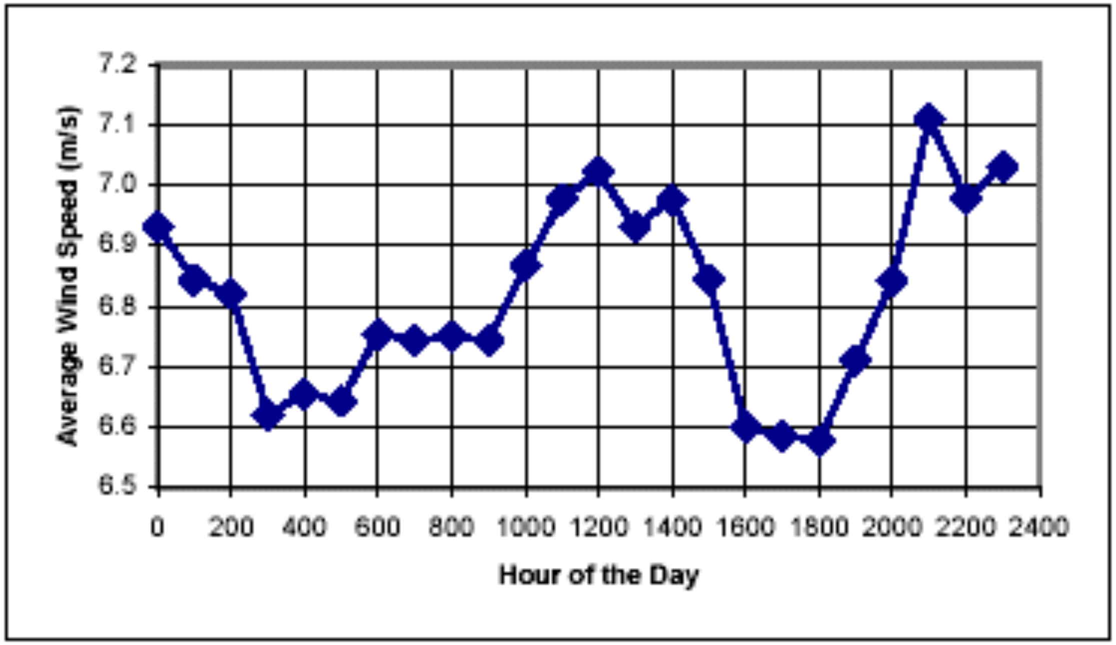
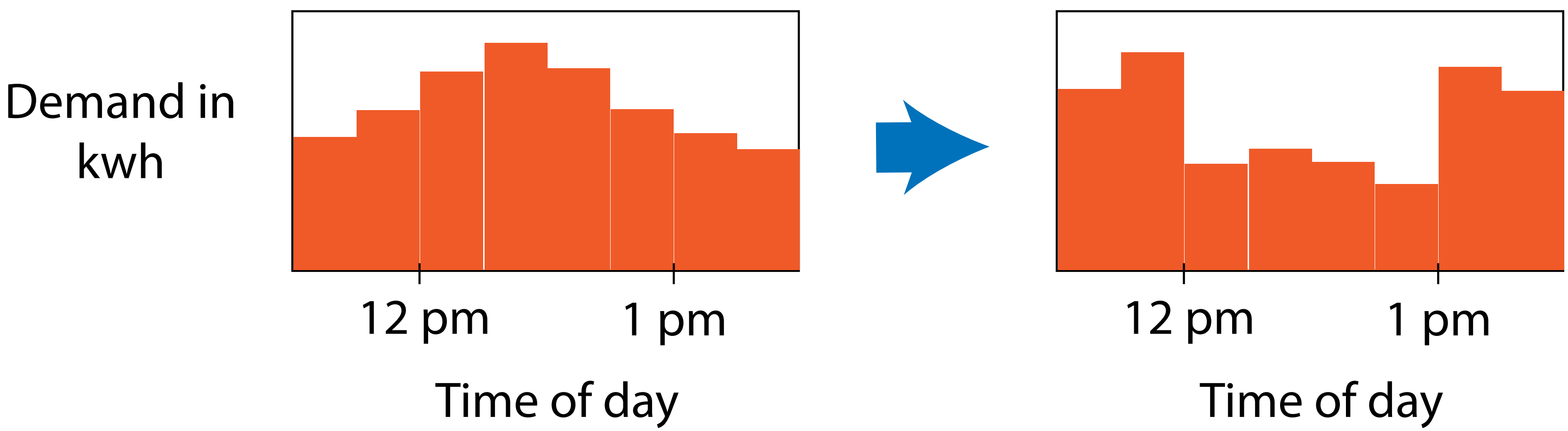
Shortcomings of the Traditional Grid

- Lots of reserve capacity
- Renewable integration

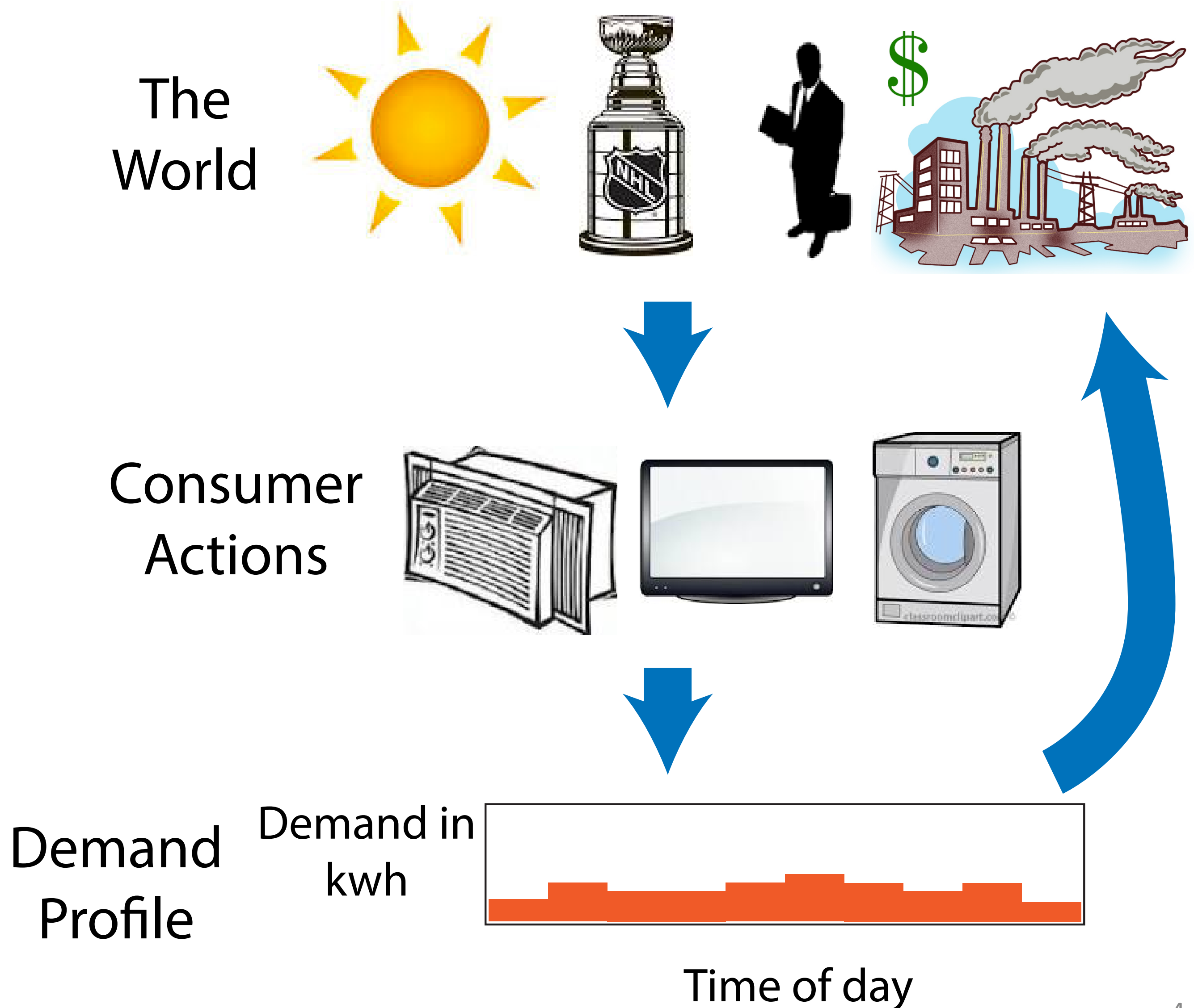


Consumer Behavior

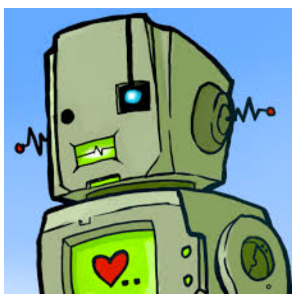
- Consumers willing to shift or reduce
  - If they are sufficiently compensated
  - If it's not too annoying to do so
- Behaviors must be coordinated

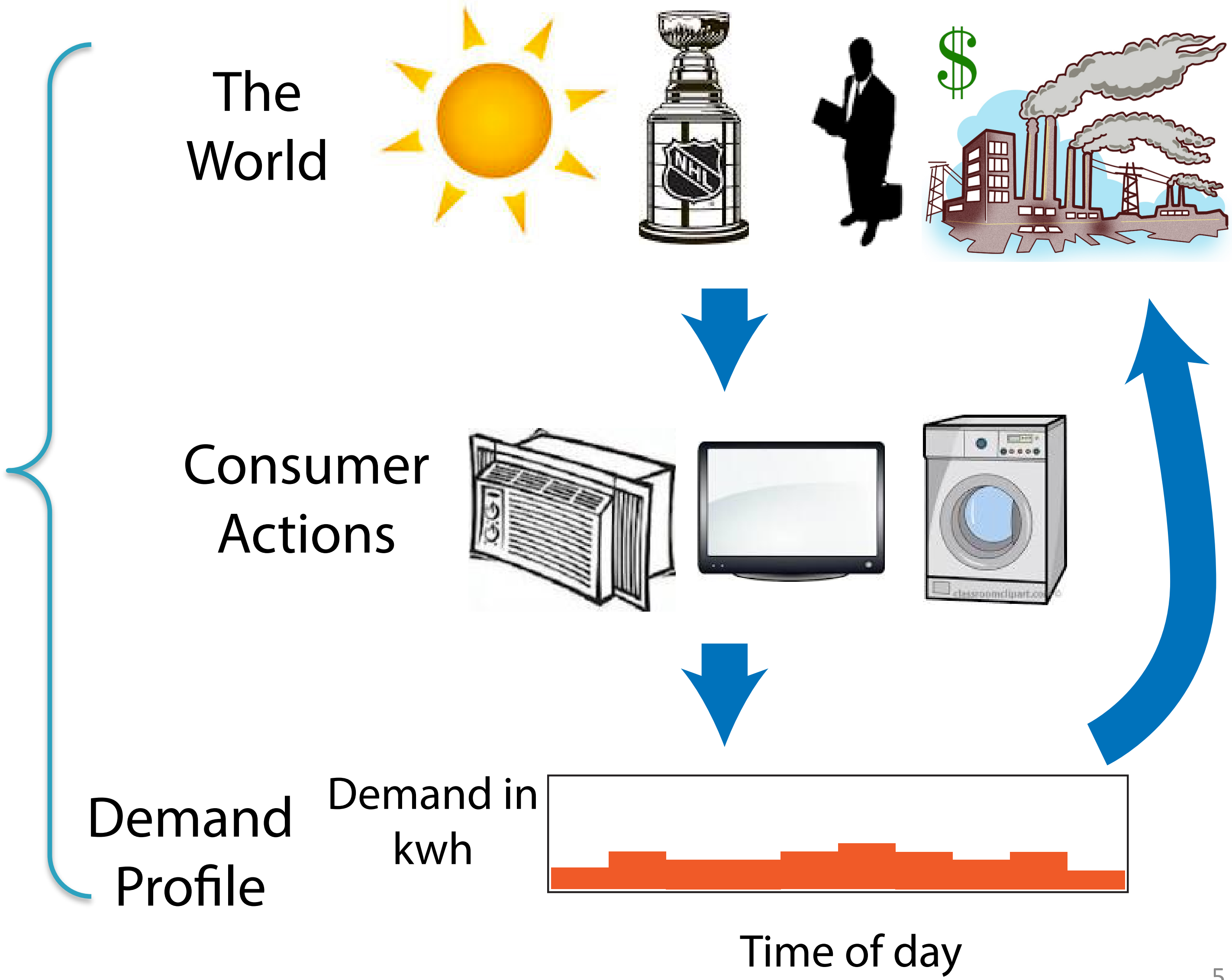


Model of Consumer Decisions



Home Energy Management Agents





Coordinating Consumer Behavior

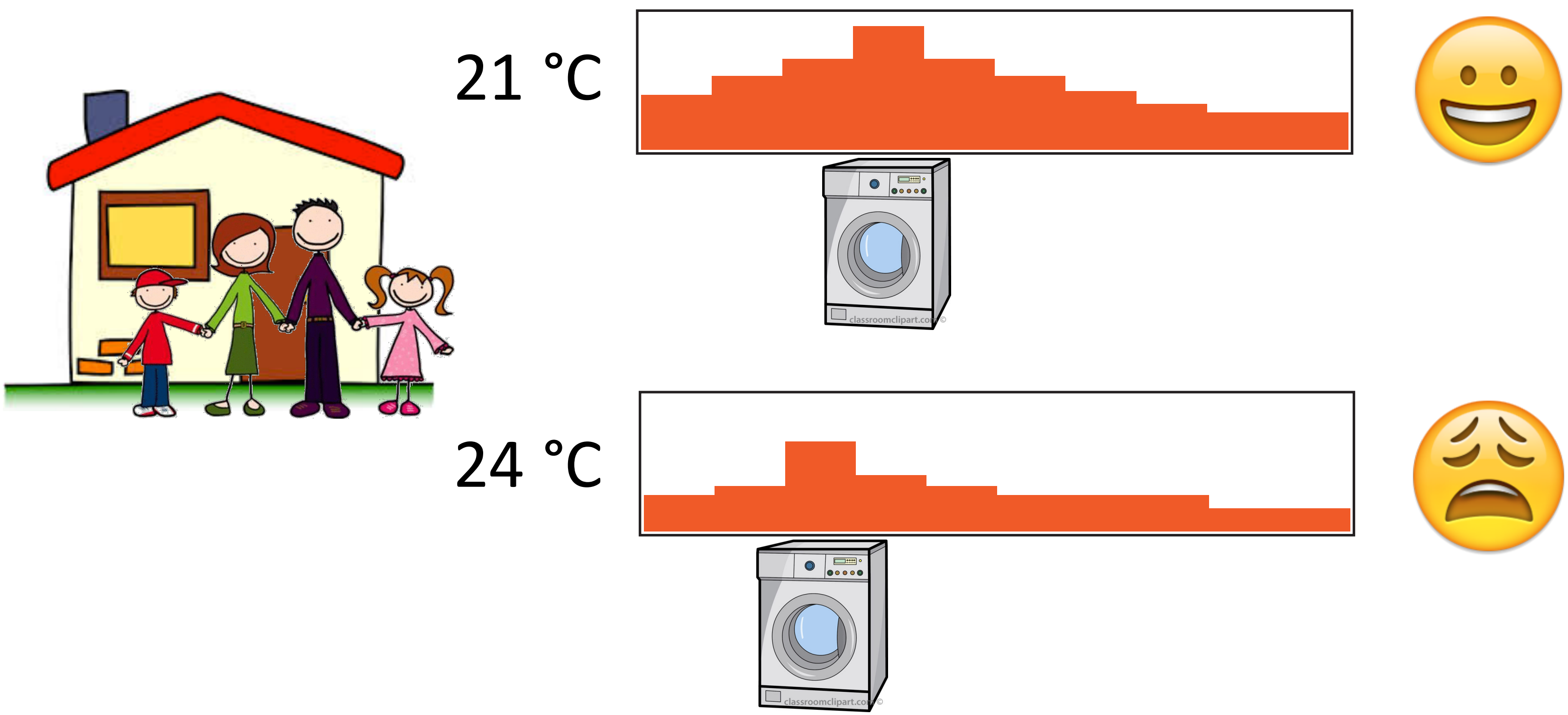
- Two decisions to make
  - What actions should agents take?
  - How should agents be compensated?
- Agents are self-interested

Outline

- Introduction ✓
- **Setting and Optimization**
- Cost Sharing Schemes
- Experiments

Consumer Model

- Each consumer i has *electricity use profiles* Π_i
  - Each profile $\boldsymbol{\pi} \in \Pi_i \subset \mathbb{R}^T$ (T time periods)
  - Each profile has a value $V_i(\boldsymbol{\pi})$ in dollars

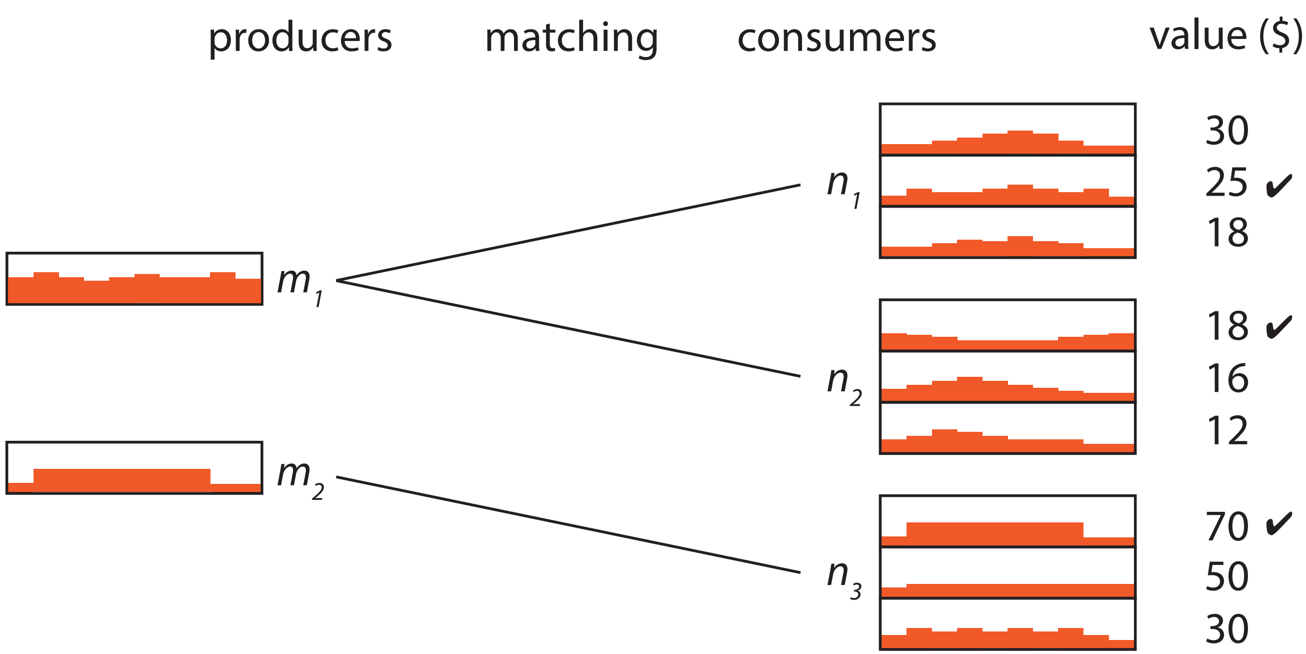


Producer Model

- Each producer *j* has *price function* $P_j \colon \mathbb{R}^T \to \mathbb{R}$
- Limited *ramp rate*
- *Base layer*: inexpensive, slow to adjust
  - Has *shutdown costs*
- *Tracking layer*: expensive, quick to adjust

Matching

- Matching μ maps consumers to producers and profiles
- Social welfare of μ: sum of profile values minus sum of producer prices



Optimal Coordination

- Find social welfare-maximizing matching
- Formulate as a mixed integer program
  - Relax matching variables
  - Require binary variables for each producer
  - Scalable: 5000 agents, 2 producers, 4 profiles, 24 time periods in 15 min.
    - ~55k continuous variables, 144 binary

Outline

- Introduction ✓
- Setting and Optimization ✓
- **Cost Sharing Schemes**
- Experiments

Cost Sharing

- View as a cooperative game
- Each coalition consists of one producer, multiple consumers
- Characteristic function $f: 2^{N \cup M} \to \mathbb{R}$

Cost Sharing Desiderata

- *Stable*: no *defections*
- *Budget-balanced*: all payments collected
- *Envy-free*: no agent prefers allocation of another agent
- *Transparent*: easy to reason about
- Computationally scalable

Core and Nash-Stable Payments

- Core payments
  - Prevent all defections
  - May not exist
- Nash-stable payments
  - Prevent defections of any single agent
  - May not exist

Shapley-Like Payments

- Want to apply Shapley values
- Shapley value for consumer n_0 who is matched to producer m_0:
  - Consider all orders agents could join m_0
  - In each, look at the cost imposed by adding n_0
  - n_0's Shapley value = avg. marginal cost over all join orders
- We adjust the payments for stability
- Computationally expensive
  - Use sampling

Similarity-Based Envy-Freeness

- Envy-freeness is a weak concept in this setting
  - Rarely will two agents have same profile
- Generalize envy-freeness

10¢/kwh

20¢/kwh

Similarity-Based Envy-Freeness Payments

- *Similarity-based envy-free payments*
  - Partition demand profiles
  - Fix the unit price in each partition
  - Optimize prices for stability
- More partitions = more flexible payments, more stability, less envy-freeness
- Intuition: prices fair because some agents have profiles in different partitions
  - Creates pressure for adjacent partitions to have competitive prices via the stability objective
- Scalable: 2500 consumers, 2 producers, 4 profiles, 24 time periods in 30 min.

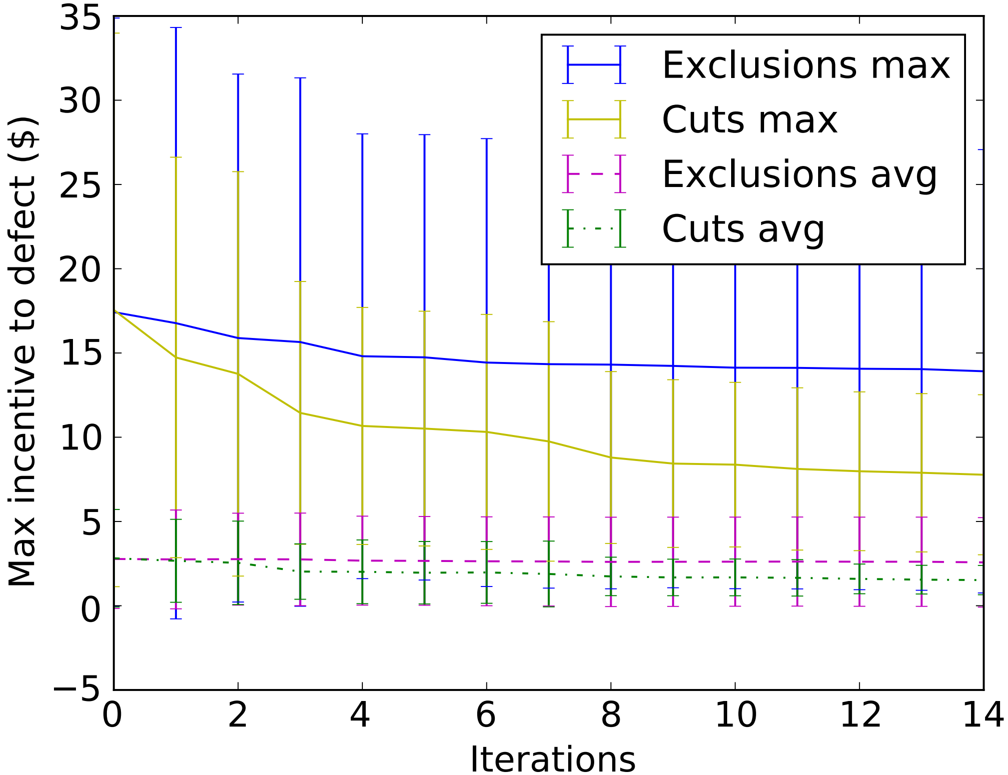
Outline

- Introduction ✓
- Setting and Optimization ✓
- Cost Sharing Schemes ✓
- **Experiments**

Experimental Setting

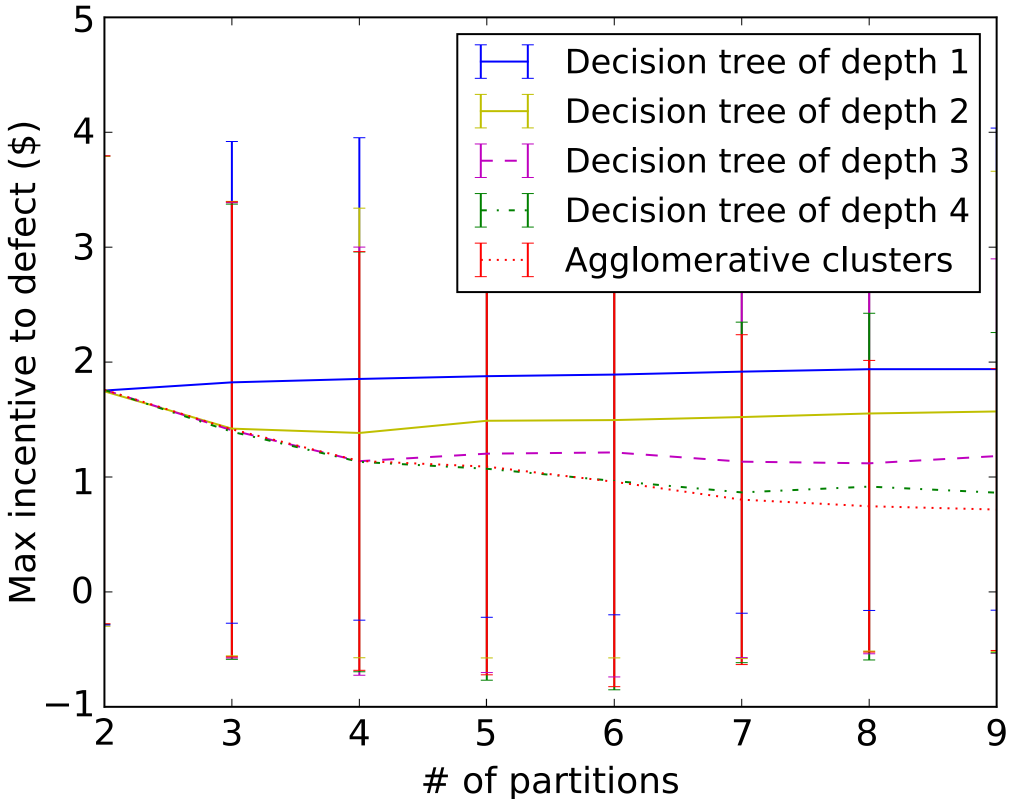
- 50 consumers, 2 producers, 4 profiles per consumer, 50 trials
  - Computational reqs. of Shapley-like payments
- Heating and cooling model based on US residential energy use data
- Weather: hot summer day

Shapley-Like Payments



- Can reduce maximum incentive to defect to around $7.5 with tuned Shapley-like Payments
  - Sacrifice a little bit of social welfare, < 2%

Similarity-Based Envy-Free Payments



- Very low max incentive to defect, < $1.75, even when using a small number of partitions
- Can increase the number of partitions to further increase stability

Conclusion

- Market model for matching electricity producers and consumers
  - Consumers may have multiple demand profiles
- Analysis of two cost sharing schemes
- Work towards our underlying goal of making consumer demand more responsive

Questions?

Future Work

- SBEF can have bad partitions
  - Partitioning scheme that supports goals of mechanism?
- Use partitions for optimization?
- Elicitation of demand profiles