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A Scoring Rule-based Mechanism for Aggregate Demand Prediction in the Smart Grid

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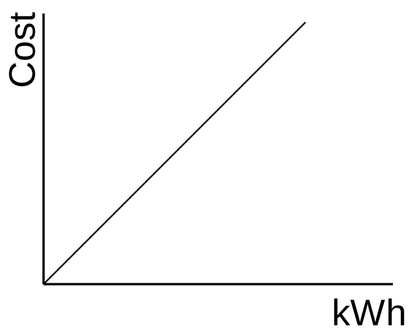
Electricity Markets

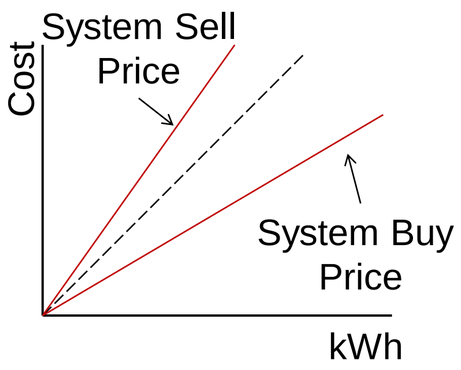
- The supply of electricity must always match the demand.
- Changing generator output in real time is costly.
- To reflect this cost and to encourage accurate prediction of future demand, there are two main markets that must be used to purchase electricity.

Forward Market



- Ahead-of-time trade

Balancing Market



- Real-time trade
- Relatively costly

The Information Aggregation Problem

The aggregator must
- Predict its customers' consumptions.
- Minimise the amount spent in the balancing market.

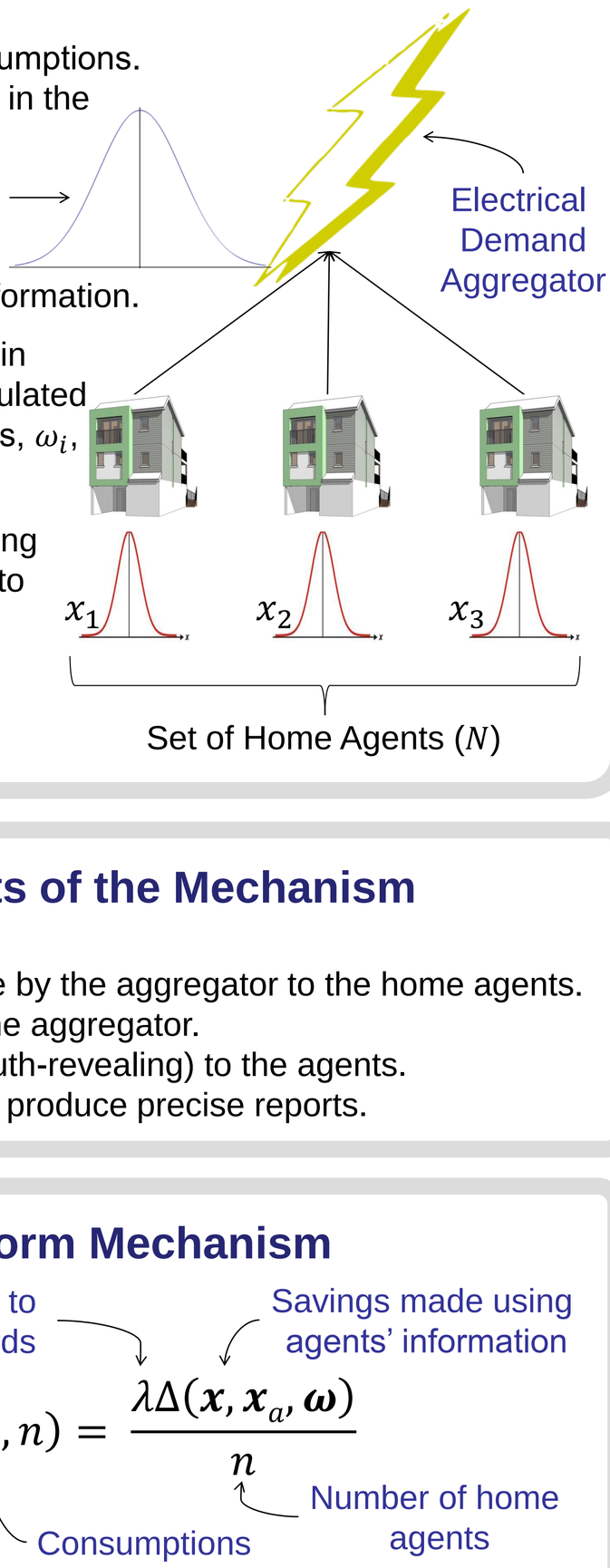
The aggregator has historical information.

Homes have more specific information.

Using this information results in savings, Δ, which can be calculated after the agents' consumptions, ω_i, have been realised.

Agents incur a cost in producing their information proportional to the information's precision.

The aggregator must pay the agents for their information.



Requirements of the Mechanism

The mechanism must:
- distribute the savings made by the aggregator to the home agents.
- be individually rational to the aggregator.
- be incentive compatible (truth-revealing) to the agents.
- encourage home agents to produce precise reports.

The Uniform Mechanism

Fraction of savings to distribute as rewards

Savings made using agents' information

$$P_i^U(\boldsymbol{x}, \boldsymbol{x}_a, \boldsymbol{\omega}, n) = \frac{\lambda \Delta(\boldsymbol{x}, \boldsymbol{x}_a, \boldsymbol{\omega})}{n}$$

Agents' reports

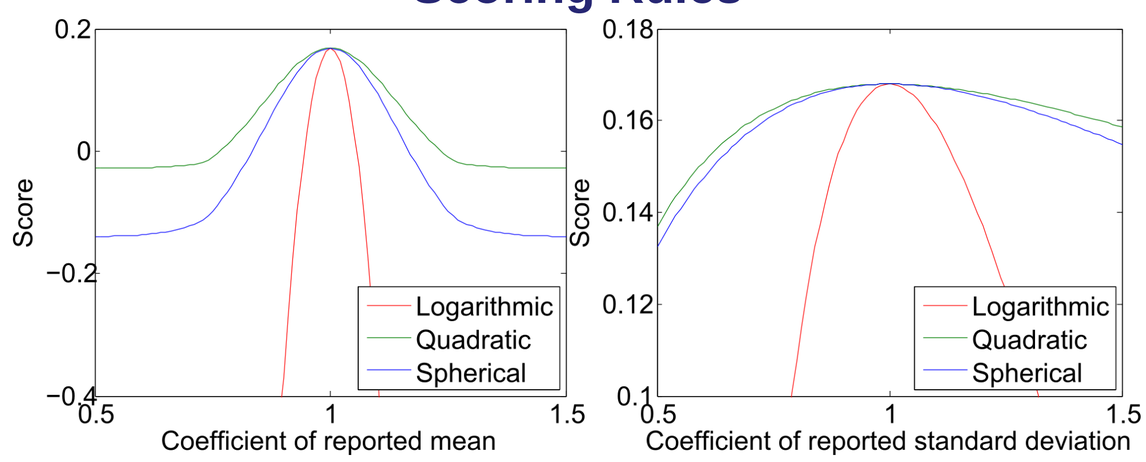
Aggregator's priors

Consumptions

Number of home agents

Strongly budget balanced, *Nash* incentive compatible, poor precision incentives

Scoring Rules



Expected scores when reporting a distribution whose mean and standard deviation has been scaled by some coefficient compared to the agent's true belief.

Strictly proper scoring rules, such as the spherical rule are mathematical functions that assign scores to probabilistic reports given a realised outcome. Their expected score is maximised when the agents truthfully report their belief.

In the continuous case, their scores are unbounded, and therefore using them to distribute payments is non-trivial.

Sum of Others' plus Max

A bound is applied to a given scoring rule, S, by constraining the maximum precision of acceptable reports to be $\leq \theta_{max}$

The maximum score when constraining precision is:

$$S_{max} = S(\langle \mu, \theta_{max} \rangle, \mu)$$

Agent i's score

Savings made using other agents' reports.

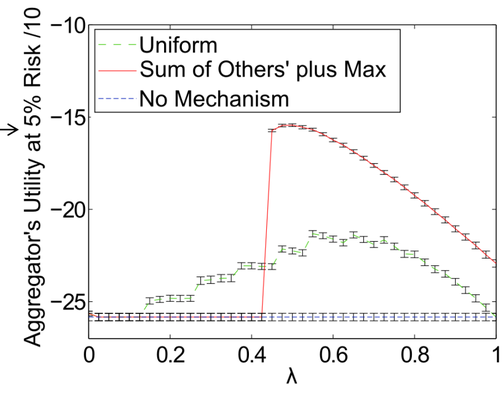
$$P_i^S(\boldsymbol{x}, \boldsymbol{x}_a, \boldsymbol{\omega}, \theta_{max}) = \frac{S(\hat{x}_i, \omega_i) \cdot \lambda \cdot \Delta(\boldsymbol{x}_{-i} \cup \{x_{a,i}\}, \boldsymbol{x}_a, \boldsymbol{\omega})}{S_{max} + \sum_{j \in N \setminus \{i\}} S(\hat{x}_j, \omega_j)}$$

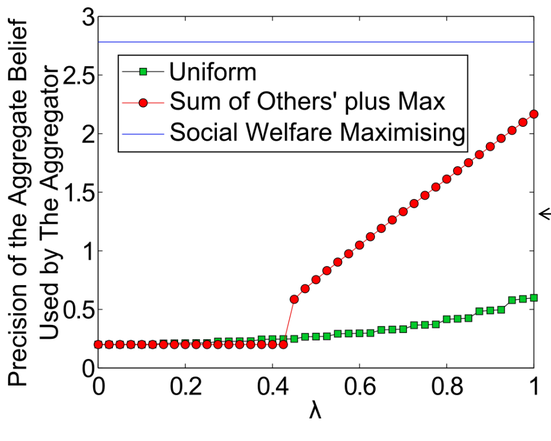
Sum of other agents' scores

Weakly budget balanced, dominant strategy incentive compatible, provides much better precision incentives.

Empirical Results

Sum of others' plus max reduces risk to the aggregator.





Sum of others' plus max encourages precise predictions.

Sum of others' plus max increases social welfare.