Impact of Market Timing on the Profit of a Risk-Averse Load Aggregator

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Motivation

- Thermostatically Controlled Loads (TCL) can arbitrage energy prices and provide reserve
- Aggregator can exploit flexibility of TCLs to bid in both markets

How does **market timing** impact the ***amount of reserve capacity*** from controllable loads?

How does **market timing** impact the ***profitability*** of a load aggregator?

- **Market timing** includes
  - **Lead time**: time between gate closure and operation
  - **Contract period**: time period for which a bid is committed

- **Method**
  - On a rolling horizon: optimize the energy cost and reserve capacity offers at a given lead time and contract period, varied from 24 hours ahead to real-time.

Related Work

- Rolling horizon optimization of TCLs [Luo, Ranzi, Dong 2017; …]
- Demand response and chance constrained programming [Brunnix, Dvorkin, Delarue, Dhaeseleer, Kirschen 2018]
- Two-stage chance constrained programming [Zhang, Wang, Zeng, Hu 2017; Zhao, Pan, Yao, Ju, Li 2020
- TCL "battery models" [Mathieu, Kamgarpour, Lygeros, Andersson, Callaway 2015; Hao, Sanandaji, Poolla, and Vincent 2015]

This presentation is based on:

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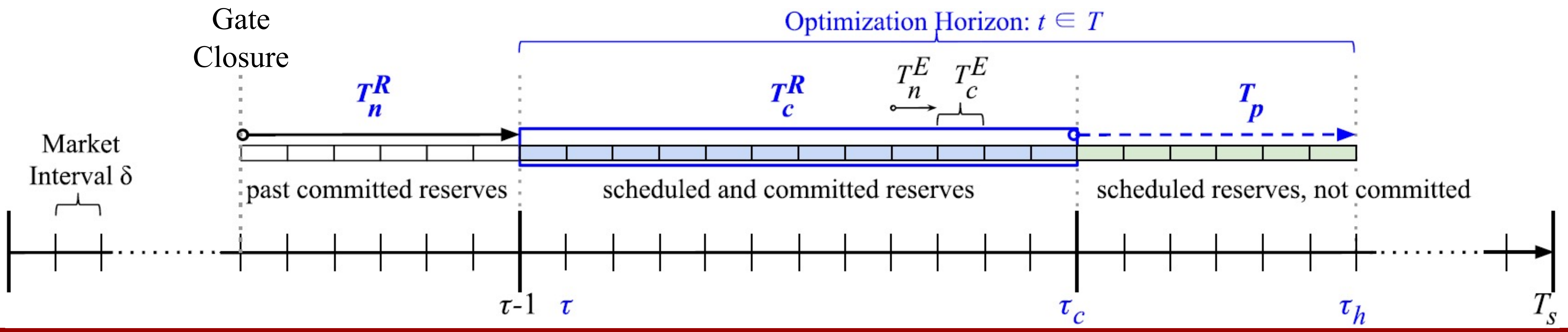
Market Framework

- **Energy** Market
  - Real-time market
  - SO publishes prices in 5 min resolution at a specified time before the 5 min interval.
- **Reserve** Market
  - Accepts bids until lead time T_n^R before each interval and releases the reserve price.
  - Accepted bids are paid for their symmetric reserve capacity.
  - Zero-mean activation signal, e.g., PJM Reg-D or FCR-N.
  - SO aims to procure reserve at minimal cost from a portfolio of different sources.
- **Assumption:** Load aggregator is a price taker.



Problem Formulation

- As an aggregator of TCLs, the objective is to minimize the cost of energy consumption $\lambda^E_{t,\omega} \cdot p^E_{t,\omega}$ while maximizing the profit from reserve capacity offers $\lambda^R_{t,\omega} \cdot p^R_t$:

$$\max.\ (1-\beta)\cdot\left(\sum_t\left(\lambda^R_{t,\omega}\cdot p^R_t - \lambda^E_{t,\omega}\cdot p^E_{t,\omega}\right) - \lambda\cdot d_\omega\right) + \beta\cdot \mathrm{CVaR}_\alpha$$

Revenue from reserve capacity	Cost from energy consumption	Penalty for deviation from 50% SOC at end of horizon	Encodes risk aversion

- Subject to a “Thermal Energy Storage” model and constraints, where energy level s_t :

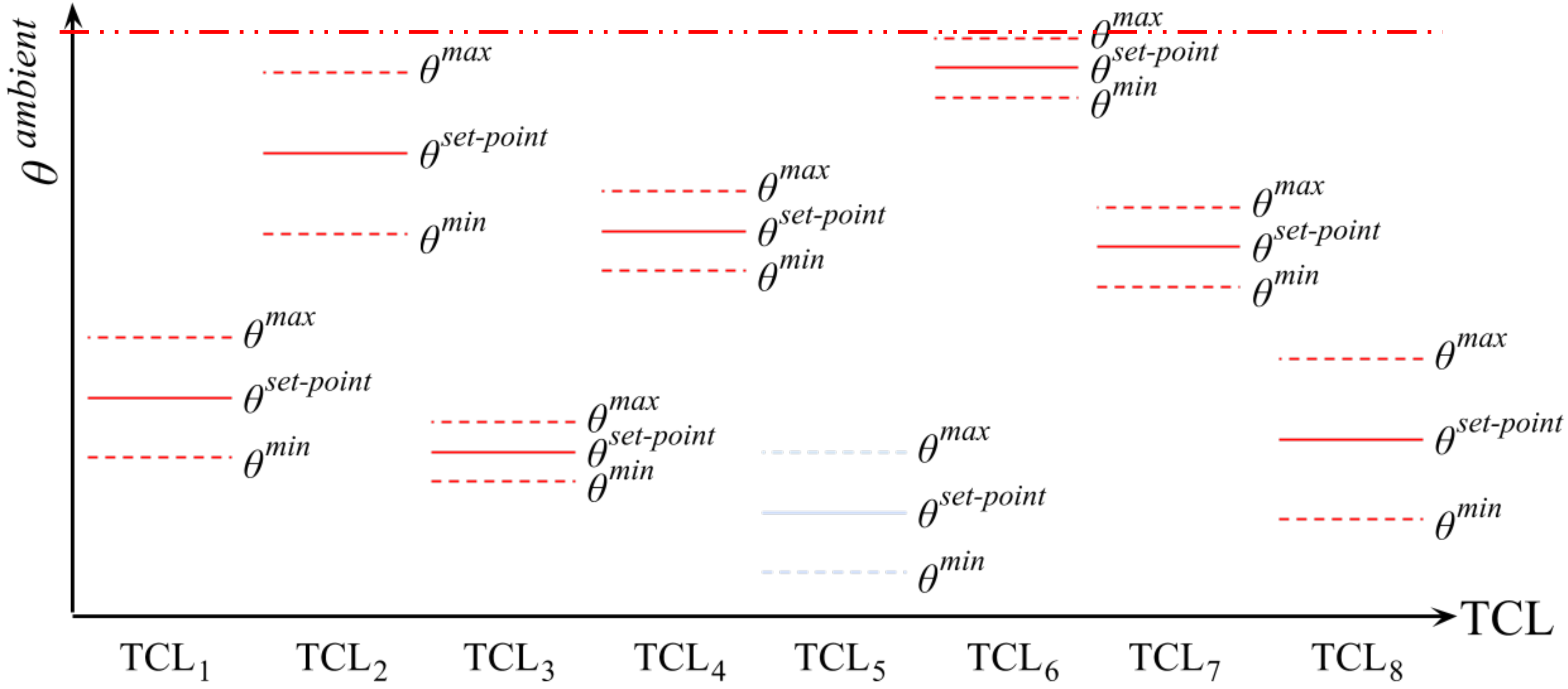
$$s_t = s_{t-1} + \Delta t\cdot\left(p^E_t - P^B_t\right)\quad \forall t$$

See: Mathieu, Kamgarpour, Lygeros, Andersson, Callaway, 2015

TCL Thermal Energy Storage Model

1000 TCLs: thermal parameters sampled from uniform distribution

Ambient temperature affects the amount of flexibility (i.e., size of thermal battery)



Mathematical Formulations

Deterministic

$$\begin{aligned} \max.\ & f(x) \\ \text{s.t.}\ & g(x) \leq 0 \\ & h(x) = 0 \end{aligned}$$

Price Uncertainty

Two-Stage (TS)

$$\begin{aligned} \max.\ & (1-\beta)\cdot q(x,\omega) + \beta \cdot \text{CVaR}_\alpha \\ \text{s.t.}\ & g(x,\omega) \leq 0 \\ & h(x,\omega) = 0 \end{aligned}$$

Availability uncertainty

Chance Constrained (CC)

$$\begin{aligned} \max.\ & f(x) \\ \text{s.t.}\ & g(x) \leq 0 \\ & h(x) = 0 \\ & \mathbb{P}\{k_i(x,\xi) \leq 0\} \geq 1-\epsilon_i\ \forall i \end{aligned}$$

Chance Constrained Two-Stage (CCTS)

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Uncertainty

Deterministic

$$\max.\ f(x)$$
$$\text{s.t.}\quad g(x) \leq 0$$
$$h(x) = 0$$

Price Uncertainty

Two-Stage (TS)

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Price Forecast

Availability uncertainty

Chance Constrained (CC)

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$$\text{s.t.}\quad g(x) \leq 0$$
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$$\mathbb{P}\{k_i(x,\xi) \leq 0\} \geq 1 - \epsilon_i\ \forall i$$

Temperature Forecast

Human Behavior

Model Error

Chance Constrained Two-Stage (CCTS)

$$\max.\ (1-\beta)\cdot q(x,\omega) + \beta \cdot \text{CVaR}_\alpha$$
$$\text{s.t.}\quad g(x,\omega) \leq 0$$
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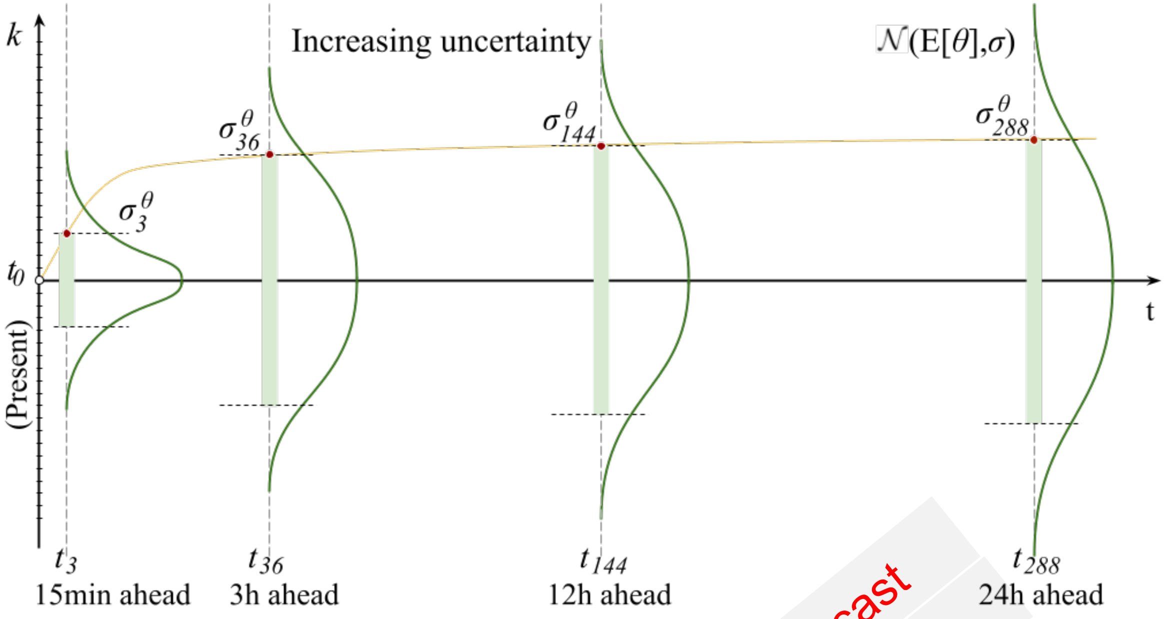
Uncertainty



Chance Constrained (CC)

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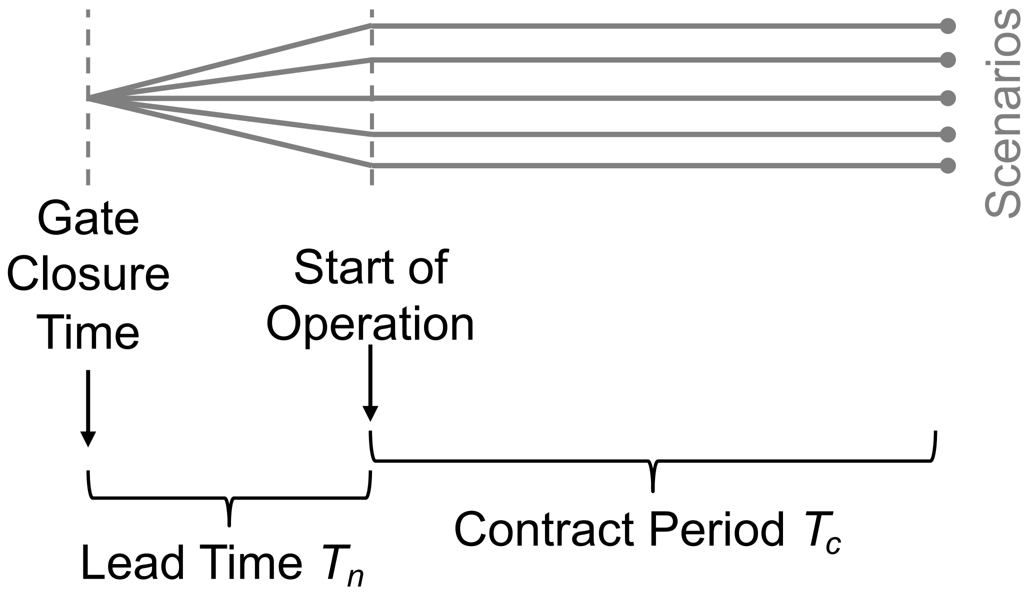
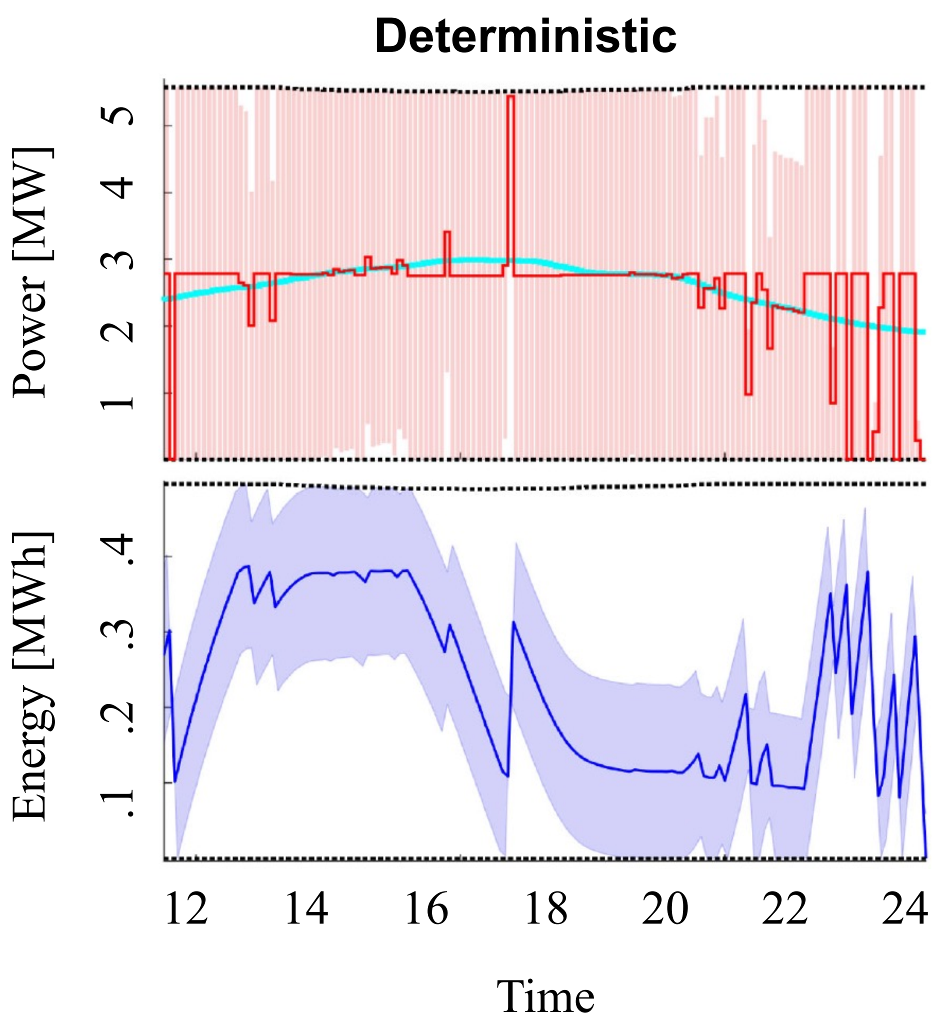
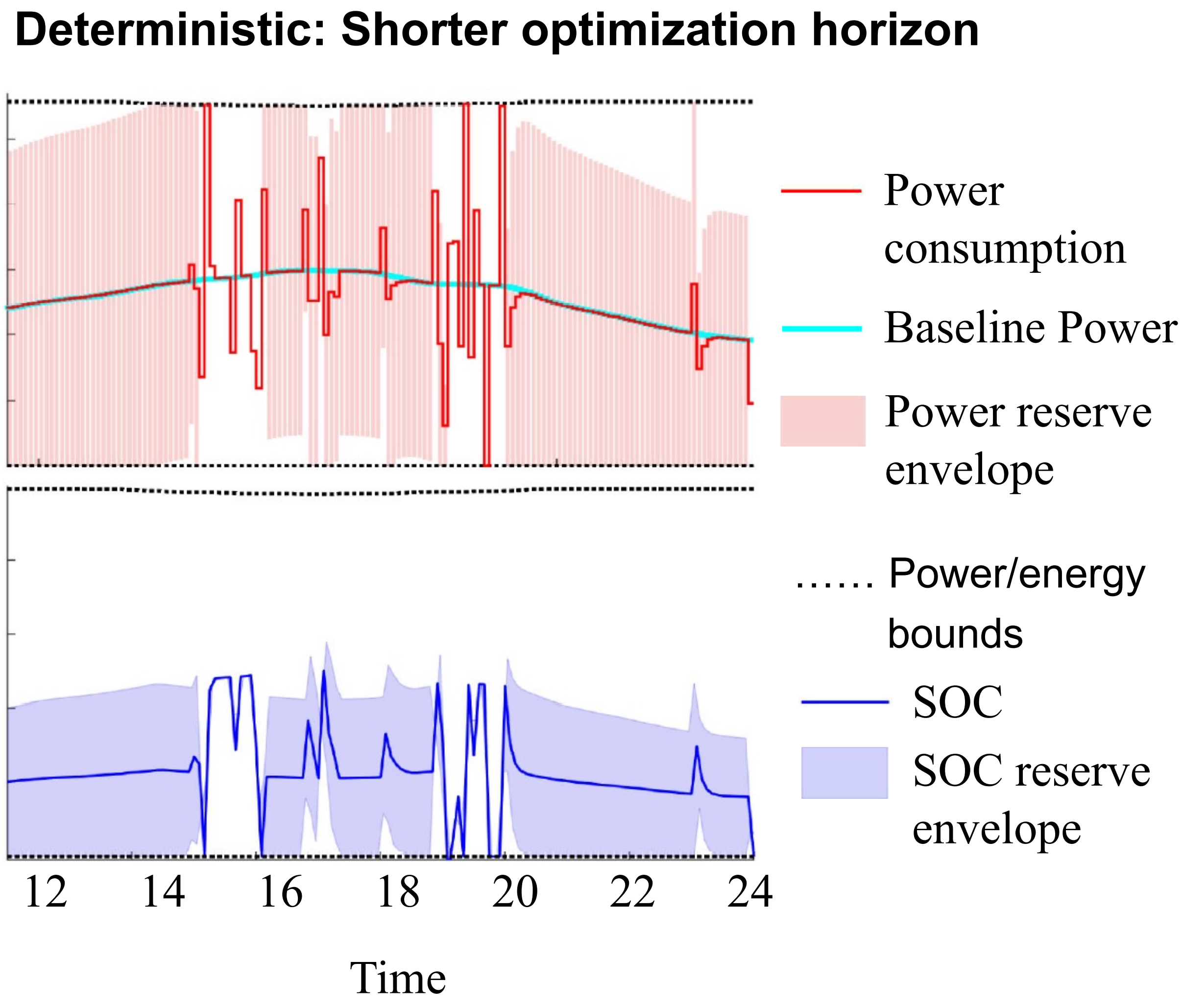
Price Forecast

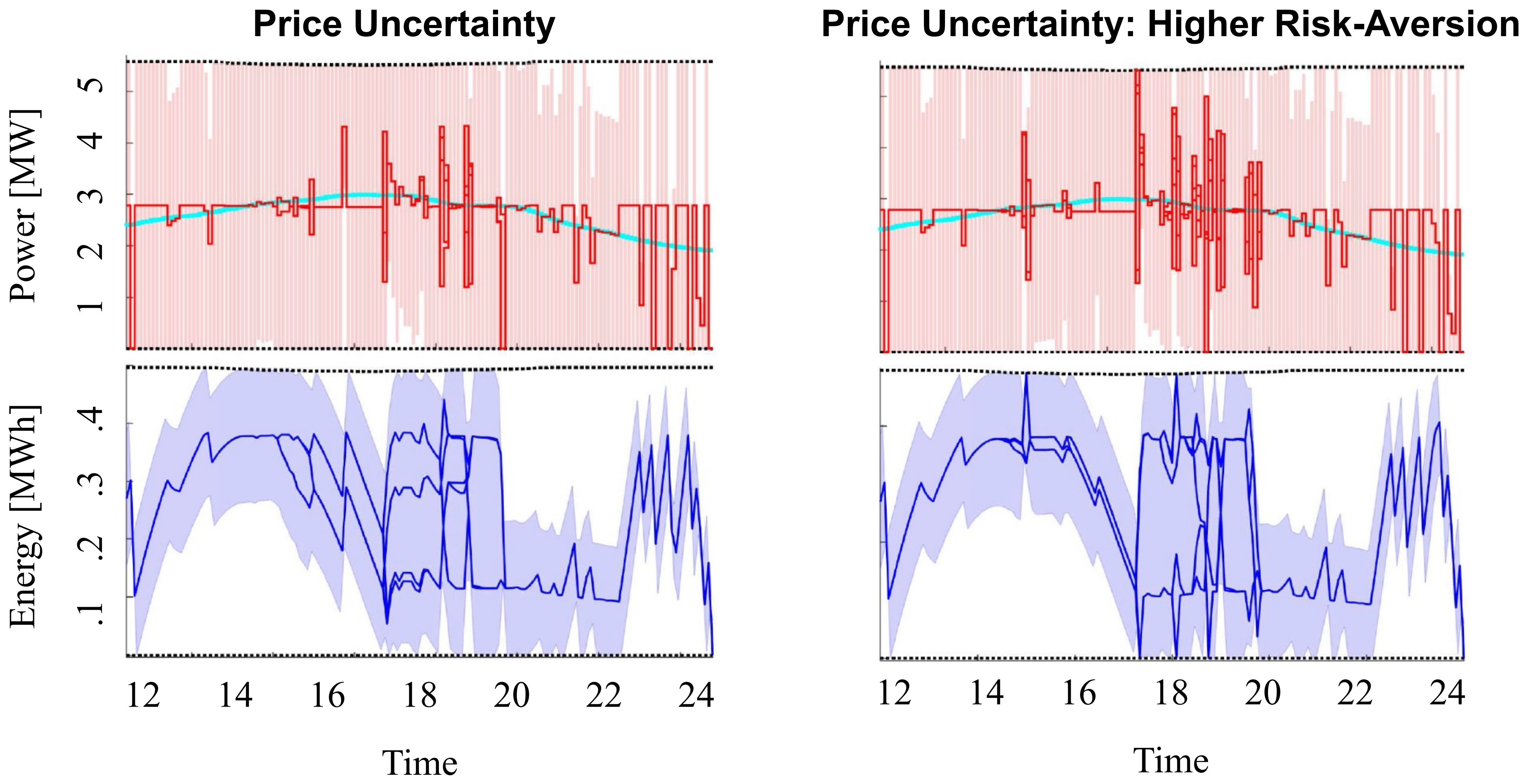


Results: Time Series

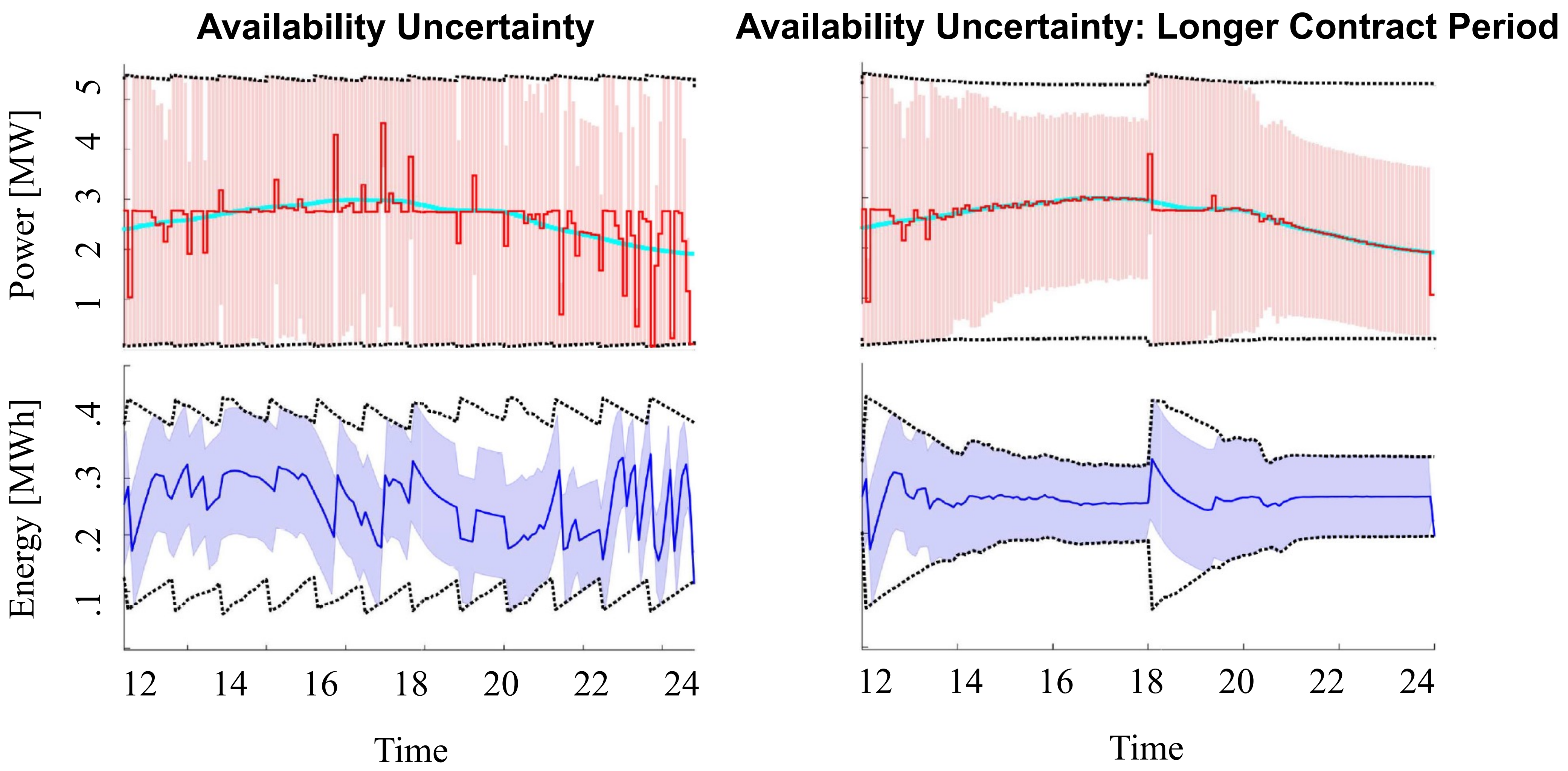




Results: Time Series

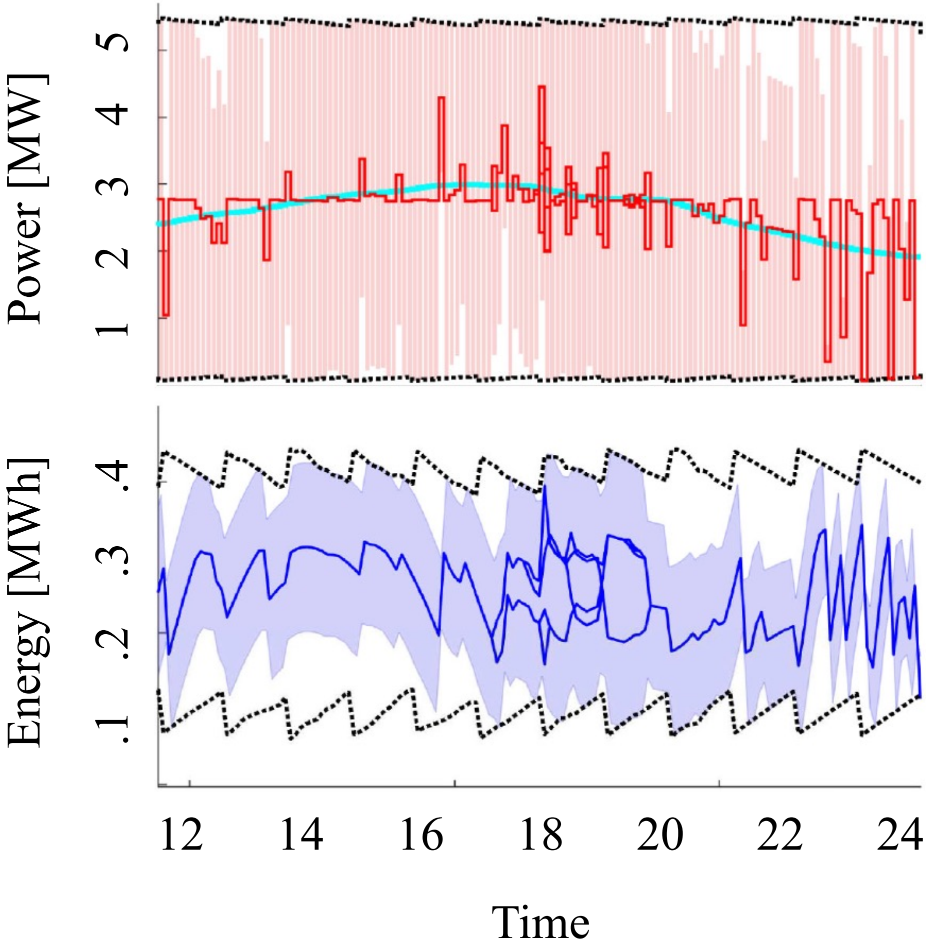


Results: Time Series

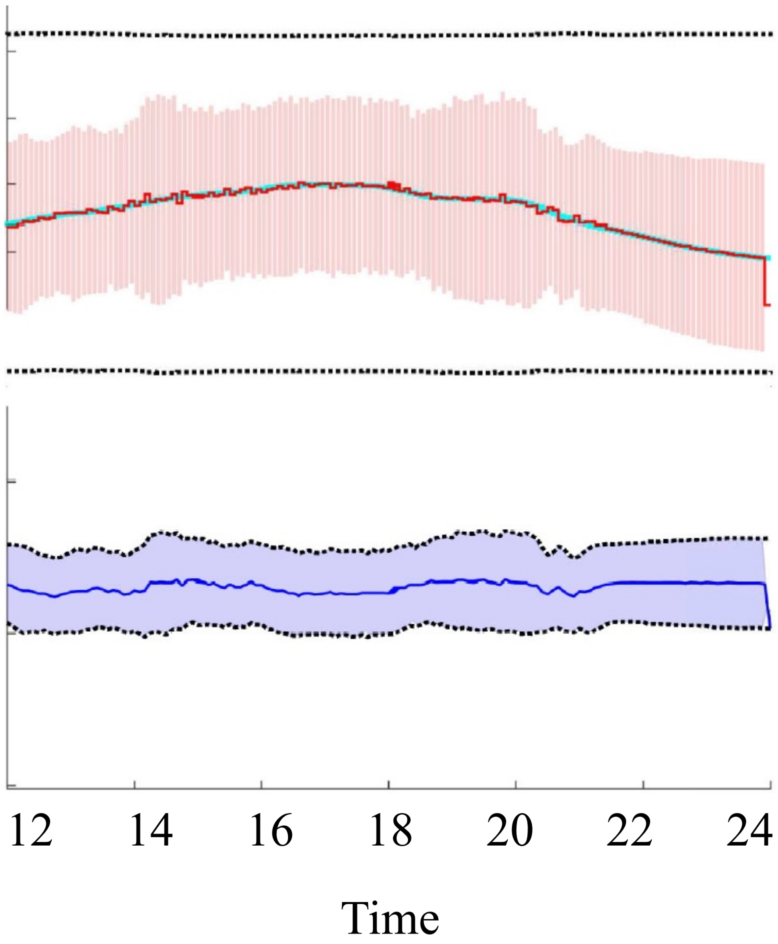


Results: Time Series

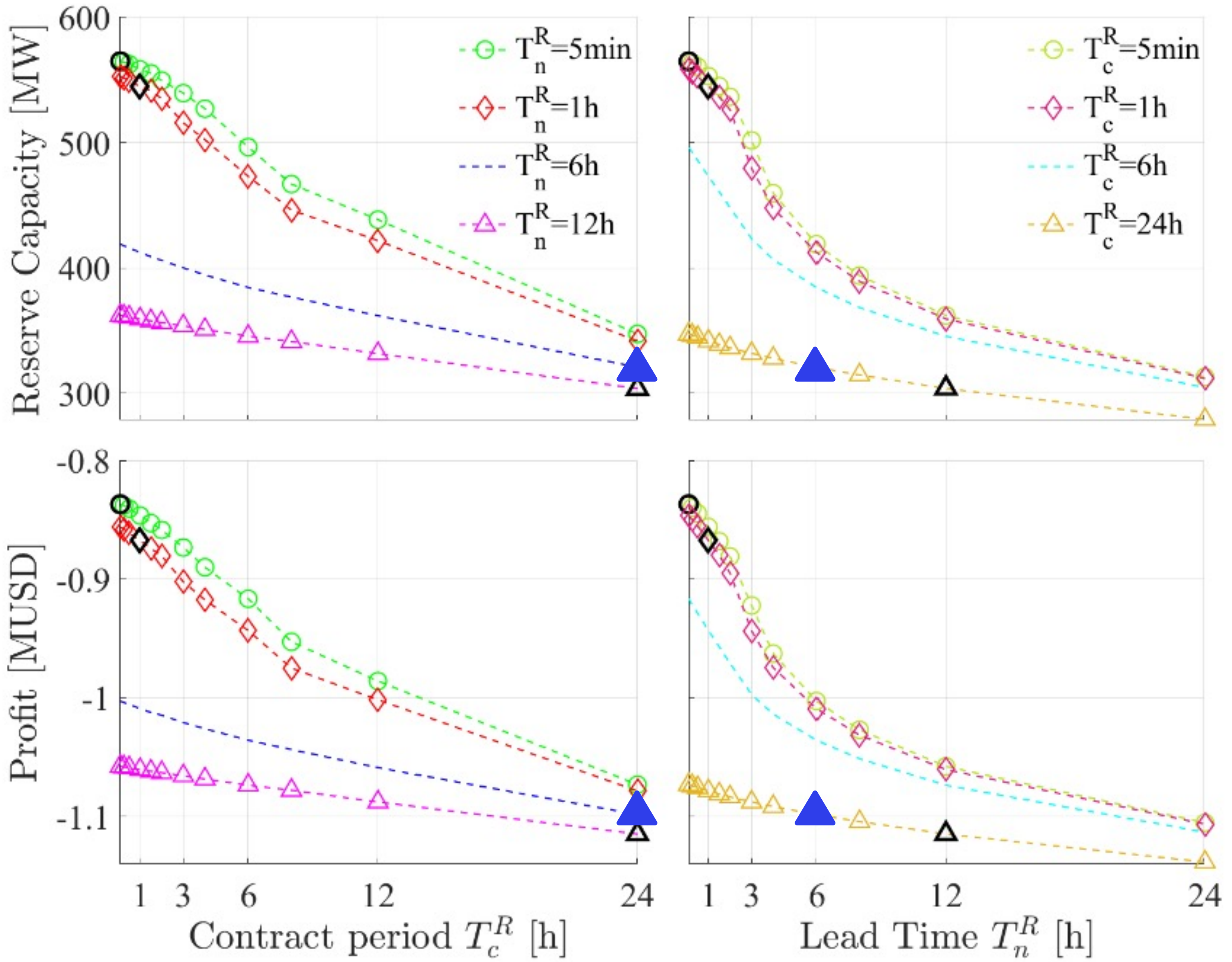
Price & Availability Uncertainty



Price & Availability Uncertainty: Longer Lead Time



Results: Market Timing



<u>Sweden FCR Market:</u>

Gate closure 18:00 D-1

- Lead Time: 6h

For the next day

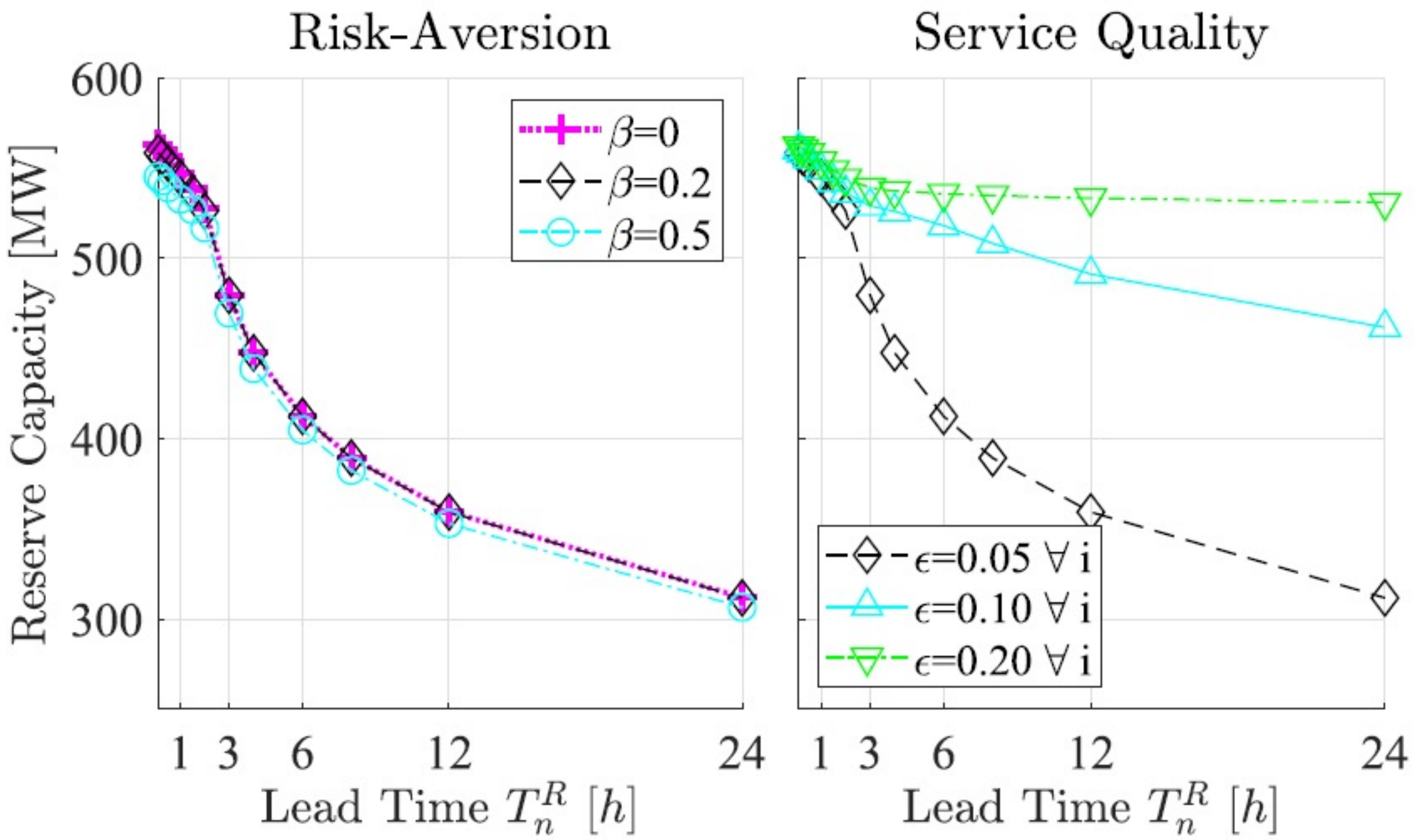
- Contract Period: 24h

- set *as* ***short*** *as possible* ***contract periods*** *and*
- *have* ***gate closure*** *as* ***close*** *as possible* ***to operation.***

Results: Sensitivity

Risk-Taking

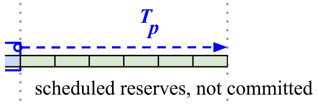
Risk-Averse



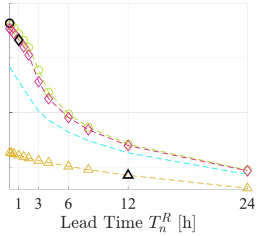
Lower Quality of Service

Higher Quality of Service

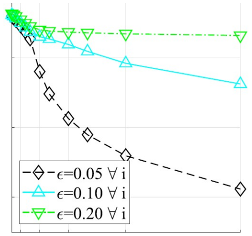
Conclusions & Policy Implications



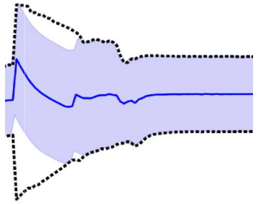
- SO sets lead time & contract period: **Aggregator can only set the prediction horizon**
  - Aggregator should plan **at least 4 hours ahead**, use poor forecasts rather than no forecast.



- Highest profitability & reserve capacity in a RT reserve market
  - **Long market timing constrains aggregator actions** via availability uncertainty.
  - **SOs** should **set short contract periods** and **have gate closure** as **close** as possible **to operation**.



- Aggregator can **balance operational cost and service quality** by tuning chance constraint violation levels.
  - Method could be used to compute viable incentives to consumers
  - **Incentives could be a function of service quality** (chance constraint violation levels)



- **Availability uncertainty narrows the energy/power bounds** of a TCL aggregation, impacts reserve capacity, feasibility, and profitability. Price uncertainty only impacts profitability.
  - Price uncertainty impacts the results less than uncertainty in TCL availability.

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