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Dynamic Contracts with Partial Observations, with application to Indirect Load Control in Power Systems

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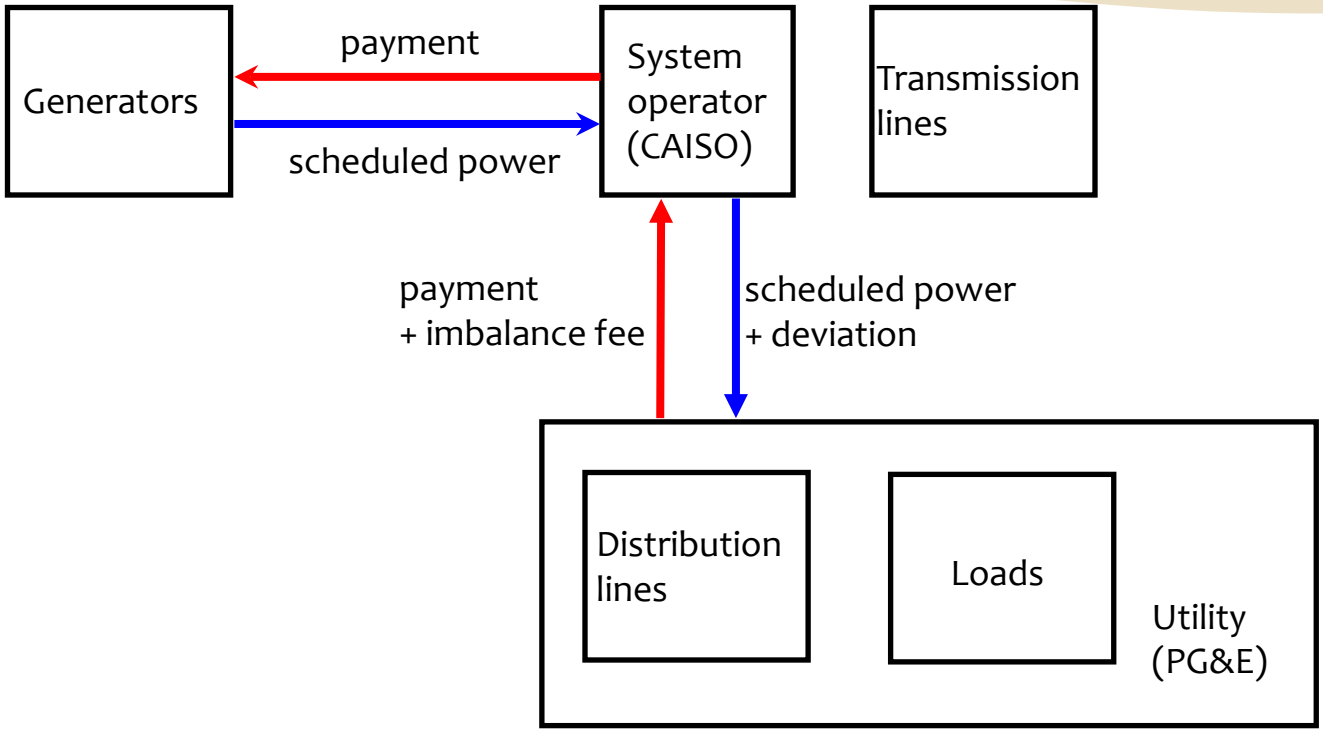
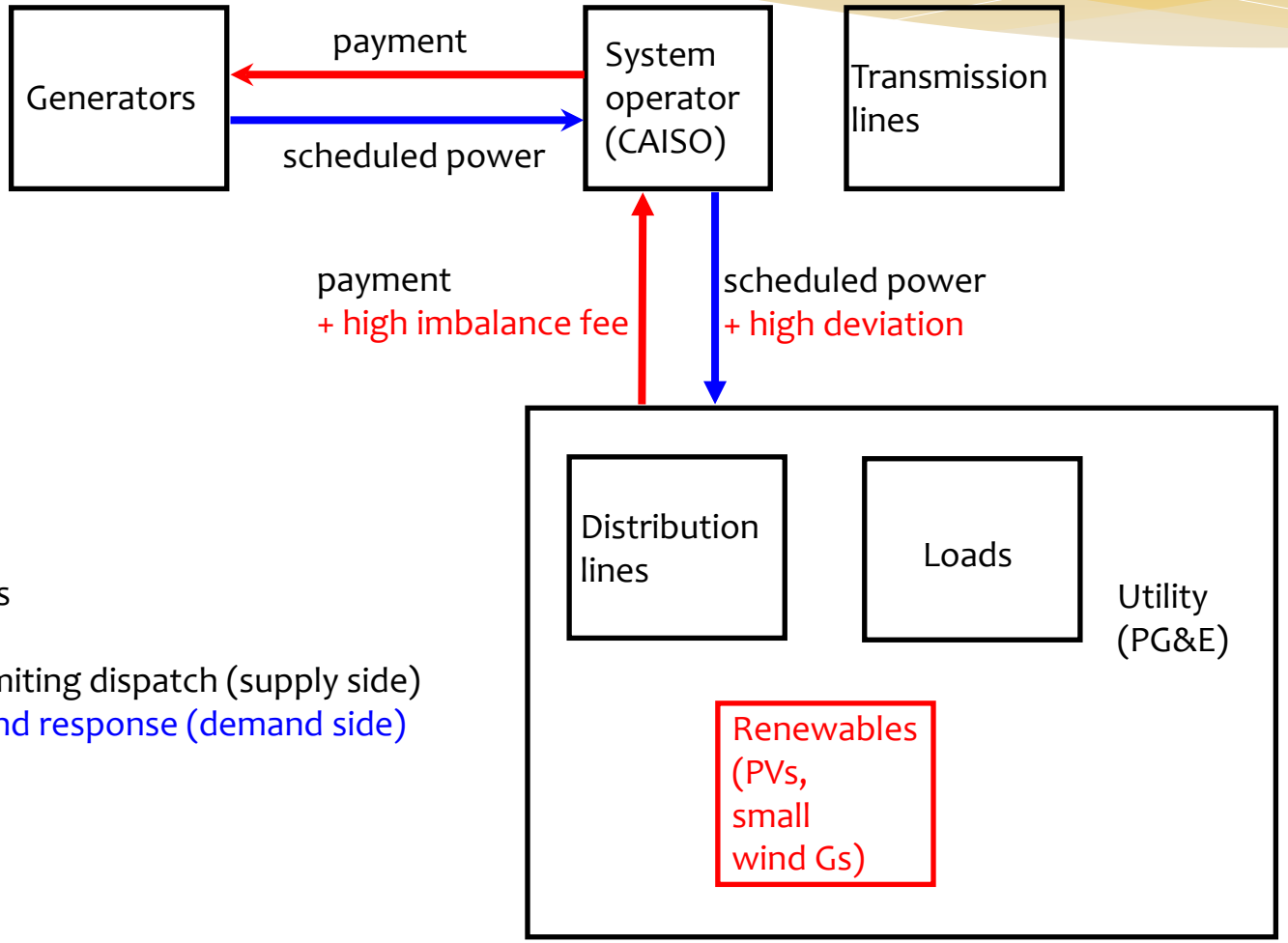
Market operations for power systems



1. Day-ahead market

2. Real-time market

Risk from uncertainties



Solutions

1. Risk limiting dispatch (supply side)
2. Demand response (demand side)

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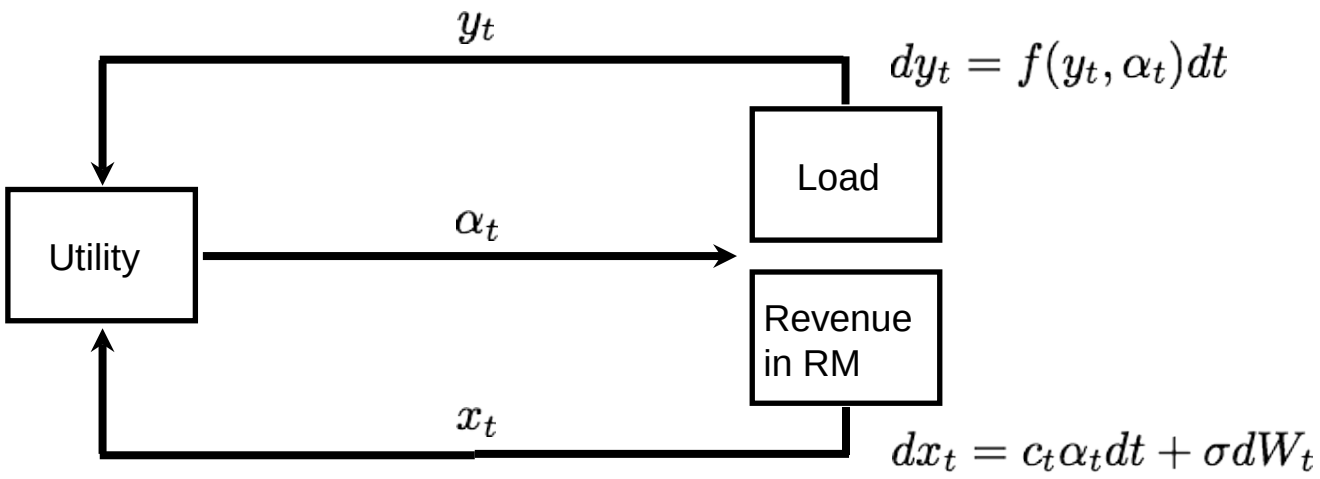
Direct load control

Cohen, Wang, *TPS*, 1988.

Mathieu, Koch, Callaway, *TPS*, 2013.

- A Utility company has the authority to control consumers' loads (e.g., PG&E controlling individual air conditioners (2013)).
- Monitoring of the consumers' loads is required for optimal performance.
- Consumers take the risk from uncertainties.



x_t : revenue in the real-time market

y_t : consumer's indoor temperature

α_t : reduction in power consumption by AC

c_t : energy price in the RM

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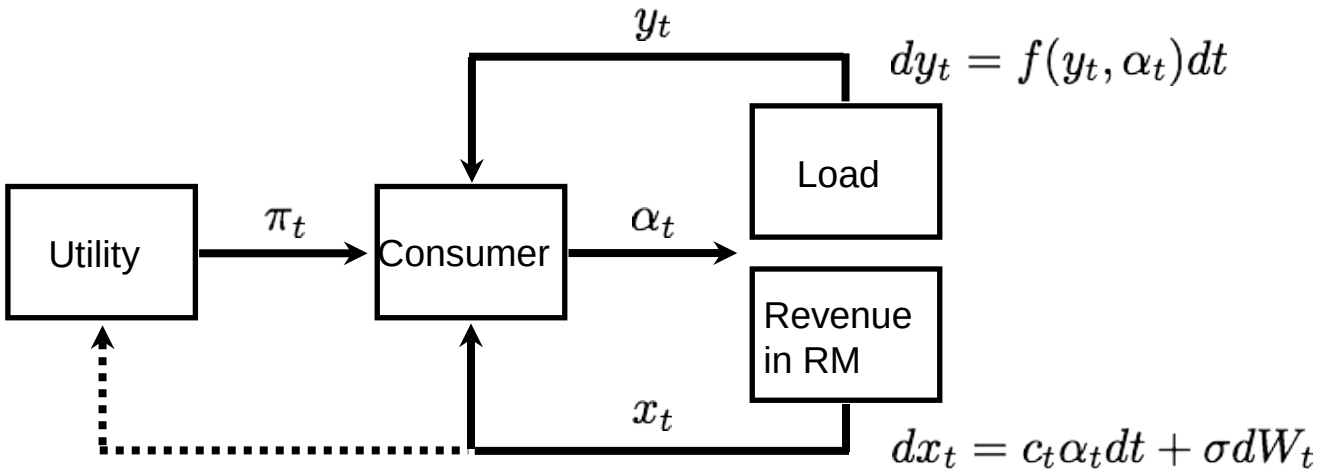
Indirect load control

Yang, Callaway, Tomlin, *in review*.

- A utility company does not have the authority to control consumers' loads.
- The utility company does not have the capability of monitoring consumers' loads.
- The utility and consumers share the risk from uncertainties through a dynamic contract.
- The utility chooses a compensation scheme such that the compensation scheme and the consumers' incentive compatible control maximize the utility's payoff



x_t :revenue in the real-time market

y_t :consumer's indoor temperature

α_t :reduction in power consumption by AC

c_t :energy price in the RM

π_t :compensation

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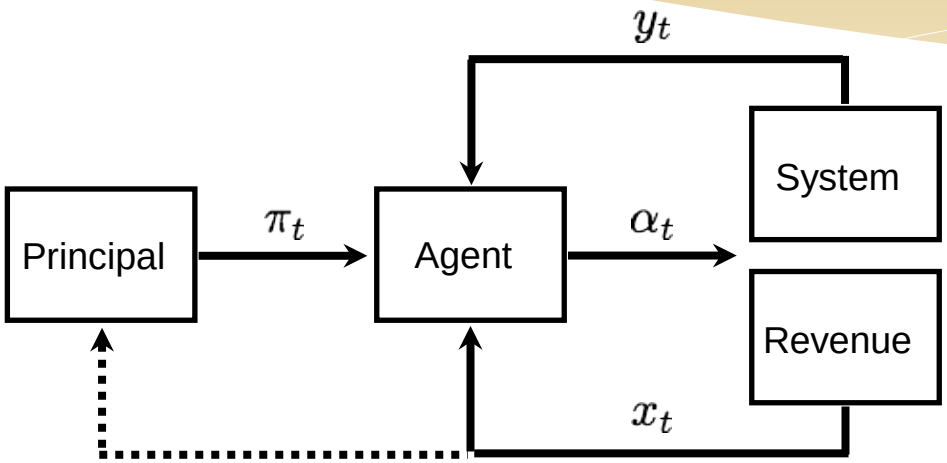
Asymmetry of information



$$dy_t = f(y_t, \alpha_t)dt$$

$$dx_t = \alpha_t dt + \sigma dW_t$$

'The agent can lie'

Expected payoffs

(Principal) $$\mathbb{E}\left[\int_0^T (dx_t + r^P(y_t, \pi_t)dt) + q(y_T) - C\right]$$

(Agent) $$\mathbb{E}\left[\int_0^T (r^A(\pi_t) - h(\alpha_t))dt + g(C)\right]$$

π_t :real-time compensation

C :end-time compensation

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[Sannikov, RES 2008]

Dynamic contract design

1. Characterize a condition in which the agent's control is incentive compatible.

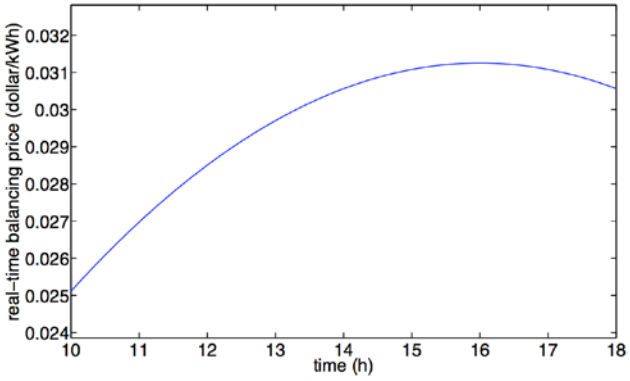
2. Choose real-time and end-time compensation such that the compensation scheme and the corresponding agent's incentive compatible control:

(a) maximize the principal's expected payoff,

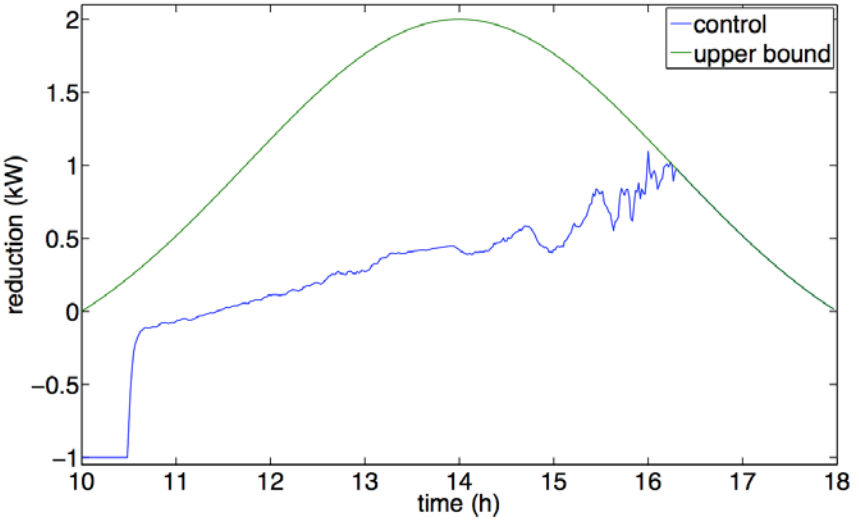
(b) make the agent's expected payoff exceed some threshold (individual rationality).

3. The contract specifies
(a) optimal compensation scheme
(b) recommended (incentive compatible) control strategy

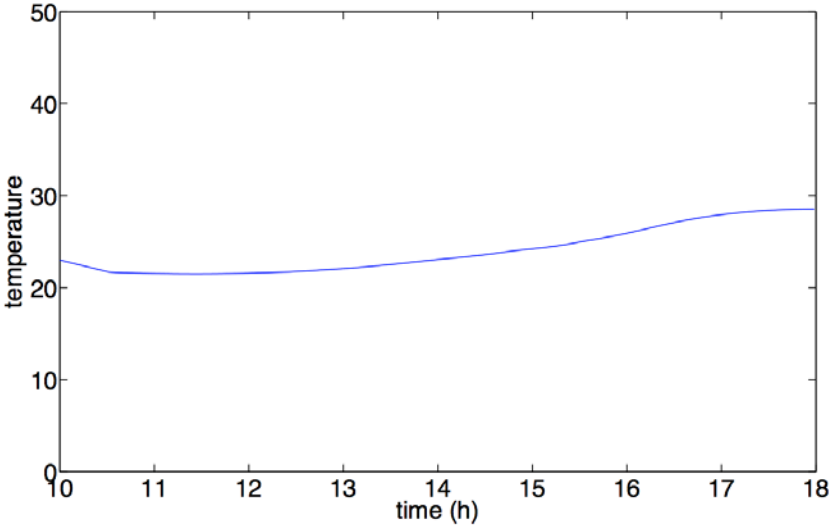
Balancing price, c_t, in the real-time market



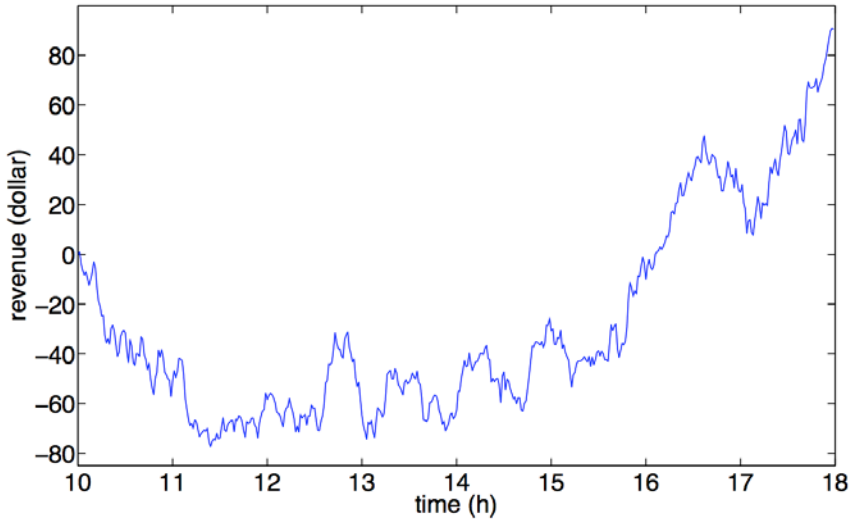
Incentive compatible control (reduction in power consumption)



Indoor temperature

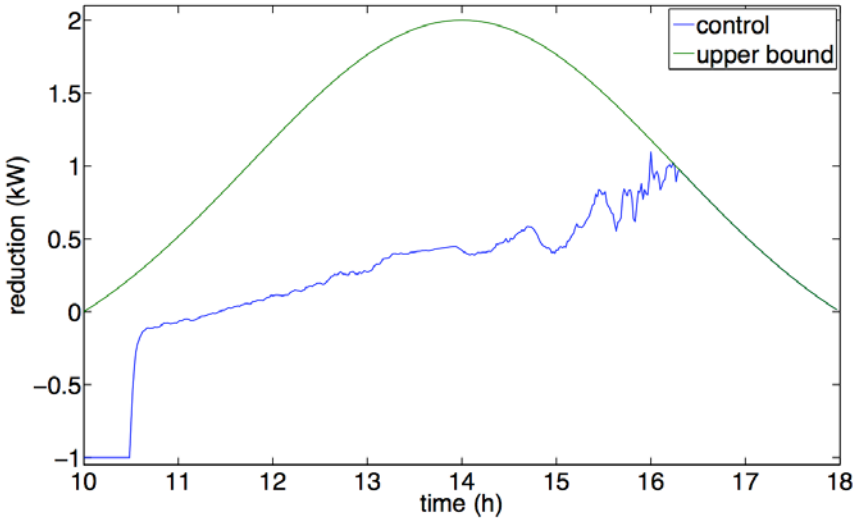


Utility's revenue process

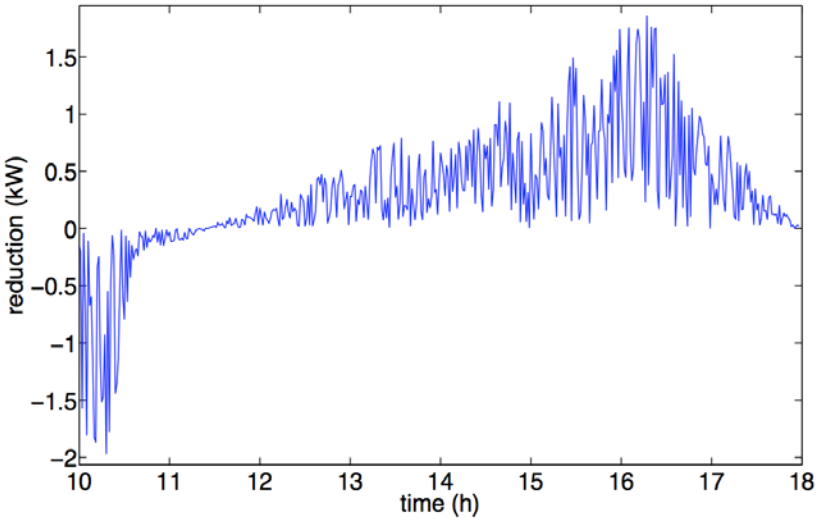


Robustness to implementation errors

Incentive compatible control
(reduction in power consumption)



100 percent implementation error
(reduction in power consumption)



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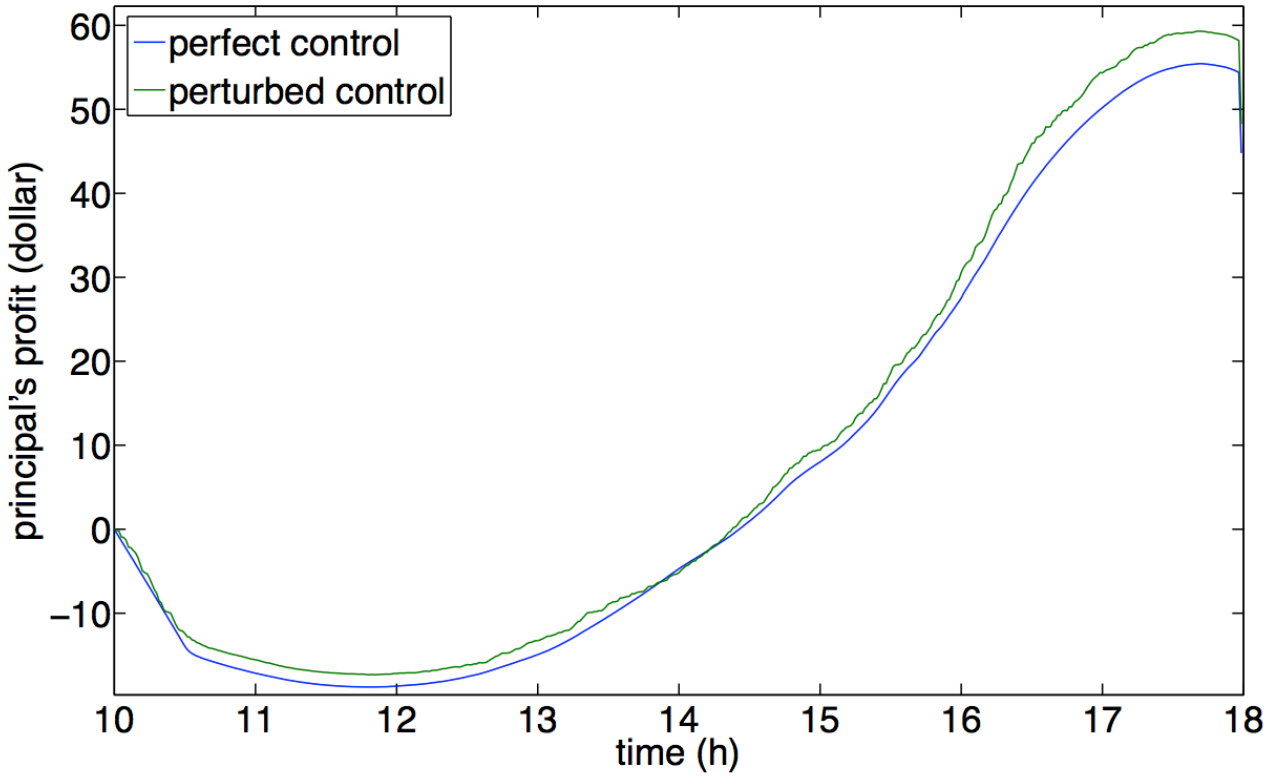
Robustness to implementation errors

The utility's profit due to the control and compensation



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Conclusion

- Optimal dynamic contract between a principal and an agent, when the principal has partial observations

- Indirect load control: a novel program for balancing uncertainties

Ongoing and future work:

- Dynamic contracts with general stochastic systems
- Models for relative risk aversion
- Hierarchical indirect load control
- Resilient dynamic contracts
- Unified theory for the quantification and management of risk and private information