Smart Power Systems of the Future: Foundations for Understanding Volatility and Improving Operational Reliability

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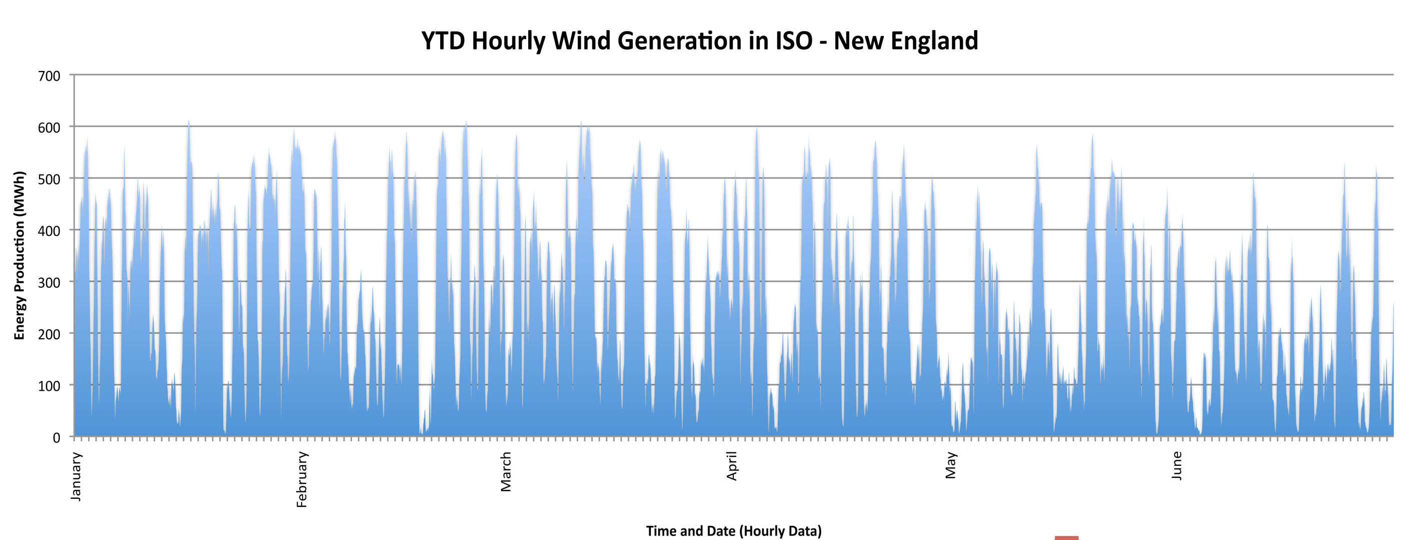
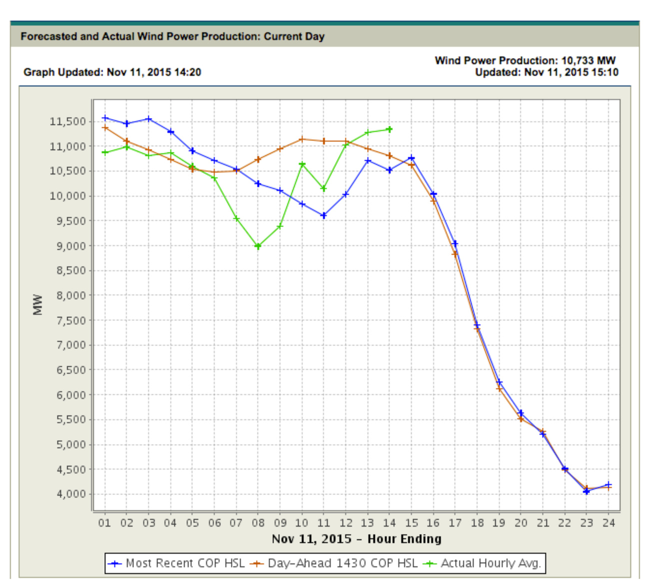
Endogenous Error Pricing for Energy Imbalance Settlements

Wind Uncertainty and the Quality of Short-term Forecasting have a Major Effect on Power System Operations and Cost

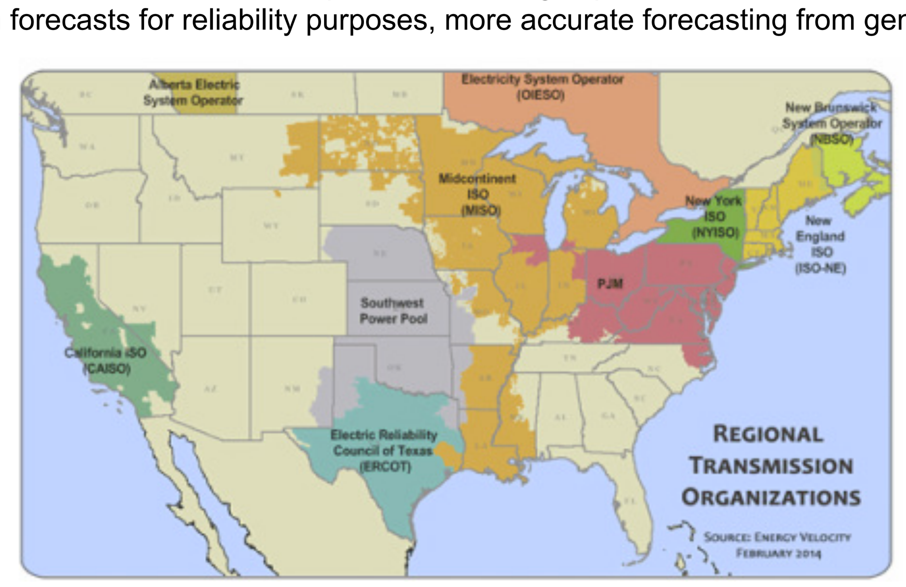




- Short-term variability in the wind resource can lead to complicated system planning and increase system risk.
- High-quality forecasting can reduce the system costs of wind integration.
- Poor forecasting can lead to suboptimal dispatch solutions and higher costs and system risk.

Proper Incentives can Align Wind Producer Operations with System Goals

- Implicit or explicit penalties imposed on the difference between real-time generation and the day-ahead bid or quantity forecast can encourage producers to make accurate predictions regarding their expected production.
- These penalties provide an incentive to improve forecasting capabilities. While ISOs are likely to continue sourcing their own forecasts for reliability purposes, more accurate forecasting from generation increases redundancy.



- Traditional generators are typically required to settle short or long positions in the real-time market, in line with the principal of the day-ahead market as a forward market for the real-time settlement. This discourages manipulation and anti-competitive behavior.
- Wind producers are increasingly required to settle the deviation between their day-ahead bid and real-time production at the real-time electricity price, for instance in ERCOT, PJM, and the UK.
- Wind forecast errors can affect the difference between day-ahead and real-time prices, so the settlement requirement results in an implicit penalty on errors in the same direction as the system-wide error.

Research Gap: Analytical Results for Endogenous Penalty Prices

- Previous literature focuses on analytical results for wind producer bidding with exogenous deviation penalties (Bitar et. al, 2012).As we will show, this suggests more conservative bidding by wind power producers and worse results in terms of system efficiency and risk.
- Computational results (Vilim, Botterud, 2014) that also consider the impact of wind forecast error on the real-time price,
- We use a simplified linear approximation to describe the effect of generation and demand forecast error on the difference between day-ahead and real-time prices, and develop analytical results for wind producer bidding in this case.

The Profit Model:

We define the difference between the day-ahead and real time price as a specific function of the wind production errors and the demand error:

$$p_{rt} = p - f(\sum_j \hat{x}_j + \phi_D)$$

Real-time Price; Day-ahead Price; Player j's final production error (post-curtailment); Demand forecast error

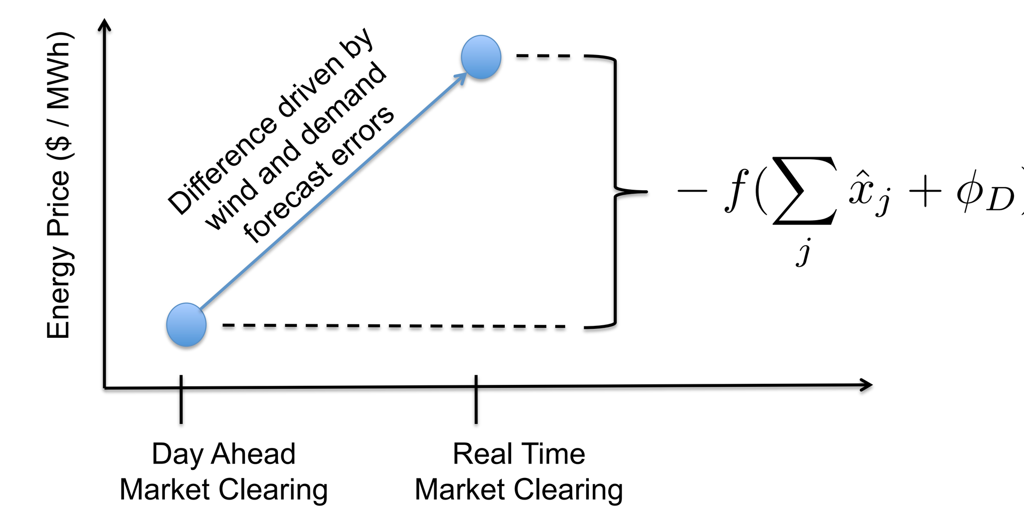
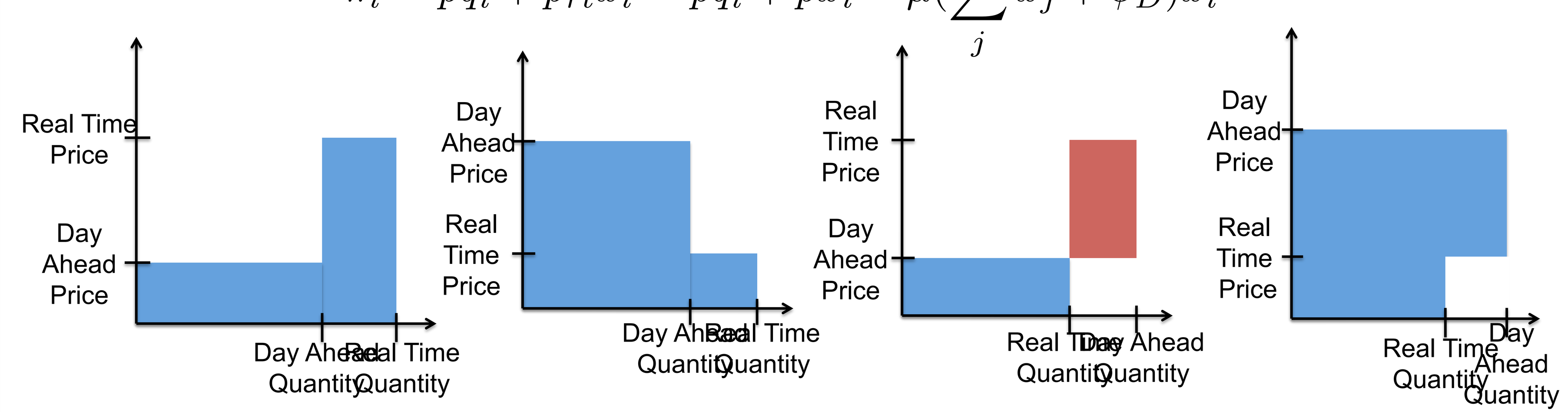


Illustration of the stylized relationship between day-ahead and real-time prices

Then, if we consider f() to be a linear function with constant μ>0, and let q_i be player i's day ahead bid, then player i's profit function is given by:

$$\pi_i = pq_i + p_{rt}\hat{x}_i = pq_i + p\hat{x}_i - \mu(\sum_j \hat{x}_j + \phi_D)\hat{x}_i$$



Example of the day-ahead/real-time settlement process for a wind generator, where profit is the blue region minus the red region.

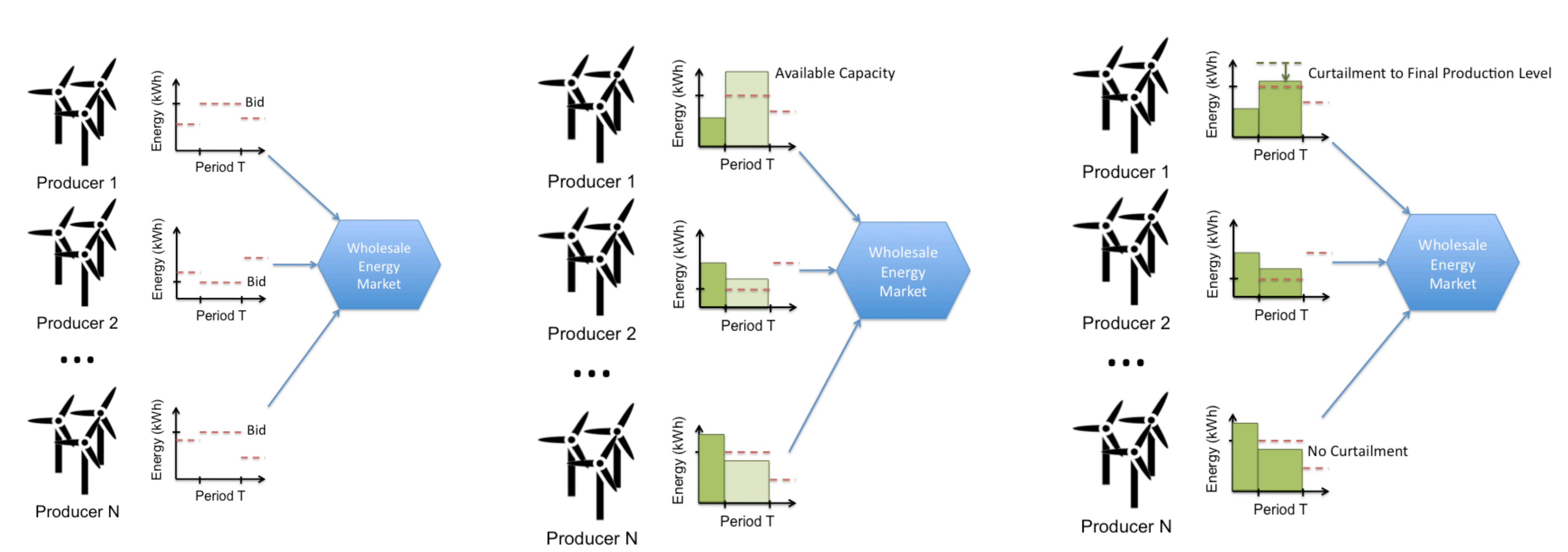
The Game Model:

- Players' strategies depend on the equilibrium strategies of other players.
- Two stage game:
  1. Day-ahead quantity bidding process: choose q_i to maximize $\mathbb{E}[\pi_i]$
  2. Real-time curtailment strategy: choose $\hat{x}_i^*$ that satisfies the following optimization problem

$$\underset{\hat{x}_i}{\text{maximize}} \quad \pi_i = pq_i + p\hat{x}_i - \mu(\hat{x}_i + \sum_{j \neq i} \hat{x}_j^* + \phi_D)\hat{x}_i$$

$$\text{subject to} \quad \hat{x}_i \leq x_i$$

- The stage two strategy informs the optimal strategy in stage one.
- Players realize their energy availability between periods and base their stage two strategy on the energy availability and strategy of the other players.



Main Results:

We define the difference between the day-ahead and real time price as a specific function of the wind production errors and the demand error:

where is the real-time price, is the day-ahead price, is player j's final curtailed production error, and is the demand forecast error.
Then if we consider f() to be a linear function with constant μ>0, and let k be player i's day ahead bid, then player i's profit function is given by:

Computational Results

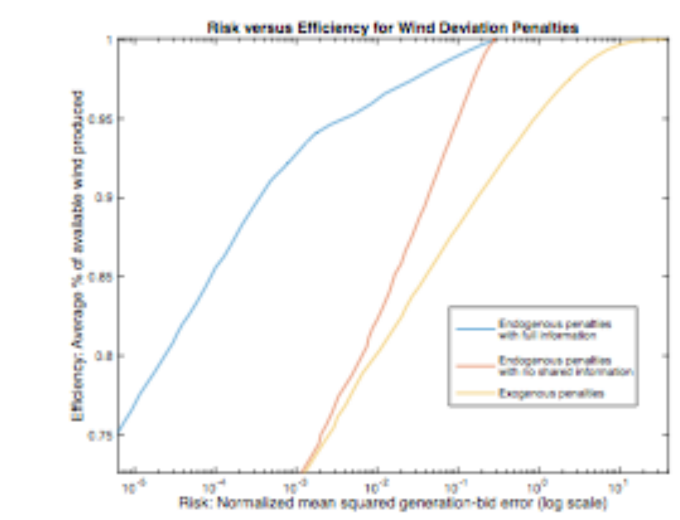


Fig. 2. Risk vs. efficiency for three model situations, as the price/penalty ratio varies from very low (bottom left) to very high (top right).

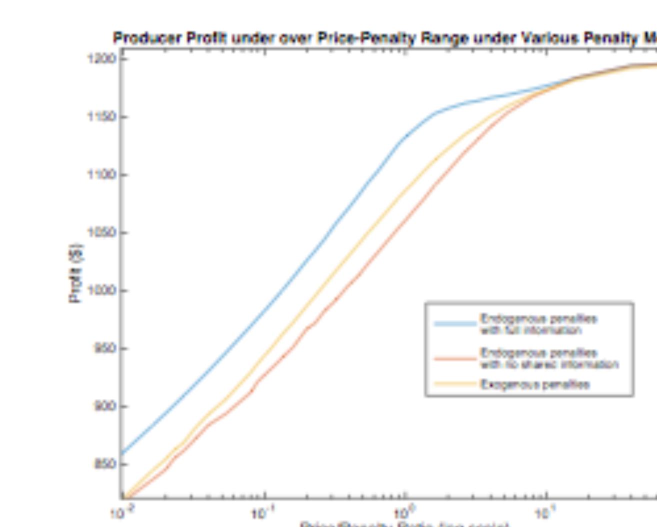


Fig. 4. Producer profit for a single, one hour settlement period over a range of price/penalty ratios

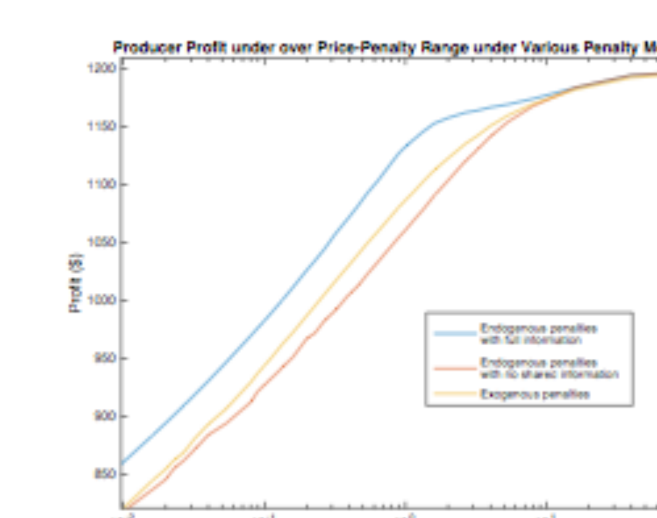


Fig. 4. Producer profit for a single, one hour settlement period over a range of price/penalty ratios

Conclusions and Future Work

Assume that players have no knowledge of competitors' energy availability in stage two, and forecasting errors are independent. Then, the optimal strategy is to curtail all errors above the curtailment limit a and to choose bids - such that .

This implies significantly better tradeoffs between risk and efficiency than the optimal response to exogenously priced settlements.