A Stochastic Dispatchable Pricing Scheme for Electric Energy Day-Ahead Markets

John R. Birge*

The University of Chicago

Booth School of Business

*Joint with Audun Botterud (Argonne National Laboratory) and Chao Li (Arizona State University)

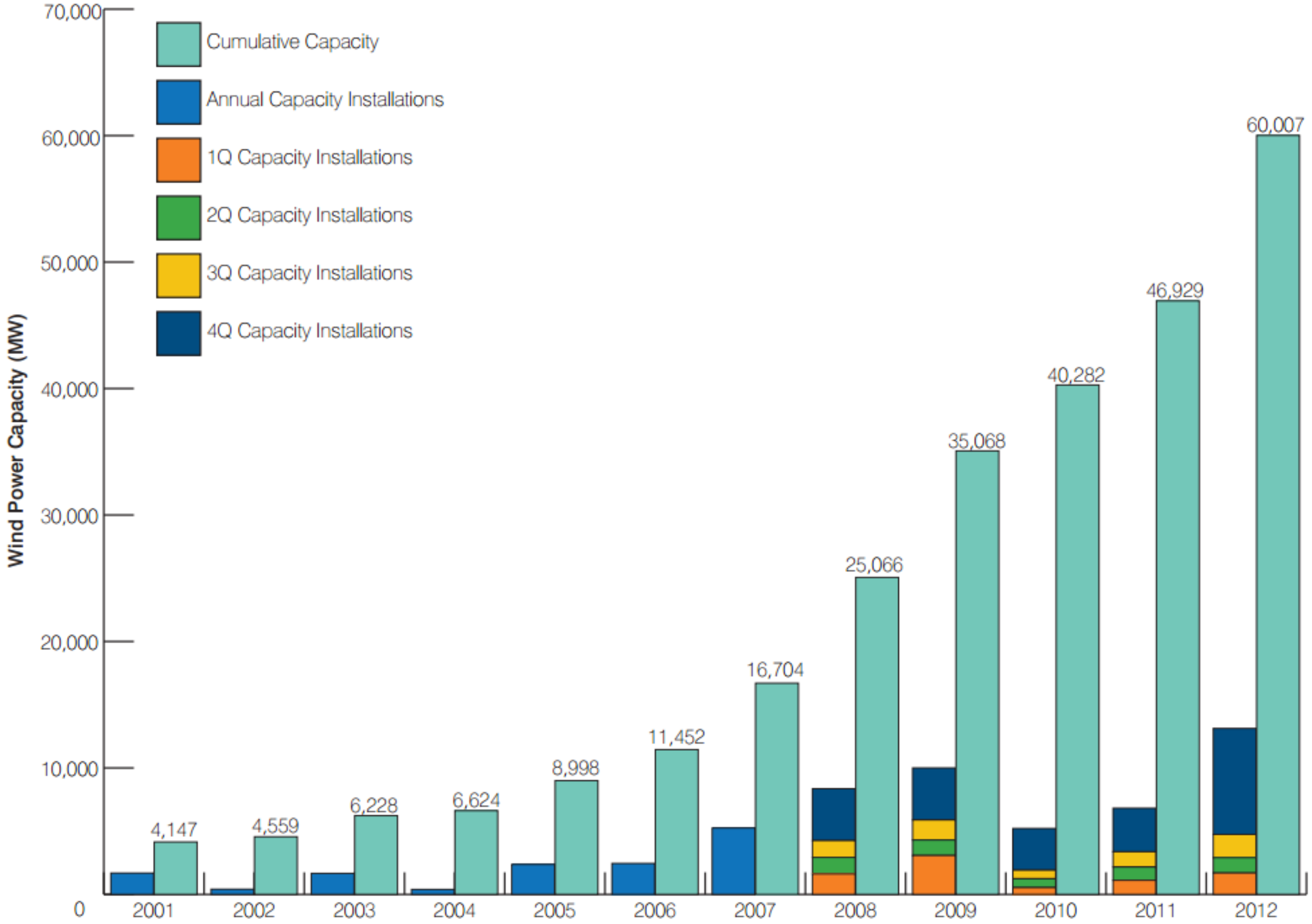
Themes

- Electricity forward and spot markets are complicated by operating requirements (start-up costs, minimum run levels and times) and uncertainty in supply and demand
- Current market designs can create efficiencies
- Redesign to include consistency in incentives and explicit recognition of uncertainty can reduce inefficiency

Outline

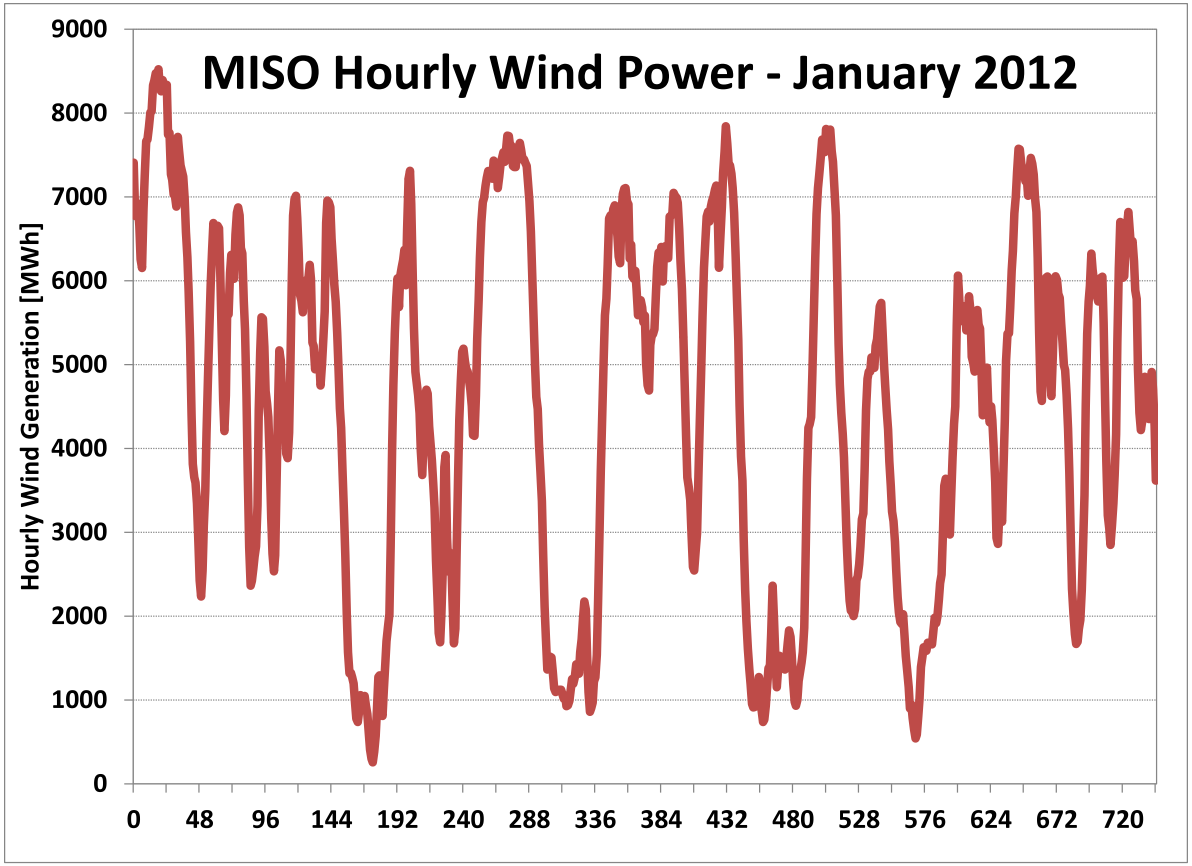
- Renewable sources and their impact
- Current market
- Issues in market design
  - Issues with non-convexities
  - Price and quantity mismatches
  - Lack of pooling incentives
- Potential resolution with stochastic optimization and smoothing

U.S. Wind Power Capacity Reaches 60 GW (282 GW Globally)



Source: AWEA, 2013 MISO 2012

Wind Variability



Impact of Renewables

- Increased intermittency=>

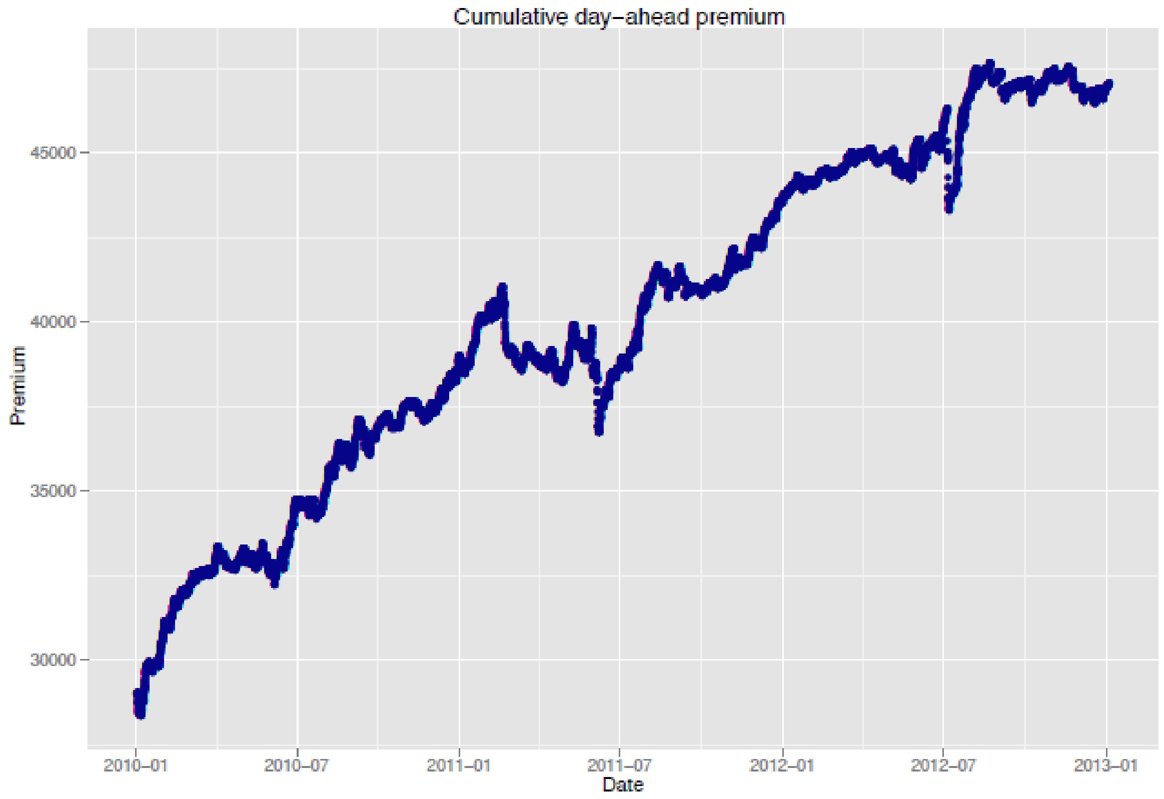
Increased need for rapid-response generation

Greater numbers of start-up/shut-down cycles for thermal generation

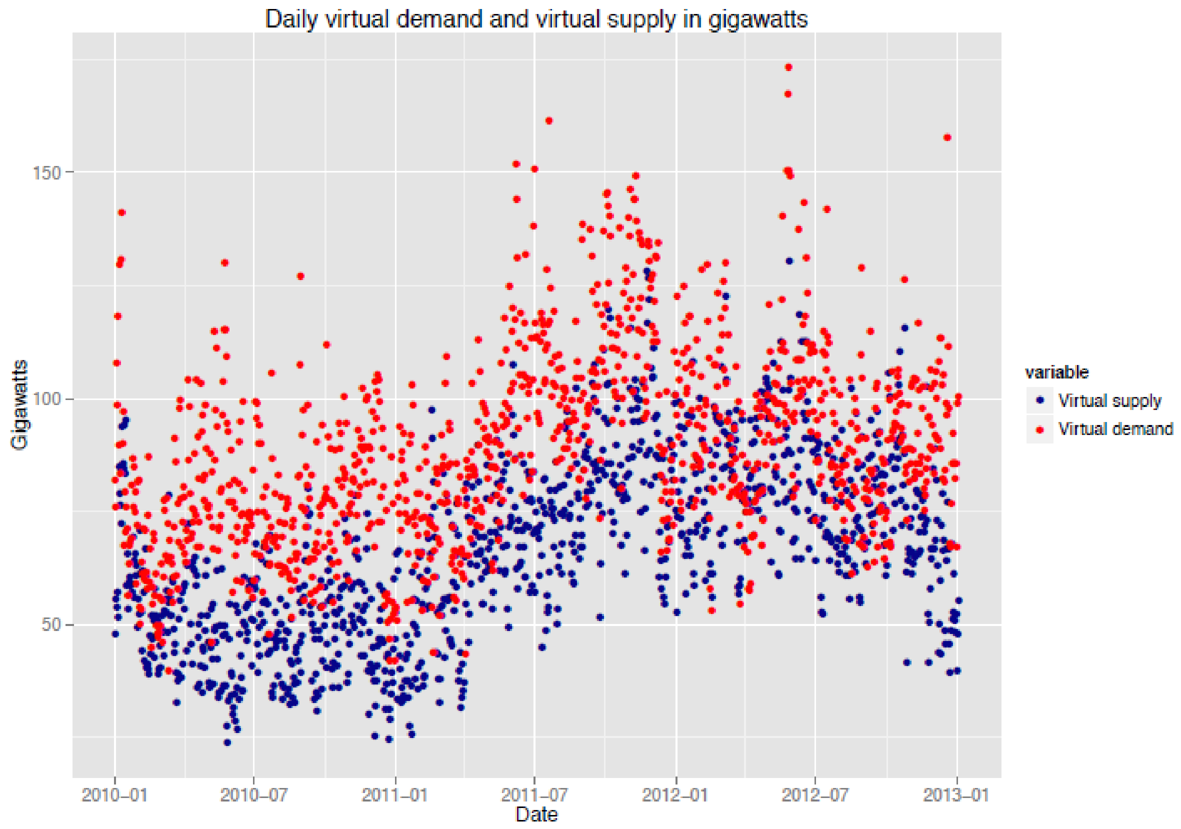
Higher potential for efficiency losses from misaligned incentives

- Objective: provide price signals that better align incentives and reduce inefficiencies

Evidence of Inefficiency: Day-Ahead Price Premium



Virtual Bidder Buying v. Selling



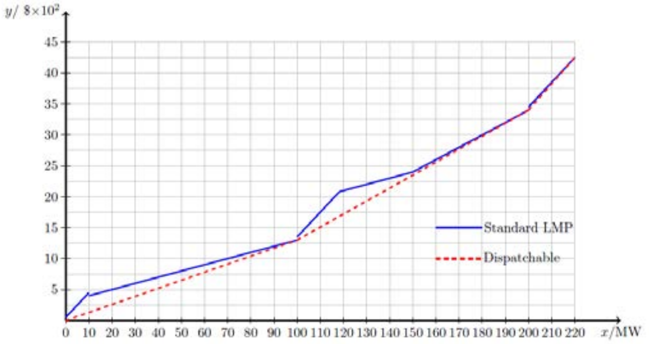
Issues in Price Signals: Non-convex Costs

- Each generator has a startup cost, variable cost, and production range
- Example:

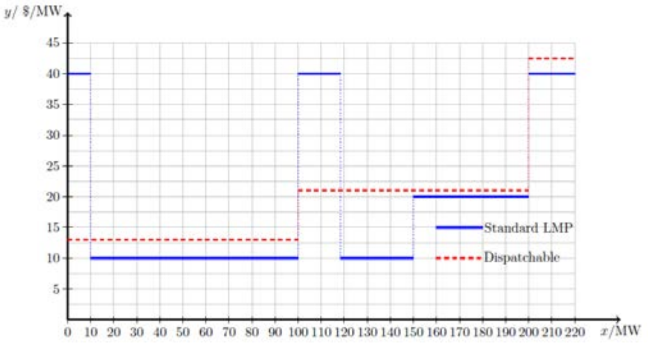
Gen	**G1**	**G2**	**G3**
fixed cost ($)	50	300	100
Pmin (MW)	0	10	50
Pmax (MW)	20	100	100
variable cost ($/MW)	40	10	20

Example Costs

Total Cost:



Marginal Cost:



Effect of Low Prices (LMP)

- Prices from marginal costs cannot support the total cost of production
- Typical market adjustment is an *uplift* charge (make-whole payment) to cover fixed costs
- Distortion can lead to inefficiency
  - Gen3 in example has additional incentive to reduce output to include Gen1

Alternatives

- Restricted model (standard LMP):

Fix commitments in optimization and use multipliers for prices

- Dispatchable model:

Relax the 0-1 commitments to fractions

- Convex hull model:

Find the convex hull or dual (Gribik, Pope, Hogan 07)

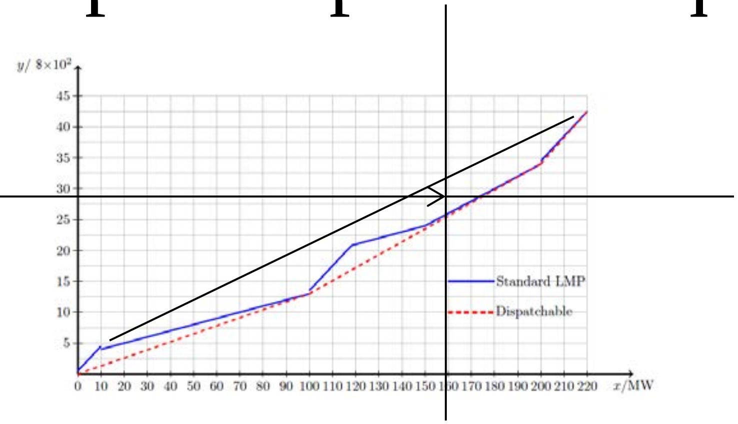
- Restrict outcomes to have no uplift (Reguant 11)

Additional Issue: Uncertainty

- If (residual) demand is uncertain, expected price and quantity is in convex hull of supply curve

=> No deterministic day-ahead market can match both expected price and quantity

(E(p),E(q))



Uncertainty Issues

- With a fixed (deterministic) model of the day ahead, nonlinearity in the cost of supply implies that matching expected prices and expected quantities between day-ahead and real-time markets is not possible
- Deterministic models cannot capture the advantages of diversification and cannot be modified to produce an efficient solution in expectation

Proposed Resolutions

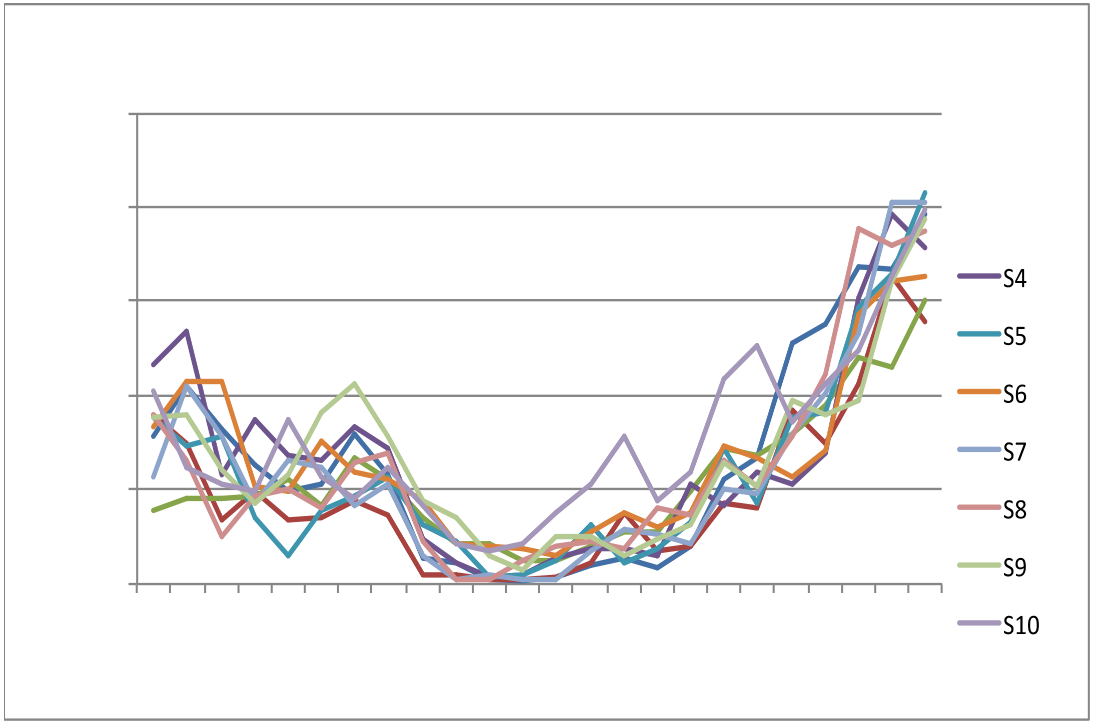
- Approximate convex hull prices:
  - Allocate fixed charges across minimum uptimes and levels of each unit
- Commit units with prices based on the expected outcomes in the real-time market
  - Solving for commitments based on day-ahead scenarios of demand and renewable output
- Reduces incentives for market power and market manipulation between energy and transmission

Basic Model: Stochastic Unit Commitment

Objective: Determine units to commit and levels of generation to meet load and to maximize expected total surplus

- Recognizing uncertainty in availability of renewable resources, demand, and other supply
- Requires generation of many future scenarios

Wind Power Day-Ahead Forecast Scenarios



- 10 wind scenarios
- Derived from EWITS data with KDF, MC sampling, and scenario reduction
- Wind unit capacity is set so that it can satisfy 30% of the daily load

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$$\min \sum_{s \in S} p_s \sum_{i \in I} \sum_{t=1}^{T} \{ g_i(x_{it}^s) u_{it}^s + h_i(u_{i,t-1}^s, u_{it}^s) \}$$

Probability of scenario s

Start-up cost

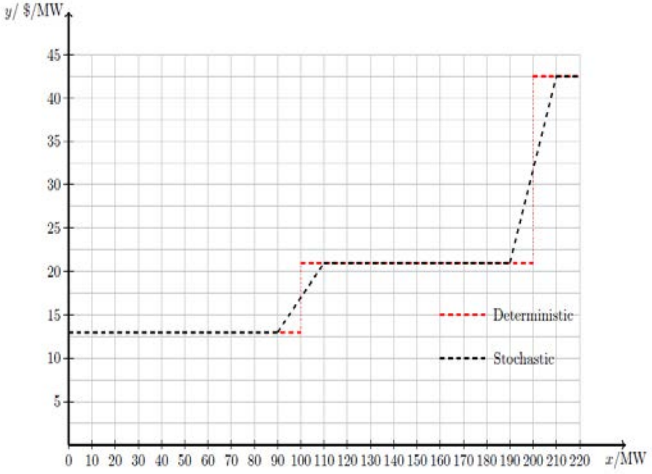
Production cost

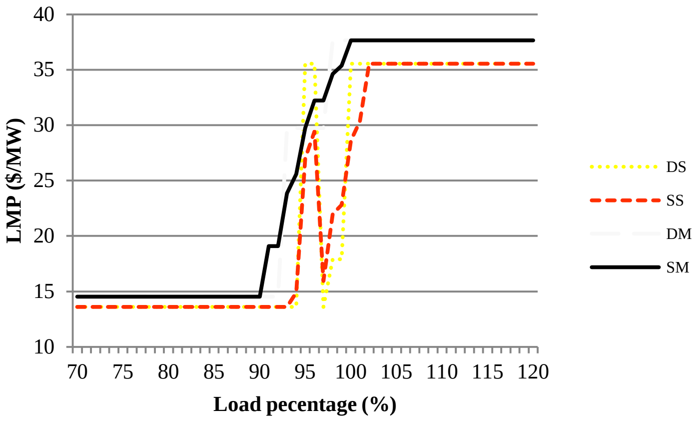
subject to:

$\sum_{l \in L_n^{in}} f_{lt}^s + \sum_{i \in I_n} x_{it}^s + \sum_{j \in J_n} w_{jt}^s = \sum_{l \in L_n^{out}} f_{lt}^s + D_t$	$\forall t, s$	Load balance
$f_{lt}^s = B_l(\theta_{nt}^s - \theta_{mt}^s)$	$\forall l = (m,n) \in L, t, s$	Flow computation
$-F_l \le f_{lt}^s \le F_l$	$\forall l, t, s$	Flow limits
$w_{jt}^s \le W_{jt}^s$	$\forall j, t, s$	Wind curtailment
$\sum_{i=1}^{I} r_{it}^s \ge R_t$	$\forall t, s$	Spinning reserve requirement
$x_{it}^s + r_{it}^s \le Q_i u_{it}^{s,b}$	$\forall i, t, s$	Maximum output
$x_{it}^s \le q_i u_{it}^{s,b}$	$\forall i, t, s$	Minimum output
$x_{it}^s - x_{i,t-1}^s + r_{it}^s \le u_{i,t-1}^{s,b} \Delta_i + (1 - u_{i,t-1}^{s,b}) \Delta_i^{SU}$	$\forall i, t \ge 2, s$	Ramp-up/Start-up
$x_{i,t-1}^s - x_{it}^s \le u_{it}^{s,b} \Delta_i + (1 - u_{it}^{s,b}) \Delta_i^{SD}$	$\forall i, t \ge 2, s$	Ramp-down/Shutdown
$u_{it}^{s,b} - u_{i,t-1}^{s,b} \le u_{i\tau}^{s,b}$	$\forall t \ge 2, s, \tau = t+1, \ldots, \min\{t + L_i - 1, T\}$	Minimum up-time
$u_{i,t-1}^{s,b} - u_{it}^{s,b} \le 1 - u_{i\tau}^{s,b}$ $\forall t \ge 2, s, \tau = t+1, \ldots, \min\{t + l_i - 1, T\}$		Minimum down-time
$u_{it}^s = u_{it}$	$\forall t, i, s$	Non-anticipativity
$x_{it}^s, r_{it}^s \ge 0$	$\forall t, i, s$	Non-negativity
$w_{jt}^s \ge 0$	$\forall t, j, s$	
$u_{it}^s, u_{it} \in \{0,1\}$	$\forall t, i, s$	Integrality

Price Effects

- Stochastic model produces smoother price responses





Test Case

- IEEE 118-Bus Example

	Deter. Standard	Stochastic Standard	Deterministic Modified	Stochastic Modified
Total Commitment Cost		150,511		
Total Dispatch Cost		747,960		
Total Load Payment	1,826,560	1,956,710	2,355,710	2,252,460
Total Uplift Payment	50,529	38,615	11,055	17,906
Total Payment	1,877,089	1,995,325	2,366,765	2,270,366
Total Generation Revenue	1,681,040	1,802,740	2,183,630	2,087,550
Total Congestion Rent	145,519	153,968	172,077	164,908

Example Implications

- Modified cost (like convex hull) provides lower uplift payments
- Stochastic model can smooth price responses with small increases in uplift payments
- Note: the commitment decisions and bids were not affected by market design in this test

Some Remaining Questions

- What is the effect of strategic bidding and changing commitment on efficiency in the stochastic market model?
- Should bidders also bid for adjustments?
- How does the convex hull (dual) pricing model compare to a no-uplift model?

Conjecture: With some assumptions, both are equivalent and efficient.

- How to run counter-factuals on ISO data?

Summary

- Electricity markets present challenges due to operating requirements and uncertainties
- Current market designs can create inefficiencies
- Allocating fixed charges or restricting uplift payments and including stochastic scenarios may improve efficiency

Thank you!

- Questions?