Accounting for Uncertainty via Operating Reserve Demand Curves

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Operating reserve demand curve proposals

RTO Insider

Gens Back PJM Pricing Proposal; Md., IMM Oppose

May 17, 2019

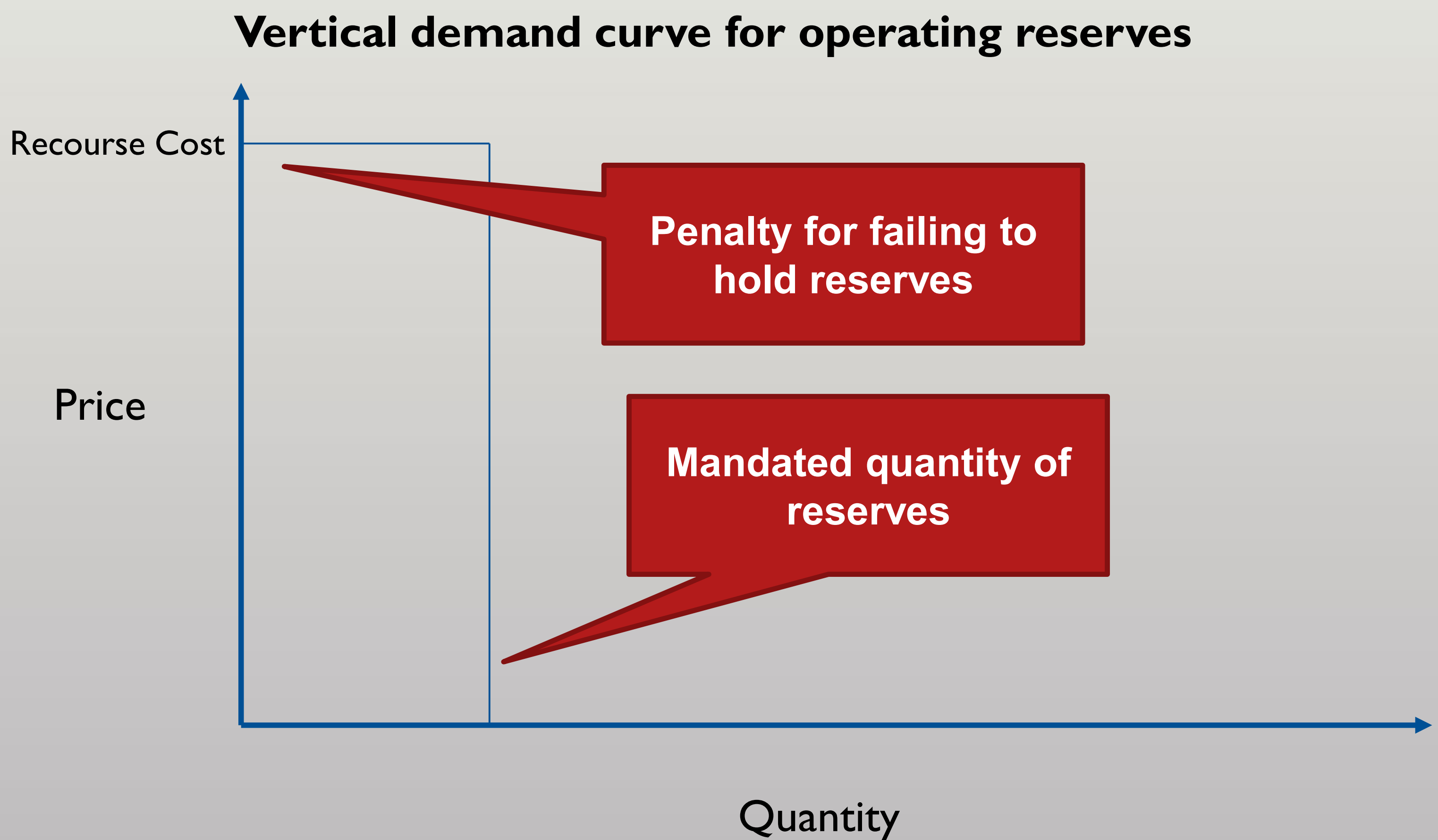
By Rich Heidorn Jr.

PJM's price formation proposal won backing from generators but Maryland regulators and the Market Monitor asked FERC to reject it, saying it would add billions in cost for negligible benefit. | *Monitoring Analytics*

- **Current ORDCs are undertheorized, with no shared understanding of why they might be useful or how to construct them**

Operating reserve demand curves

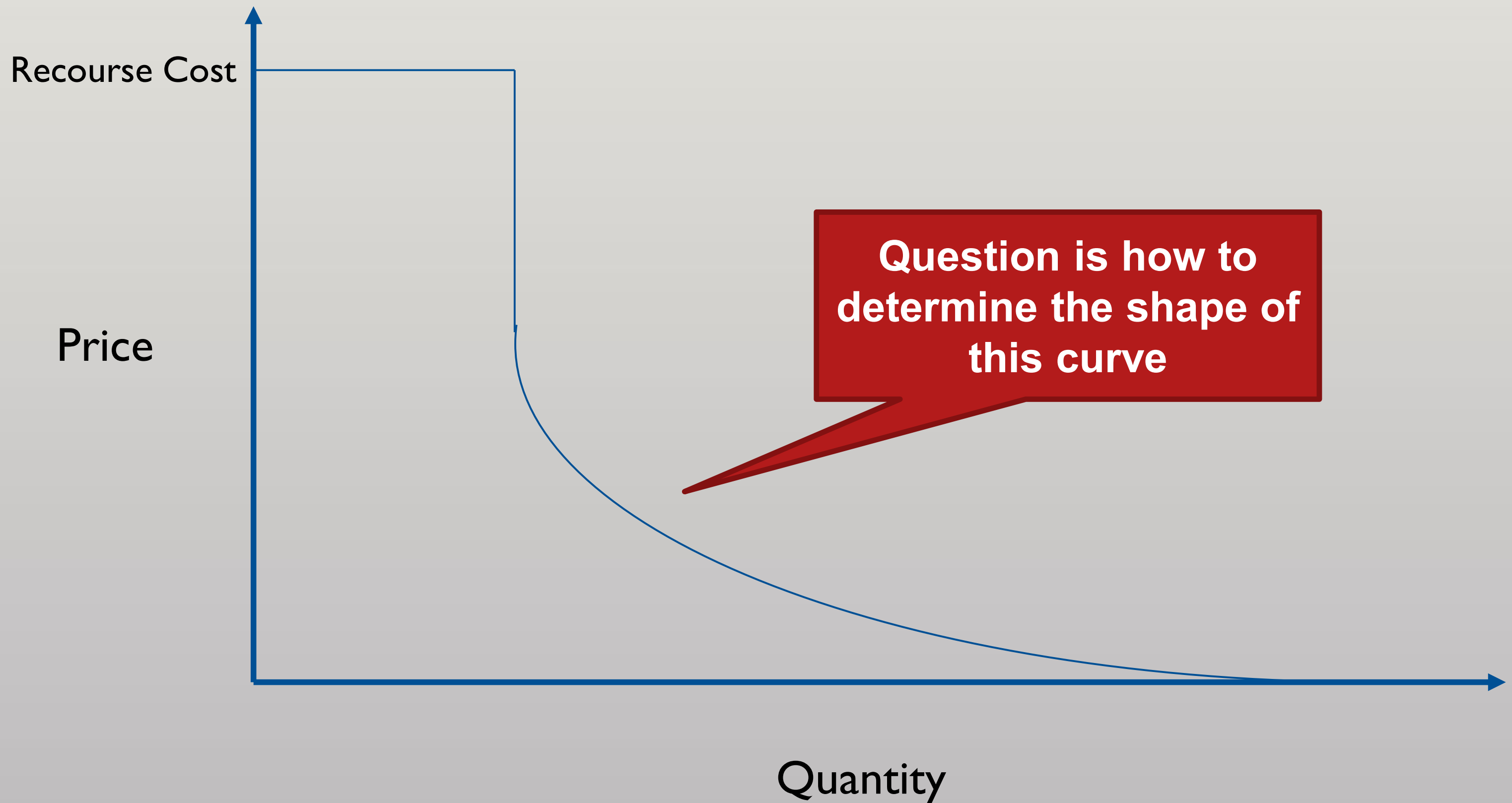
ORDC proposals alter demand for reserves above minimum quantity



Operating reserve demand curves

ORDC proposals alter demand for reserves above minimum quantity

Sloped demand curve for operating reserves



Contributions

This talk hopes to convince you of three things:

1. **Current deterministic models for unit commitment and economic dispatch lead to inefficient pricing**

2. **The goal of ORDCs should be to approximate outcomes expected in efficient stochastic markets**

3. **If ORDC efforts are successful, uplift payments and enhanced pricing schemes to address non-convexity should be revisited**

Outline

- Stochastic ideal
- Deterministic defects
- Quasi-stochastic improvements
- Future market design challenges

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Stochastic ideal

Example system

Suppose we want to serve a known demand of 200 MW in a single period with the following generators:

Resource	Min Output (MW)	Max Output (MW)	No-load Cost ($/period)	Energy Cost ($/MWh)
Wind	0	$U(0,100)$	0	0
Gen 0	0	120	0	50
Gens $n = 1 \dots 100$	1	1	$n + 50$	0

100 block-loaded units arranged in order of no-load cost

Wind is sole source of uncertainty

Cost is incurred if unit committed

We need to maintain reserves of $20 - \varepsilon$, and have recourse action (or penalty) of $950/MWh in the event of a shortfall

Stochastic unit commitment

Stochastic unit commitment problem for the example system can be stated as

$$\max_{u:u_g\in\{0,1\}} \quad -\sum_{g\in G} C_g^{NL} u_g + \mathrm{E}[H(u;W)]$$

Commitment status of thermal generators

Expected surplus in dispatch given uncertain wind availability

Stochastic unit commitment

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$$\max_{u:u_g\in\{0,1\}} \quad -\sum_{g\in G} C_g^{NL} u_g + \mathrm{E}[H(u;W)]$$

Observations:

- **If available wind $W = 50$ MW, need 170 MW of thermal capacity to meet 200 MW while providing $20 - \varepsilon$ MW of reserves**
- **This can be achieved with 120 MW from Generator 0 plus 50 block-loaded units**

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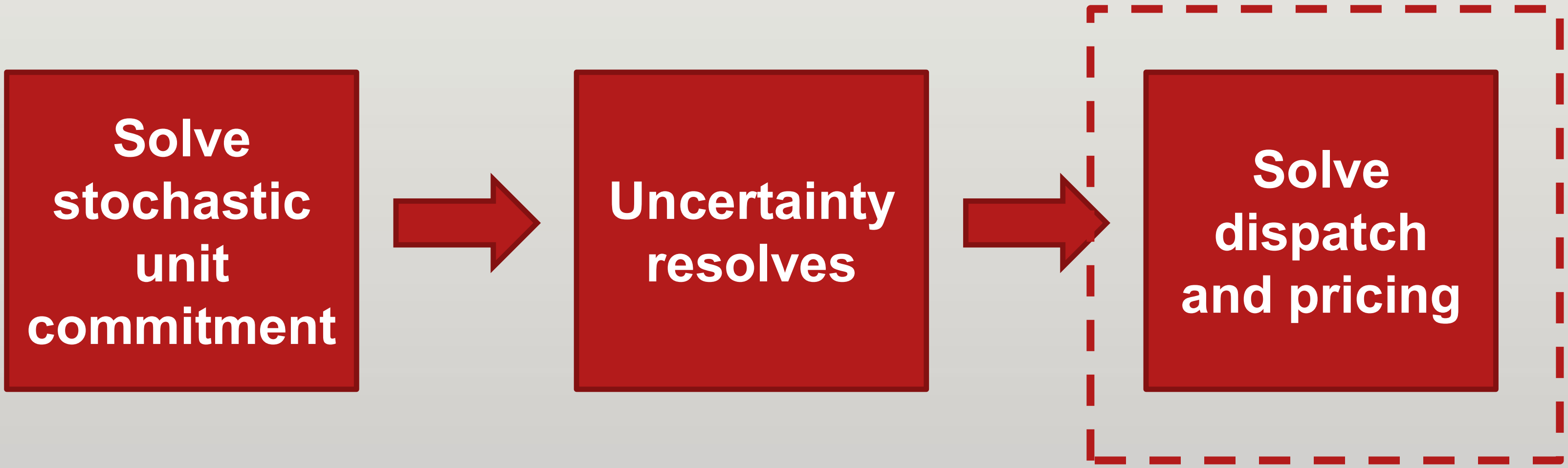
Solution:

- **Optimal: commit Gen 0 through Gen 90**
- **210 MW of thermal capacity is committed**
- **Ten percent chance of reserve shortfall**
- **Last unit committed has total cost $\boldsymbol{C_{90}^{NL} = \$140}$**

Stochastic ideal



Pricing results

- **LMP $\lambda(W;\hat{u})$ and reserve clearing price $\mu(W;\hat{u})$ depend on the chosen commitment solution $\hat{u}$ as well as the realization of wind W**
- **Assume optimal commitment $u^* = \hat{u}$ is chosen, i.e., 210 MW of thermal capacity is committed**

Prices given optimal commitment

Range	Probability	Wind (MW)	$\lambda(W;\hat{u})$	$\mu(W;\hat{u})$
1	0.1	$0 \leq W < 10$	\$1,000/MWh	\$950/MWh
2	0.9	$10 \leq W \leq 100$	\$50/MWh	\$0/MWh

Average LMP of \$145/MWh driven by 10% chance of reserve shortage

Bid cost recovery in expectation

Consider profitability of most expensive committed unit, Generator 90:

- **Incurs no-load cost of $\$140$**
- **Produces one unit of energy**
- **If $W \geq 10$, has loss of $\$140 - \$50 = \$90$**
- **If $W < 10$, has profit of $\$1,000 - \$140 = \$860$**
- **In expectation, profit of $\$5$ without any need for make-whole payments in scenarios with losses**
- **Make-whole payments in this setting amount to socializing losses and privatizing gains**

➤ **Bid cost recovery is not guaranteed in every scenario, but holds in expectation**

Stochastic market clearing

Principle of competitive markets:

- **Want the commitment and production schedule preferred by generators to be socially optimal**
- **If Generator 90 is risk neutral and shares the system operator's estimate of wind distribution, prefers to be committed despite potential for loss**

Bid cost recovery in expectation is a key property of stochastic competitive equilibrium

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Pricing issues

Two mechanisms likely lead to inefficiently low prices in current markets:

1. **Load biasing in deterministic non-market reliability unit commitment processes**
2. **Point forecasts in deterministic economic dispatch models**

Inefficient pricing leads to "missing money" compensated through capacity markets despite having little relevance to capacity

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Deterministic unit commitment

Suppose operators use a deterministic unit commitment model in the example system:

Deterministic unit commitment

Deterministic unit commitment on its own will not yield good solution given underlying uncertainty:

- **Demand of 200 MW**
- **Reserves of $20 - \varepsilon$**
- **Wind assumed at 50 MW**
- **Balance of 170 MW supplied by 120 MW from Generator 0 plus 50 block-loaded units**

With no adjustments, deterministic solution is to commit only 50 block-loaded units instead of 90

Load biasing in unit commitment

Operators can bias load to produce a better solution:

$$\max_{u,p,r,d,o,w} \quad V^D d + V^R o - \sum_{g\in G} (C_g^{NL} u_g + C_g^{EN} p_g)$$

$$s.t. \quad d + b - w - \sum_{g\in G} p_g = 0$$

$$o - \sum_{g\in G} r_g = 0$$

$$P_g^- u_g \leq p_g \qquad \forall g \in G$$

$$p_g + r_g \leq P_g^+ u_g \qquad \forall g \in G$$

$$d \leq D^+, o \leq R^+, w \leq \overline{W}$$

$$p_g, r_g \geq 0 \qquad \forall g \in G$$

$$d, o, w \geq 0$$

Add biasing term b to power balance constraint

- **Ideally, operators choose bias $b = 40$ to induce optimal solution of 90 block-loaded units**

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Price effect of load biasing

Committing additional units affects the probability of reserve shortfall after uncertainty is realized

Expected prices given different load biases

Bias	Probability of Reserve Shortfall	$E[\lambda(W;\hat{u})]$
40	0.10	$145.00/MWh
45	0.05	$97.50/MWh
50	0.00	$50.00/MWh

Expected prices drop below total cost of most expensive unit

- **Any conservatism on the part of operators can lead to violation of bid cost recovery in expectation**

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Point forecasts in economic dispatch

In reality, random variables are known only after dispatch, and vary throughout dispatch interval:

Price effect of point forecasts

- **Price from deterministic model is marginal cost under expected operating conditions**
- **In example system, if $\overline{\boldsymbol{W}} = 50$ MW is used then reserves are plentiful and $\boldsymbol{\lambda}(\overline{\boldsymbol{W}}; \widehat{\boldsymbol{u}}) = \$50/\mathrm{MWh}$**
- **Price under expected conditions is much lower than expected price given potential conditions, i.e.,**

$$\boldsymbol{\lambda}(\overline{\boldsymbol{W}}; \widehat{\boldsymbol{u}}) < \boldsymbol{E}[\boldsymbol{\lambda}(\boldsymbol{W}; \widehat{\boldsymbol{u}})]$$

With "hockey-stick" marginal cost curves typical of electricity markets, point forecasts can prevent bid cost recovery in expectation

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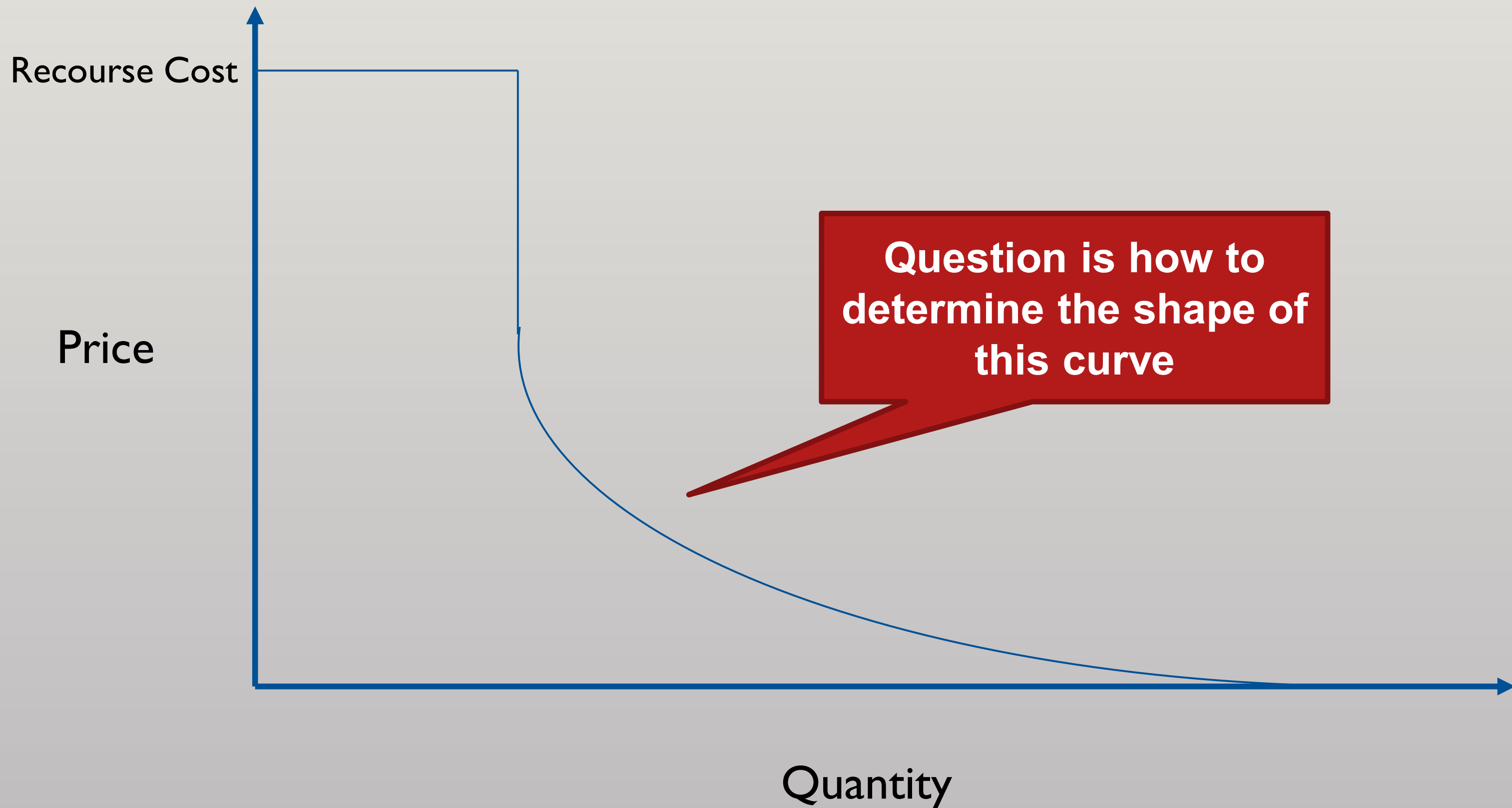
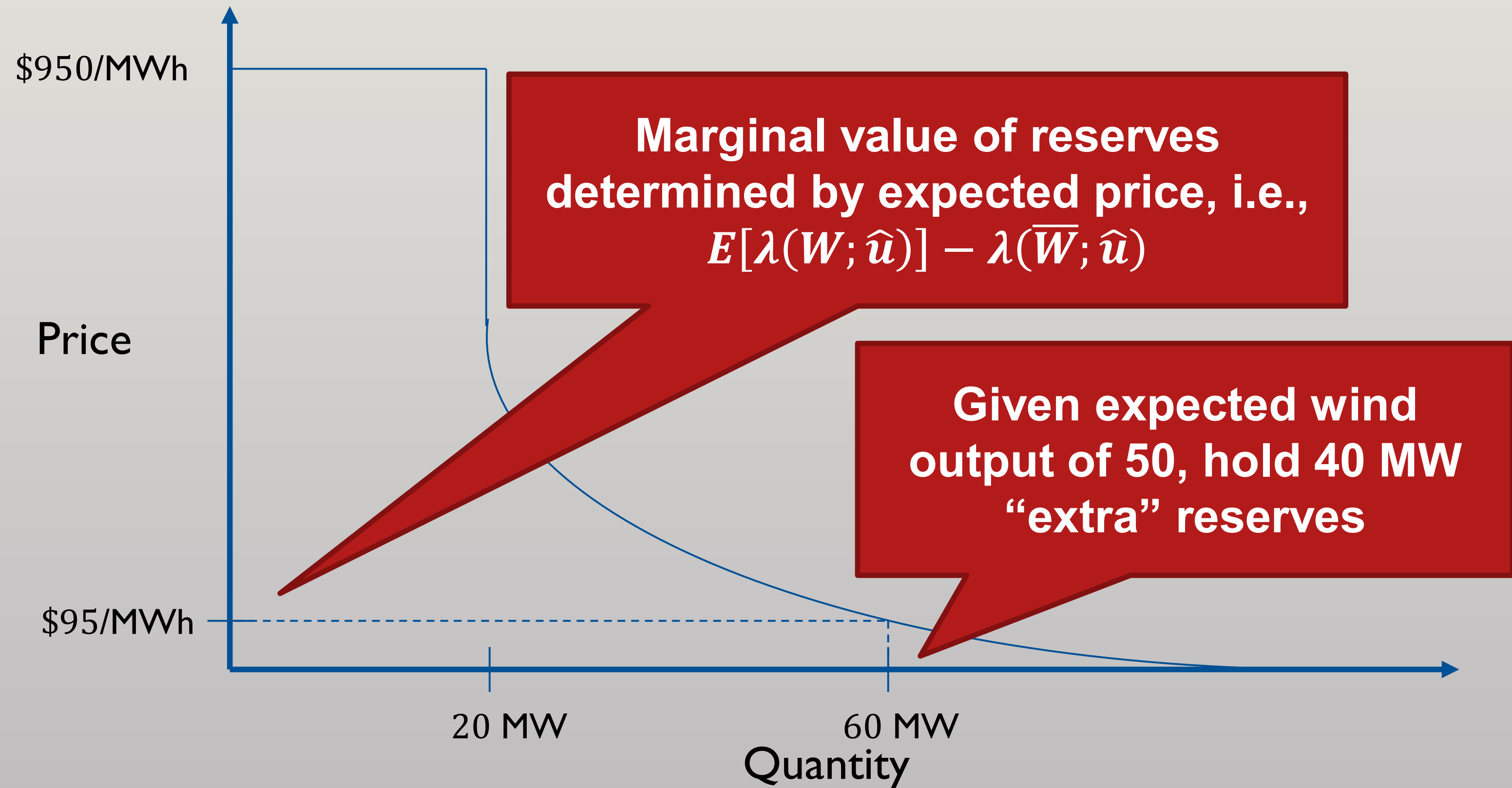


Approximating the stochastic ideal

Proposed goal for ORDCs is to connect marginal value with prices arising stochastic model

Sloped demand curve for operating reserves



Conclusion

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- More implications for future market design in working paper posted at http://www.optimization-online.org/DB_HTML/2019/10/7414.html