Modeling Approaches for Assessing Novel Market Designs for Energy Adequacy

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Calls for Capacity Market/Resource Adequacy Reform

UTILITY DIVE Deep Dive Opinion Library Events Press Releases Topics

PJM, MISO, ISO-NE. 'The capacity markets are not all right,' FERC's Christie warns.

UTILITY DIVE Deep Dive Opinion Library Events Press Releases Topics

PJM capacity prices set another record with 22% jump

LATITUDE MEDIA | COVERING THE NEW FRONTIERS OF THE ENERGY TRANSITION

Resilience is the true opportunity cost of electricity demand growth

CANARY MEDIA

Clean energy journalism for a cooler tomorrow

Texas plan to stop next grid disaster could cost customers billions

A new report finds that a proposal to improve grid reliability could cost much more than alternatives and still fail to prevent winter blackouts.

electrek

Solar adds more new capacity to the US grid in 2024 than any energy source in 20 years

Our Motivation

- Inform policy discussions on market reform for resource adequacy
- Evaluate market design proposals in Lo Prete et al. (2024)

Many Reforms Proposed, but Difficult to Evaluate

	Ensures energy adequacy	Procures generation resources that support flexibility and other essential grid needs	Fosters demand-side participation	Encourages energy storage participation	Promotes revenue sufficiency	Lowers financing cost for capital-intensive resources	Weakens incentives to exercise market power	Promotes energy affordability	Includes clean energy goals	Considers network restraints
Spees	◐	◐			◐				●	◐
Wolak	●	○	◐	◐			◐		◐	
Cramton	◐	◐	◐	●			●		◐	
Pierpont and Nelson				◐		●			○	
Pierpont				◐		●			○	
Fabra	●	◐	○	◐	●	●		◐		
Corneli	●	●		○	●				●	
Gimon	◐	○	○	○	○				○	
Keay and Robinson	◐	○	●	○	◐					
Grubb				○	○			●		
Tesfatsion	●	●	○	◐	◐					●

Legend

● Focus of proposal
◐ Discussed in proposal
○ Insufficient information
Not mentioned

Source: Lo Prete, Chiara, Karen Palmer, and Molly Robertson (2025). "Time for a Market Upgrade? A Review of Wholesale Electricity Market Designs for the Future."Energy Economics (148), August. Available at https://www.sciencedirect.com/science/article/abs/pii/S0140988325004670.

Our Motivation

- Inform policy discussions on market reform for resource adequacy
- Evaluate market design proposals in Lo Prete et al. (2024)
- Demonstrate benefits & risks of our own proposed market design components (“state of the world”-contingent markets)
  - Shift focus to energy adequacy by explicitly considering supply and demand under various weather and market outcomes
  - Incentivize resources to bid & reveal their expected availability
    - Instead of relying on administratively-determined accreditation (e.g., ELCC)
  - Consider truly extreme events
    - E.g., be prepared for the next Winter Storm Uri, not just a more typical weather year
    - In discussions with RFF insurance market experts to draw risk management insights

Key Questions

- How can we assess the cost and reliability tradeoffs of proposals?
- What types of model(s) do we need for these assessments?
- Which model features are most important to include?
- Is there value in combining model types? If so, which ones and how?

Common Model Types: Market Design for Resource Adequacy

Cost Minimization	Agent-based	Equilibrium
• Minimize total system costs subject to physical constraints • Use a central planner's perspective	• Simulate participant behavior using decision rules • Agents can gain information and update beliefs	• Leverage game-theoretic and economic principles • Consider objectives for each market participant • Solve using market-clearing conditions

Illustrative Example

- For each prospective resource $i \in I$:

$$(Profit)_i = \underbrace{P^* K_i - E_i}_{\substack{\textbf{Capacity Market} \\ \textbf{+ Entry Profit}}} + \beta \underbrace{\left(\sum_t (p_{it}^* - MC_{it}) q_{it} - F_i \right)}_{\substack{\textbf{Real-time Market} \\ \textbf{Annual Profit}}}$$

- where:
  - K_i = Available capacity
  - q_{it} = Output (MWh) in period $t \in T$
  - MC_{it} = Operating costs including fuel
  - F_i = Annual fixed costs
  - E_i = Entry costs

  - P^* = Capacity price
  - p_t^* = Real-time price
  - β = Discount factor

Illustrative Example: Cost Minimization

$$\min_{\boldsymbol{e},Q} \sum_i \left[E_i + \beta \left(\sum_t MC_{it} q_{it} + F_i \right) \right] e_i$$

- s.t. operating constraints
- where:
  - e is an I-dimensional vector of Boolean entry decisions
  - Q is an $I \times T$ matrix of real-time resource output with elements q_{it}

- **Examples**: production cost models, capacity expansion models

Illustrative Example: Agent-based

$$Max_{e_i,b_i,\boldsymbol{q}_i} \underbrace{\left[P(\boldsymbol{b})^* K_i - E_i + \beta\left(\sum_t (p_{it}^*(\boldsymbol{q}_t) - MC_{it})q_{it} - F_i\right)\right] e_i}_{=(Profit)_i}$$

- where:
  - $\boldsymbol{b}$ is an I-dimensional vector of Boolean capacity market bids
- Write e_i^*, b_i^*, q_{it}^* as functions of beliefs about competitors' actions (with error)
- Determine how these beliefs are updated with market outcomes
- Simulate each resource's actions

Illustrative Example: Equilibrium

$$Max_{e_i,b_i,\boldsymbol{q}_i} \underbrace{\left[P(\boldsymbol{b})^* K_i - E_i + \beta\left(\sum_t (p_{it}^*(\boldsymbol{q}_t) - MC_{it})q_{it} - F_i\right)\right] e_i}_{= (Profit)_i}$$

- Impose equilibrium conditions, e.g.,
  - The capacity market and real-time markets clear (i.e., supply = demand)
  - The profit of the least profitable resource that enters is zero
  - The resources have accurate beliefs about competitors on average
    - With some idiosyncratic error

Strengths & Weaknesses of Common Model Types

Cost Minimization	Agent-based	Equilibrium
• **Pro**: Tractable analysis of complex systems • **Con**: Assume away strategic behavior	• **Pro**: Incorporate imperfect decision-making • **Con**: Difficult to reproduce, poor transparency	• **Pro**: Incorporate strategic behavior • **Con**: Multiple equilibria risk, computationally intensive

Examples of Available Models by Type

Cost Minimization	Agent-based	Equilibrium
• ReEDS, IPM, PROMOD, TEMOA, Strategist, E4ST, Plexos, Aurora, MARKET ANALYTICS, TIMES, Switch, Markal, GenX	• Anwar et al. (2022), Bhagwat et al. (2017)	• Allcott (2013) • Guo et al. (2023)

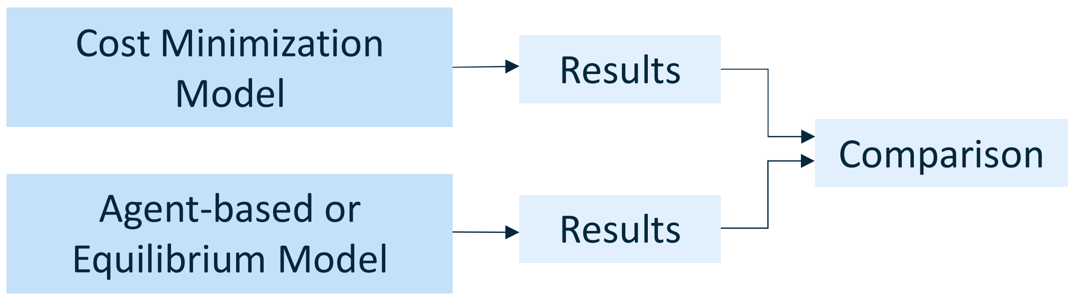
- May need a coauthor to use current agent-based or equilibrium models

Research Supports Considering Key Features

- Strategic behavior
  - Capacity market design leads to market power (PJM IMM 2023)
- High temporal resolution (Helistö et al. 2019, Mantegna et al. 2024, Siala et al. 2022)
  - Key to determining the optimal generation portfolio, modeling storage
- Spatial resolution / transmission constraints (Siala et al. 2022)
  - Especially for modeling wind generation
- Operating constraints (Helistö et al. 2019, Raichur et al. 2015)
  - For better generation portfolio, cost estimates, and emissions estimates
  - E.g., reserves, hydro availability, seasonal capacity, fuel switching capability, ramping capability
- Uncertainty in weather and market conditions?

Benefits of Combining Model Types in Parallel

- It may be intractable to capture all desired features in one model
- Could solve two separate models to explore different features, e.g.,
  - Cost minimization model with detailed operating constraints, high temporal and spatial granularity to identify operational issues by scenario
  - Equilibrium / agent-based model with uncertainty to analyze strategic bidding
- Focus subsequent analysis on designs that perform well in both models



Benefits of Combining Model Types in Series

- Market design analyses for resource adequacy have 2+ stages:
  - Stage 1: Capacity or forward market
  - Stage 2: Real-time dispatch
- Most important features may differ at different stages
  - Strategic bidding behavior most important in Stage 1?
  - Operational constraints most important in Stage 2?

Cost Minimization Model (Stage 2) → Agent-based or Equilibrium Model (Stage 1) → Results → Comparison

Potential Starting Point

- Stage 1: Equilibrium model
  - Initial goal: Resources choose bid price
  - Longer-term goal: Resources choose price and quantity bids
- Stage 1.5: Entry/exit decisions
  - Initial assumption: Resources included in Stage 2 IFF selected in Stage 1
  - Longer-term considerations:
    - Allow resources to choose to not bid into capacity market
    - Consider barriers to entry? Out-of-market payments?
- Stage 2: An existing cost minimization model of real-time power markets
  - Incorporate any scarcity prices or RA performance incentives

Potential Research Questions

- What are the benefits & risks of various proposed RA market designs?
  - Are there incentives for over-/under-bidding of price or quantity?
- How do proposals compare in terms of welfare?
  - Expected welfare? The distribution of welfare outcomes?
  - Short run vs. long run?
- How may tweaks to current capacity markets (e.g., performance incentives) change participation, bidding, prices, & unserved energy?

RESOURCES *for the* FUTURE

Thank you.

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Discussion Questions

- Are we missing any model types?
- Does combining these tools seem worthwhile? Why/why not?
- How to structure a modeling approach to assessing various market designs?