A Structural Econometric Model of the Dynamic Hourly Electricity Production Game in California
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Why Study California?

- Functional grid with low carbon-intensity
- Renewable Portfolio Standard (20% current)
- First U.S. Cap & Trade with price floor
California’s four future energy challenges

- Renewable Portfolio Standard: 33% by 2020

![Mandated Renewables Fraction](image)

- Cap & Trade (at least 100 Million Tons CO$_2$e reduced by capped entities by 2020)$^1$
- Climate Change induced water scarcity reducing hydro ramping support$^2$
- Loss of baseload capacity (nuclear)


$^2$ Garfin et al., 2013
Research Question: How “should” we satisfy the RPS?

Study the optimal mix of renewable capacity

► Renewable investments imposing grid stability and capacity requirement externalities on grid

Current ratio: 40% Solar / 60% Wind
Research Question: How “should” we satisfy the RPS? (cont)

- Renewables not operating in accordance with cost-minimization
- Particular mix of renewables has significant influence on:
  - Grid volatility and stability
  - Ramping requirements
  - Necessity of expensive capacity market
  - Potential curtailment of renewables (but then need more renewable capacity to satisfy RPS...)
  - Utility-scale rapid storage

Therefore, important to find ideal RPS blend, and dynamic profit-max structural econometric model shows us how to get there
The Model

- Structural econometric model with profit-max agents
  - Plant/techtype-unit level for Natural Gas, Nuclear, Hydro and Coal
  - Sector level Renewable-by-tech, Imports, Fringe
- Dynamic game - each agent optimizing current hourly production based on:
  - Others’ actions
  - State variables (e.g. temperature (CDD) & water availability)
  - Current and future payoff
- Dynamics allows:
  - Across-hour constraints
  - Plants to forego current profits in order to maximize net present current and future profits
The Model (cont.)

- Dataset: Apr 2010 to Dec 2012 (2013 available in August)
- Endogenous renewable capacity investment model by sector
Why model electricity dynamically when studying volatility?

- Current actions are allowed to restrict the choice set of future actions
- Plants can forego current profits to maximize overall discounted profits

\[ V_i(s_t) = \pi_t(Actions_t, s_t; \theta) + \beta \cdot E[V_i(s_{t+1} | Actions_t, s_t; \theta)] + \varepsilon_{i,t} \]
Econometric Model: Supports Importance of Proper RPS Selection

Initial econometric estimates make sense:

- Volatility: Fuel efficiency penalty for
  - Rapid ramping
  - Startup
  - Shutdown
- Non-zero time to ramp for many traditional plants
Distribution of Demand Across Year

CAISO Hourly Demand Distribution

Median 26,000MWhs (CAISO) & 75% Hours Below 30,000MWhs
Scaled PV / Wind to Meet 33% RPS for ‘10-‘12 Demand

- More relevant if RPS % has 2020+ growth
- External validity: Relevant for Germany / other regions now
Renewable Portfolio Production: Midnight

Production Distribution at Night (1am)

- 100% Solar Portfolio (no production)
- 100% Wind Portfolio
Renewable Portfolio Production: Morning

Production Distribution in Morning (8am)

- Blue line: 100% Solar Portfolio
- Red line: 100% Wind Portfolio
Renewable Portfolio Production: Midday

Production Distribution at Midday (11am)

- **100% Solar Portfolio**
- **100% Wind Portfolio**
Renewable Portfolio Production: Early Evening

Production Distribution in Early Evening (6pm)

- 100% Solar Portfolio
- 100% Wind Portfolio
Next Slides’ Equation: Matching Demand and Renewable Output

\[(D - \text{Ren MW})_t - (D - \text{Ren MW})_{t-1} = \text{MW Ramp}_t\]

- \(\text{MW Ramp}_t > 0\): Load-following tech increase output above last hour’s output by \(\text{MW Ramp}_t\)
- \(\text{MW Ramp}_t < 0\): Load-following tech decrease output below last hour’s output by \(\text{MW Ramp}_t\)
Traditional Ramp: Midnight

Traditional Generator Ramping Requirements (1am)

- Blue line: 100% Solar Portfolio
- Red line: 100% Wind Portfolio
Traditional Ramp: Morning

![Traditional Generator Ramping Requirements (8am)](image)

- **100% Solar Portfolio**
- **100% Wind Portfolio**
Traditional Ramp: Midday

Traditional Generator Ramping Requirements (11am)

Density

1 Hr Ramp (MWhs) Net of Renewables

-20,000 -10,000 0 10,000 20,000 30,000

100% Solar Portfolio 100% Wind Portfolio
Traditional Ramp: Early Evening

Traditional Generator Ramping Requirements (6pm)

- **Density**
  - 0.0005
  - 0.0004
  - 0.0003
  - 0.0002
  - 0.0001
  - 0.001

- **1 Hour Ramp (MW/h) Net of Renewables**
  - -5,000
  - 0
  - 5,000
  - 10,000
  - 15,000

- **Graph Lines**
  - **Blue**: 100% Solar Portfolio
  - **Red**: 100% Wind Portfolio
Conclusion

Our model is the first of its kind to analyze California’s electricity markets integrating the following features:

▶ Profit maximization of renewable generators to look at RPS grid stability (diverges from cost-minimizing conclusions)
▶ Structural econometric estimation of parameters using data on observed behavior and state variables
▶ Plants operate under uncertainty about future (transition density of potential futures)
▶ Model / allow for market power and other strategic interactions
Policy relevance - optimizing RPS and renewable incentives

- What sectors of renewables do current state and federal policies encourage?
- Is this the “right” mix?”
- If not, how to change incentives to induce ideal mix
Thank you!