How to Have Fun in Electricity Policy Modeling

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Benjamin F. Hobbs

bhobbs@jhu.edu
Dept. Geography & Environmental Engineering
Dept. of Applied Mathematics & Statistics
Whiting School of Engineering
The Johns Hopkins University

California ISO Market Surveillance Committee

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I. Why Model?

II. Fun with Simple Models
1. Who should be responsible for CO\textsubscript{2} compliance?
2. Who should be given free CO\textsubscript{2} allowances?

III. Fun with Complex Models
3. How much SO\textsubscript{2} reduction can you get from smarter power system operation?
4. Will the Bush Administration NSR reforms harm the environment?
5. Where in the U.S. might market power become a problem?
Definition of Electric Power Models

- **Models that:**
  - simulate or optimize ...
  - the operation and/or investment of production, transport, and use of electric power ...
  - and its economic, environmental, and other impacts ...
  - using mathematics and, perhaps, computers

- **Focus here: “bottom-up” engineering economic models**
  - Behavioral and technical components
  - Used for:
    - firm-level decisions
      - (min costs, max profits)
    - policy-analysis
      - (simulate reaction of market to policy)
Structure of Models

Multifirm Market Models with Strategic Interaction

Single Firm Models
- Design/Investment Models
- Operations/Control Models

Demand Models

Market Clearing Conditions/Constraints
All Models are Wrong … Some are Useful

- **Very large models**
  - Actual grid operations and planning
  - Need:
    - numerical solutions that can be implemented
    - policy conclusions for specific systems

- **Very small models**
  - Quick insights in policy debates
  - Need:
    - transparent models to convincingly communicate implications of assumptions
    - general conclusions

- **In-between models**
  - Forecasting and impact analyses of policies
  - Need:
    - ability to simulate many scenarios
    - but still represent “texture” of actual system
Surprising conclusions, Overturn policy beliefs

- **California:**
  - “Load-based CO$_2$ trading will be cheaper for consumers than Source-based”

- **Netherlands:**
  - “Giving CO2 allowances to new generation investment will not distort prices & generation mix”

- **Ohio:**
  - “Significant SO$_2$ reductions from changed system operation not possible”

- **US:**
  - “Bush Administration NSR reforms will keep old plants around and increase pollution”

- **US:**
  - “Market power in bulk power markets will be worse in more isolated markets than in midwest”
Fun with Simple Models
Two simple models of CO₂ issues:
1. Who should be responsible for CO₂ compliance?

- **California AB32:**
  - Mandates CO₂ reductions to 1990 levels by 2020

- **Focus of policy debate: “Point of Compliance” for CO₂ allowance “cap and trade” system**
  - Power plants (sources) or Load serving entities (LSEs)?
  - Elsewhere, source-based dominates
    - Allocate allowances to power plants, and then trade
      - Total emissions can’t exceed cap
    - E.g., Title IV SO₂ program, RGGI
  - Load-based proposed for California
    - Mean emissions of LSE power purchases ≤ cap
    - Cheaper (Synapse Energy, 2007)?
    - Provide more motivation for energy efficiency (NRDC)?
Source-Based Market Schematic

CO₂ Market

Allowance Allocation

Emissions

GenA

Power Market

Power Sales

Consumers

GenB

Emissions

Allowance Allocation
Source-Based Market: Market Participant Optimization Problems

CO₂ Market:

\[ E_A g_A + E_B g_B \leq \text{ALLOW}_A + \text{ALLOW}_B (= \text{CAP}) \]
(Price = \( p_{\text{CO}_2} \))

GenA chooses \( g_A \geq 0 \):

\[ \text{MAX} (p_A - C_A - p_{\text{CO}_2} E_A)g_A + p_{\text{CO}_2}\text{ALLOW}_A \]
subject to: \( g_A \leq \text{CAP}_A \)

GenB chooses \( g_B \geq 0 \):

\[ \text{MAX} (p_B - C_B - p_{\text{CO}_2} E_B)g_B + p_{\text{CO}_2}\text{ALLOW}_B \]
s.t.: \( g_B \leq \text{CAP}_B \)

Power Market

\( g_A = d_A \)  
(Price = \( p_A \))

\( g_B = d_B \)  
(Price = \( p_B \))

Consumers choose \( d_A, d_B \geq 0 \):

\[ \text{MIN} p_A d_A + p_B d_B \]
s.t.: \( d_A + d_B = L \)

What's the equilibrium?
Source-Based Market Equilibrium Problem: Find \( \{p_A, p_B, p_{CO2}; g_A, \mu_A; g_B, \mu_B; d_A, d_B, \lambda\} \) satisfying:

\[
E_A g_A + E_B g_B \\
\leq ALLOW_A + ALLOW_B = CAP \\
(price = p_{CO2})
\]

\[
0 \leq g_A \perp p_A - C_A - p_{CO2} E_A + p_{CO2} \partial ALLOW_A / \partial g_A - \mu_A \leq 0 \\
0 \leq \mu_A \perp g_A - CAP_A \leq 0
\]

\[
0 \leq g_B \perp p_B - C_B - p_{CO2} E_B + p_{CO2} \partial ALLOW_B / \partial g_B - \mu_B \leq 0 \\
0 \leq \mu_B \perp g_B - CAP_B \leq 0
\]

\[
g_A = d_A \\
(price = p_A)
\]

\[
g_B = d_B \\
(price = p_B)
\]

10 Conditions, 10 Unknowns
Load-Based Market: Market Participant Optimization Problems

GenA chooses $g_A \geq 0$:

$$\text{MAX } (p_A - C_A)g_A$$

subject to: $g_A \leq \text{CAP}_A$

GenB chooses $g_B \geq 0$:

$$\text{MAX } (p_B - C_B)g_B$$

s.t.: $g_B \leq \text{CAP}_B$

Consumers choose $d_A, d_B \geq 0$:

$$\text{MIN } p_A d_A + p_B d_B$$

s.t.: $d_A + d_B = L$

$$E_A d_A + E_B d_B \leq L \times \text{Rate} = \text{CAP}$$
Analytical Conclusions


- **Power prices:**
  - Uniform in source-based system
  - Differentiated in load-based system
    - higher for cleaner generation
    - endangers efficiencies of PJM-like spot markets
- **Allowance prices the same**
- **“Load side carbon cap is likely to cost California consumers significantly less than supply side cap—Potentially billions of dollars per year.”**
  - Contrary to speculation, net costs to consumers **same**
  - ... If allowances are auctioned to generators, and consumers get proceeds
    - ... if no damage to spot markets
- **Attempts to separate emissions trading from power trading in load-based system are actually VERY complex source-based systems**
  - E.g., “Tradeable Emission Attribute Certificates”, “CO2RCs”
2. How Does Allowance Allocation Affect the Price Impacts of CO₂ Trading?

“... if the expansion of the generation park (by incumbents or newcomers) is associated with a free allocation of emission allowances, then players will base their long-term investment decisions on the long-term marginal costs, including the costs of the CO₂ allowances, but by subtracting the subsidy that lowers the required mark-up for the fixed costs ... On balance, the power price will not be increased.”


True in an industry with time-varying demand, no storage, and a mix of production types?

• Will the least-cost generation mix still result, and all the allowances rent returned to consumers?
Simple Analysis: 3 Gen Types

Emissions limit: 20 or 40 MT/yr
- 94%, 47% of unconstrained emissions

Elastic demand

Generator assumptions:

<table>
<thead>
<tr>
<th>Technology</th>
<th>Fixed Cost (€/kW)</th>
<th>Var Cost (€/MWh)</th>
<th>CO2 (Ton/MWh)</th>
<th>Allocation of Allowances to New Investment (relative) (1/MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustion Turbine</td>
<td>50</td>
<td>80</td>
<td>0.6</td>
<td>0.35</td>
</tr>
<tr>
<td>Combined Cycle (Gas)</td>
<td>75</td>
<td>40</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Pulverized Coal</td>
<td>120</td>
<td>20</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
Effects of Giving Away Allowances

- **Distort investment**
  - If give away > 50% of allowances to new investment, major distortion ...
  - Overinvest in coal and combustion turbines—some never operated (built to get allowances)

- **Increases social cost of CO₂ control**
  - At least doubles (if give all away to new investment)
  - Distortion worse at smaller levels of CO₂ reduction
  - Power prices may not change much; instead most of social cost is loss of government allowance rent
3. Potential For Emissions Dispatch in Ohio: Is there any?


Assumptions:
- Whole state
- All generation units “must run”
- 8760 hours
- Random outages
- No fuel switching
- 1989 fuel costs

Method:
- Probabilistic Production Costing

Emissions Dispatch:
- Use dirty units less, & clean units more
- Emissions decrease, costs increase

Ohio coal jobs
Emissions Dispatch + Fuel Switching

$B/y$

E.D. alone

(Millions)

E(SOx Emissions), tons/yr
4. NSR Reforms: Evisceration of the Clean Air Act, or Needed Streamlining?

- **Issue:** Old coal-fired plants & emissions

- **Reform:** Would exempt power plant maintenance and upgrades from having to install BACT

- **Conflict:**
  - Supporters: Reform offers flexibility to industry
    - promotes efficiency and modernization
    - without emission increases
  - Opponents (e.g., "Changing All the Rules," New York Times, 4/4/04):
    - Old NSR more effective in motivating old power plants to clean up
    - Reform will result in more emissions than would occur otherwise
**NAS/NRC NSR Study (2006)**


- Used ICF Integrated Planning model (LP, $\sim 10^6$ variables)
- Given the new EPA caps on $SO_x$, $NO_x$ emissions:
  - Evisceration of CAA?
  - Either:
    - reform would have minimal effect on national emissions, or
    - aggressive NSR would be a costly way to achieve emissions reductions compared to tighter caps
5. Where is the Potential for Market Power Highest?

US Eastern Interconnection Nash-Cournot Model


- 100 nodes representing US control areas
- 829 generating firms
  - ~100 largest (> 1000 MW) are "Cournot"
  - Assume full vertical divestiture
- Linearized "DC" load flow
  - 814 constrained interfaces

www.nerc.com/regional/
What was the profession of John Nash’s father?

Electric power engineering
Conjecture: Markups worse in peripheral markets

Variations in Market Power over Space: Simulated Cournot Markups

$\varepsilon = -0.1$

Hour 12, June 2000

Highest Bar = 30.5%
Variation in Market Power Over Time:
PJM June 2002 Simulations

Exports (-) and Imports (+) [MWh]

Hour of Day

Exports (-) and Imports (+) [MWh]

% PCM: (Cournot P - Comp P)

Competitive P
Contradictory Conclusions

- Need more insights in policy and market design ⇒
  - Simple, appropriate models
  - Economic fundamentals

- Need solutions that recognize uncertainties and technological peculiarities ⇒
  - Computational technology needed for large-scale stochastic, non-convex problems
  - Theory needed to derive incentive-compatible prices for stochastic, non-convex markets

Have fun!