Interaction of Oligopolistic Transmission–Constrained Power Markets with Renewable Portfolio Standards, Green Pricing Programs, & Emission Allowances

Yihsu Chen
Benjamin F. Hobbs
24th Annual North American Conference of USAEE/IAEE
Washington, DC

Dept. Geography & Environmental Engineering
Whiting School of Engineering
The Johns Hopkins University
Baltimore, MD USA

Funded by NSF and USEPA STAR Program
Outline

- Questions
- Model Structure and Computation Approach
- Application
- Results
Questions of Interest

Accounting for the interactions of

- transmission constraints & energy markets
- green power
- renewable portfolio standards
- NO\textsubscript{\chi} markets,

... the following questions are addressed:

- What is the impact of market power on prices of energy (grey, green premium), renewable energy credits (RECs), and NO\textsubscript{\chi} allowances?
- What is the impact on social surplus?
- What is the magnitude of productive inefficiency?
- What is the rationale for players’ behavior in markets?
Model Structure and Computational Approach: Direct Solution of Equilibrium Conditions

1. Derive 1st-order conditions for each player
2. Impose market clearing conditions
3. Solve resulting system of conditions (complementarity problem) with PATH
Application Background
PJM Market and USEPA NO\textsubscript{x} Program

- Peak: 49,000 MW
- Average Price: 30.7 [$/MWh]
- Moderate Concentrated: HHI ~ 1,500
- 14 node, 18 arc system
- 9 producers
- 80% sales either forward contracted, or by vertically integrated firm

**USEPA NO\textsubscript{x} Program**
- Cap-and-Trade
- May 1st – Sep. 30th (3,672 hrs)
  - Approximated by 5 load periods
- 9 States in 2000

Source: www.pjm.com
Green Pricing Programs

- 29 marketers offering green power (8 States and DC)
- Retail green premium: 0.5-2.5 ¢/kWh
- 0.028% of total US sales (2001)

- >350 utilities in 33 states offer green pricing programs
- Utility green premium: 0.7-17.6 ¢/kWh
- 0.017% of total US sales (2001)


http://www.nrel.gov/docs/fy04osti/35119.pdf
Renewable Portfolio Standards (RPS)

- 14 states mandate RPS

- RPS requirement differs by state, e.g.,
  - 30% by 2000 in ME
  - 1.1% by 2002 in AZ

- 5 States allow trading in renewable energy credits (RECs)

We assume a RPS of 5.5% under four competition scenarios:

<table>
<thead>
<tr>
<th>Scenario \ Market</th>
<th>Grey Power Market</th>
<th>Green Power Market</th>
<th>NOx Permits Market</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp.</td>
<td>Price-Taking</td>
<td>Price-Taking</td>
<td>Price-Taking</td>
</tr>
<tr>
<td>MP Grey</td>
<td>Cournot</td>
<td>Price-Taking</td>
<td>Price-Taking</td>
</tr>
<tr>
<td>MP/G/G</td>
<td>Cournot</td>
<td>Cournot</td>
<td>Price-Taking</td>
</tr>
<tr>
<td>MP/G/G/NOx</td>
<td>Cournot</td>
<td>Cournot</td>
<td>Conjectured</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Response</td>
</tr>
</tbody>
</table>
Results: Price Comparison

Sale-Weighted Avg. Grey Power Price

<table>
<thead>
<tr>
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<th>Comp.</th>
<th>MP Grey</th>
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<th>MP/G/G/NOx</th>
</tr>
</thead>
</table>

Green Premium

<table>
<thead>
<tr>
<th></th>
<th>Comp.</th>
<th>MP Grey</th>
<th>MP/G/G</th>
<th>MP/G/G/NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Premium [$/MWh]</td>
<td>17</td>
<td>17</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

REC Price

<table>
<thead>
<tr>
<th></th>
<th>Comp.</th>
<th>MP Grey</th>
<th>MP/G/G</th>
<th>MP/G/G/NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>REC Price [$/MWh]</td>
<td>98</td>
<td>0</td>
<td>31</td>
<td>31</td>
</tr>
</tbody>
</table>

NOx Permit Price

<table>
<thead>
<tr>
<th></th>
<th>Comp.</th>
<th>MP Grey</th>
<th>MP/G/G</th>
<th>MP/G/G/NOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx Allowance Price [$/ton]</td>
<td>2229</td>
<td>1135</td>
<td>1187</td>
<td>1255</td>
</tr>
</tbody>
</table>
Welfare Analysis
Compared to Competitive Scenario

Social Welfare

<table>
<thead>
<tr>
<th>Scenario Comp.</th>
<th>0.0 M$</th>
<th>-64 M$</th>
<th>-72 M$</th>
<th>-67 M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>0.995</td>
<td>0.994</td>
<td>0.995</td>
</tr>
</tbody>
</table>

Consumers Surplus

<table>
<thead>
<tr>
<th>Scenario Comp.</th>
<th>0.0 M$</th>
<th>-551 M$</th>
<th>-479 M$</th>
<th>-462 M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>0.949</td>
<td>0.955</td>
<td>0.957</td>
</tr>
</tbody>
</table>

Producers Surplus

<table>
<thead>
<tr>
<th>Scenario Comp.</th>
<th>0.0 M$</th>
<th>498.4 M$</th>
<th>421.1 M$</th>
<th>406.4 M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>1.316</td>
<td>1.267</td>
<td>1.257</td>
</tr>
</tbody>
</table>

ISO Revenue

<table>
<thead>
<tr>
<th>Scenario Comp.</th>
<th>0.0 M$</th>
<th>-35 M$</th>
<th>-34 M$</th>
<th>-31 M$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.00</td>
<td>0.507</td>
<td>0.521</td>
<td>0.563</td>
</tr>
</tbody>
</table>
Efficiency Comparison
Compared to Competitive Scenario

Productive Inefficiency

Productive Inefficiency
Increase in cost relative to least-cost means of serving MW demands for green & grey energy

Market power leads to:
7.0%-7.6% productive inefficiency
Player’s Strategies

PECO largest in power, longest in permit and REC Markets (modeled with Cournot and NO\textsubscript{x} conjectured price response)

**MP Grey → MP/G/G (Add MP in Green)**

PECO restrains green output and increases grey output

- \( p^{REC} \uparrow (0 \rightarrow 31$/MWh) \)
- \( p^E \downarrow (27.1 \rightarrow 26.3$/MWh) \)

PECO worse off
CS goes up (lower \( p^E \))
PS goes down
SW goes up

**MP/G/G → MP/G/G/NO\textsubscript{x} (Add MP in NO\textsubscript{x})**

PECO expands output, sells fewer NO\textsubscript{x} permits

- \( p^{NO_x} \uparrow (1,187 \rightarrow 1,255$/ton) \)
- \( p^E \downarrow (26.3 \rightarrow 26.2$/MWh) \)

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Conclusion

- Interactions of electric (grey and green), RECs, and NO$_x$ markets can be investigated by Cournot and conjectured NO$_x$ pricing assumptions in a large-scale model (20,000 variables).

- Detailed market representation allows a variety of welfare and efficiency analyses, and insights on players’ strategies.

- Next:
  - variable wind outputs
  - suppliers’ long-term investment decisions under various oligopoly scenarios
QUESTIONS AND COMMENTS?