WIND ENERGY AND NEGATIVE PRICING

Is Production Tax Credit to Blame?

Yu Wang
Iowa State University

Shan Zhou
Georgia Institute of Technology
Production Tax Credit has Stimulated Wind Capacity Growth

Impact of Production Tax Credit Expiration and Extension on U.S. Annual Installed Wind Capacity

Chart by Union of Concerned Scientists
Negative price is the signal for down-regulation

PTC enables wind producers to bid at negative prices
Wind power and negative prices

- Wind power production is related to electricity wholesale prices
  - Renewable energy reduce electricity price in wholesale markets (Moreno, López, and García-Álvarez 2012; Traber and Kemfert 2011; Woo et al. 2011)
  - In regions with high wind penetration, wind production can cause spikes of negative prices (Brandstätt, Brunekreeft, and Jahnke 2011; Nicolosi 2010).

- Negative prices are results of system imbalance
  - In the central western European market, negative prices are correlated with forecast errors of load and wind and solar generation (Brijs et al. 2015)

- Negative prices are signals for downward dispatching generation, and reliable grid needs the downward flexibility

- PTC affects wind capacity installation, and enables wind producers to bid in negative prices
Research question

- The “incompressibility of power systems” is a barrier for renewable power integration
- Negative prices are “market distortions” that need to be addressed
- “PTC aggravates the problem of negative pricing”
- Does PTC cause more negative pricing hours?
Conceptual framework

- Load forecast
- Minimum generation events
- Wind forecast
- Wind speed
- Other generation
- Nuclear/coal generation
- Curtailment
- Wind generation
- PTC
- Demand
- Dispatched generation
- Negative prices
- Congestion
- Bid
Model

\[ D = \alpha + \beta_0 \cdot \text{PTC} + \beta_i \cdot X_i + \varepsilon \]

Where, 
- \(D\) is the dependent variable, hour of negative prices
- \(\beta_0\) is the coefficient of the policy variable
- \(X_i\) is the non-policy independent variables, including wind generation, short-term load forecast error, day-ahead mid-term load forecast error, minimum generation events, and transmission outages
- \(\beta_i\) is the coefficient of \(X_i\)
- \(\alpha\) is the constant
- \(\varepsilon\) is the error term
Data

- Real-time LMP
- Four MISO regional trading hubs
  - Michigan hub
  - Indiana hub
  - Minnesota hub
  - Illinois hub
- Data is extracted from MISO’s monthly market assessment reports and information forum presentations
- From 01/2012 to 06/2015
Table 1. Summary of the independent and dependent variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Obs</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative price</td>
<td>hour</td>
<td>42</td>
<td>23</td>
<td>22.3</td>
<td>0</td>
<td>78</td>
</tr>
<tr>
<td>Wind generation</td>
<td>GWh</td>
<td>42</td>
<td>3048.7</td>
<td>836.4</td>
<td>1371</td>
<td>4637</td>
</tr>
<tr>
<td>Transmission outage</td>
<td>#</td>
<td>42</td>
<td>3947.2</td>
<td>1160.8</td>
<td>1753</td>
<td>6000</td>
</tr>
<tr>
<td>Minimum generation event</td>
<td>#</td>
<td>42</td>
<td>0.2</td>
<td>0.5</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>PTC1</td>
<td>-</td>
<td>42</td>
<td>0.4</td>
<td>0.5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>PTC2</td>
<td>-</td>
<td>42</td>
<td>0.6</td>
<td>0.7</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Short-term load forecast error</td>
<td>%</td>
<td>42</td>
<td>0.0084</td>
<td>0.0390</td>
<td>0.0016</td>
<td>0.255</td>
</tr>
<tr>
<td>DA mid-term load forecast error</td>
<td>%</td>
<td>42</td>
<td>0.0129</td>
<td>0.0038</td>
<td>0.007</td>
<td>0.0216</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Code</th>
<th>PTC1</th>
<th>PTC2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/12-12/13</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1/14-12/14</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>1/15 – 6/15</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Results

- Wind Electricity Generation (GWh)
- Negative Pricing (Hour)

Legend:
- wind generation
- negative price hours
# Results

Table 3. Regression results for negative pricing hours

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coefficient</td>
<td>Robust Std. Err.</td>
</tr>
<tr>
<td>PTC1</td>
<td>-7.8</td>
<td>7.7</td>
</tr>
<tr>
<td>PTC2</td>
<td>-6.5</td>
<td>4.5</td>
</tr>
<tr>
<td>lg(Wind generation)</td>
<td>-10.4</td>
<td>14.5</td>
</tr>
<tr>
<td>lg(Short-term load forecast error)</td>
<td>74.7*</td>
<td>33.4</td>
</tr>
<tr>
<td>lg(Day-ahead mid-term load forecast error)</td>
<td>11.1</td>
<td>16.9</td>
</tr>
<tr>
<td>Minimum generation event</td>
<td>26.2**</td>
<td>4.8</td>
</tr>
<tr>
<td>lg(Transmission outage)</td>
<td>4.6</td>
<td>11.6</td>
</tr>
<tr>
<td>constant</td>
<td>568</td>
<td>304</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.3844</td>
<td></td>
</tr>
</tbody>
</table>

* p<0.05, ** p<0.01
### Testing indirect effect

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>lg(Wind generation)</th>
<th>lg(Wind generation)</th>
<th>Negative Prices</th>
<th>Negative Prices</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTC1</td>
<td>-0.21**</td>
<td>0.07</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PTC2</td>
<td>-</td>
<td>-</td>
<td>-0.20*</td>
<td>0.10</td>
</tr>
<tr>
<td>lg(Short-term load forecast error)</td>
<td>1.34**</td>
<td>0.31</td>
<td>1.18**</td>
<td>0.31</td>
</tr>
<tr>
<td>lg(Day-ahead mid-term load forecast error)</td>
<td>-0.19</td>
<td>0.13</td>
<td>-0.22</td>
<td>0.14</td>
</tr>
<tr>
<td>Minimum generation event</td>
<td>0.05</td>
<td>0.09</td>
<td>0.03</td>
<td>0.08</td>
</tr>
<tr>
<td>lg(Transmission outage)</td>
<td>0.13</td>
<td>0.11</td>
<td>0.21*</td>
<td>0.10</td>
</tr>
<tr>
<td>Constant</td>
<td>14.27</td>
<td>2.43</td>
<td>12.65</td>
<td>2.35</td>
</tr>
<tr>
<td>R²</td>
<td>0.6814</td>
<td>0.6493</td>
<td>0.3779</td>
<td>0.3753</td>
</tr>
</tbody>
</table>

Wind generation → PTC → -0.21 → Negative Pricing
Case Study - Texas

- Largest wind producer in the U.S.
- 39.4 GWh in 2014
- 22% of national wind energy
- Over 10% of Texas electricity
Fewer wind curtailments and negative prices after grid expansion

Chart by EIA
Case Study – Iowa Lakers Electric Cooperative

- Iowa is the 2nd largest wind producer in the U.S.
- Iowa Lakes Electric is a non-profit distribution-only coop
- Owns 14 wind turbines with a total capacity of 21 MW
- The biggest installed wind capacity of any U.S. distribution-only coop

Chart by Iowa Lakers Electric Coop
Case Study – Germany’s energy storage

- Germany is the largest wind energy producer in Europe with 50.670 TWh electricity and 31,331.9 MW installed wind power net capacity
- *Huntorf compressed air energy storage plant (CASE)*
- CASE is the world’s first and still largest utility-scale compressed air storage plant
- Capacity: 321 MW
- Short rump up time - 6 minutes
Conclusions

- Current data is rather limited in estimating PTC’s impact on negative prices
- Negative pricing hours are positively correlated with load forecast errors and minimum generation events
- Case studies of high wind penetration regions suggest solutions for better wind integration: transmission expansion, efficient siting close to local demand centers, and energy storage