Relation between wind and electricity prices in a deregulated market: the case of Ireland

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TransAtlantic Infraday Conference, Washington DC

7 November 2014
Interaction between greater renewable generation and electricity prices

- Growing importance of renewables
- How does this affect consumers in the short run? (effect on prices)
- Look at actual (historic) results
Why Ireland?

- Main characteristics of Irish Single Electricity Market:
  - Compulsory market with capacity payments
    - System-wide data, publicly available on (half)hourly basis
  - Limited interconnection with other systems (i.e. GB)
    - Easier to identify effect of wind
  - Wind has grown from 900MW to almost 2100MW between 2008 and August 2012 (instantaneous penetration up to 50%)
The Irish electricity market: SEM

- Centrally dispatched pool market with capacity payments and uniform price
- Explicit bidding code of practice and Market Monitoring Unit
  - Generators bid SRMC
  - No strategic behavior in the spot market
  - Code of practice needed to avoid market power
    - Largest firm (incumbent) had 44% generation share in 2011
The Irish electricity market: SEM

- Day ahead: generators bid, System Operator defines merit order and dispatch
- Same day: adjustment for transmission congestion/system reliability/wind/demand
- All generators receive System Marginal Price (SMP = Shadow Price + Uplift)
  - Shadow Price: bid of marginal plant (MC)
  - Uplift: cost of turning on if marginal plant would otherwise make losses (start up + no load cost)
- Constraint payments for generators that are forced to deviate from dispatch (not addressed today)
Data

1. Most of the data come from SEM-o, the Single Electricity Market operator
2. Half-hourly data (aggregate to hourly) from 2008 to August 2012 on
   ■ Prices
      ▪ Shadow Price
      ▪ Uplift
   ■ Plant availability
3. System Operators:
   ■ Demand
   ■ Wind generation (actual, i.e. post curtailment)
4. Daily fuel prices (Reuters)
Shadow Price and fuels

Figure: Relation between shadow price and generation fuels, €/MWh

Fuels prices lagged 24 hours
Summary Statistics 2008-Aug2012

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obs</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>ShadowPrice (€/MWh)</td>
<td>40824</td>
<td>49.28</td>
<td>22.12113</td>
<td>0</td>
<td>494.56</td>
</tr>
<tr>
<td>Uplift (€/MWh)</td>
<td>40824</td>
<td>10.89</td>
<td>20.987</td>
<td>0</td>
<td>645.495</td>
</tr>
<tr>
<td>Gen. margin (MWh)</td>
<td>40824</td>
<td>3398.47</td>
<td>963.7736</td>
<td>286.9665</td>
<td>6339.784</td>
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<tr>
<td>Wind (MWh)</td>
<td>40824</td>
<td>447.34</td>
<td>370.21</td>
<td>1.68</td>
<td>1833.22</td>
</tr>
<tr>
<td>Load (MWh)</td>
<td>40824</td>
<td>4060.59</td>
<td>885.20</td>
<td>2163.78</td>
<td>6774.00</td>
</tr>
<tr>
<td>Gas price_{t-24} (€/MWh)</td>
<td>40824</td>
<td>19.87</td>
<td>5.88</td>
<td>4.62</td>
<td>32.14</td>
</tr>
<tr>
<td>Coal price_{t-24} (€/MWh)</td>
<td>40824</td>
<td>4.36</td>
<td>1.18</td>
<td>2.48</td>
<td>8.11</td>
</tr>
<tr>
<td>CO₂ price_{t-24} (€/MWh)</td>
<td>40824</td>
<td>12.59</td>
<td>6.39</td>
<td>0.01</td>
<td>24.95</td>
</tr>
</tbody>
</table>

Correlation Shadow Price vs Wind = -0.06
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Shadow Price

Shadow Price: Model choice

► Time Series analysis?
► No
  ► Generators bid once in the day-ahead (complex bidding)
  ► Bids valid for all periods in day
  ► Huisman, Huurman, and Mahieu (Energy Economics 2007), Weron (Energy Economics, 2008) suggest considering daily electricity prices as a series of 24 separate contracts
  ► However, there is correlation between hours
Shadow Price: Model choice

Aggregate data to hourly level

Estimate simultaneous system of equations
  ▶ residuals correlated across groups (hours of day)
  ▶ correction for autocorrelation within groups (AR1)

System of equations with $i = 1, \ldots, n, \ldots, 24$ (number of hours)
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Shadow Price: model

System of equations with $i = 1,...n,...24$ (number of hours)

$$P_{i,d} = \alpha_i + \sum_h \beta_i^h L_{i,d}^h + \gamma_i W_{i,d} + \sum_j \zeta_i^j F_{i,d-1}^j + \mu_i CO_{d-1} + \theta_i \text{mar}_{i,d} + \sum \kappa^s D^s_i + \epsilon_{i,d}$$

(1)

where

$P =$ shadow price
$L =$ demand
$W =$ wind
$F =$ fuel prices
$CO =$ $CO_2$ permit prices
$mar =$ generation margin
$D =$ dummy variables (month-year)
### Shadow Price: Results (select)

<table>
<thead>
<tr>
<th>Hour</th>
<th>$Load_H$</th>
<th>$Load_L$</th>
<th>Wind</th>
<th>$Gas_{d-1}$</th>
<th>Gen.Marg.</th>
<th>PStor·Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>n.a.</td>
<td>0.004**</td>
<td>-0.003**</td>
<td>0.830**</td>
<td>-0.002**</td>
<td>0.000</td>
</tr>
<tr>
<td>2</td>
<td>n.a.</td>
<td>0.006**</td>
<td>-0.003**</td>
<td>0.668**</td>
<td>-0.002**</td>
<td>-0.003**</td>
</tr>
<tr>
<td>3</td>
<td>n.a.</td>
<td>0.004**</td>
<td>-0.004**</td>
<td>0.814**</td>
<td>-0.002**</td>
<td>-0.005**</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.003*</td>
<td>0.002**</td>
<td>-0.005**</td>
<td>1.032**</td>
<td>-0.005**</td>
<td>0.003**</td>
</tr>
<tr>
<td>17</td>
<td>0.012**</td>
<td>0.002</td>
<td>-0.005**</td>
<td>1.291**</td>
<td>-0.006**</td>
<td>0.002</td>
</tr>
<tr>
<td>18</td>
<td>0.034**</td>
<td>-0.002</td>
<td>-0.010**</td>
<td>0.967</td>
<td>-0.012**</td>
<td>0.002</td>
</tr>
<tr>
<td>19</td>
<td>0.016**</td>
<td>-0.003</td>
<td>-0.004</td>
<td>3.353**</td>
<td>-0.011**</td>
<td>-0.007*</td>
</tr>
<tr>
<td>20</td>
<td>0.005</td>
<td>0.001</td>
<td>-0.004</td>
<td>1.073*</td>
<td>-0.009**</td>
<td>-0.006*</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Observations 31,056

** $p<0.01$, * $p<0.05$, based on z values
Average effect of wind

Wind coefficient, averaged across 24 hours, weighted by demand:

-0.0037

- Increasing wind generation by 100MWh → shadow price decreases by 0.9%
- Going from no wind to the average wind generation (482MWh) → shadow price decreases by 4.2%
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Uplift
Uplift: Model choice

1. Zero must be taken into account
2. Distribution of the uplift rightly skewed: negative binomial

Estimation by a two-parts hurdle model
Uplift: Model choice

\[
\begin{align*}
\text{Probability}(\text{uplift} > 0|\mathbf{X}) &= F(\mathbf{X}) \\
U_{\text{t}} &= G(\beta \mathbf{X}') + \epsilon \quad \text{if} \quad \text{uplift} > 0
\end{align*}
\]  \tag{2}

- Regressors in the **probit equation** are: $\Delta Wind$ and $\Delta Loads$.
- Regressors in the **poisson equation** are: loads, wind, system margin, fuel prices, seasonal dummies, TH and Moyle dummies.
Uplift: 1st part (prob uplift > 0)

1. Wind in difference is significant and negative (-.0014)
2. Loads in difference significant and positive (0.003)
3. Month-year dummies significant
### Uplift: 2nd part (marginal results)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loads (MWh)</td>
<td>0.0003**</td>
<td></td>
</tr>
<tr>
<td>Wind (MWh)</td>
<td>-0.0002**</td>
<td></td>
</tr>
<tr>
<td>Gen.Marg. (MWh)</td>
<td>-0.0001**</td>
<td></td>
</tr>
<tr>
<td>Gasprice €/MWh</td>
<td>-0.0238**</td>
<td>0.004</td>
</tr>
<tr>
<td>Coalprice €/MWh</td>
<td>0.094*</td>
<td>0.04</td>
</tr>
<tr>
<td>Moyle Outage dummy</td>
<td>-0.1649**</td>
<td>0.056</td>
</tr>
<tr>
<td>Tur.Hill Outage dummy</td>
<td>-0.1169**</td>
<td>0.031</td>
</tr>
<tr>
<td>Month-Year dummies</td>
<td>Yes**</td>
<td></td>
</tr>
<tr>
<td>N.Obs.</td>
<td>40,824</td>
<td></td>
</tr>
</tbody>
</table>

st. errors in parentheses. ** p<0.01, * p<0.05
Gas coefficients per hour, 2008-2012

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th></th>
<th>Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.007</td>
<td>13</td>
<td>0.006</td>
</tr>
<tr>
<td>2</td>
<td>-0.016</td>
<td>14</td>
<td>-0.006</td>
</tr>
<tr>
<td>3</td>
<td>0.007</td>
<td>15</td>
<td>-0.024</td>
</tr>
<tr>
<td>4</td>
<td>0.007</td>
<td>16</td>
<td><strong>-0.035</strong></td>
</tr>
<tr>
<td>5</td>
<td>-0.009</td>
<td>17</td>
<td>-0.029</td>
</tr>
<tr>
<td>6</td>
<td>-0.03</td>
<td>18</td>
<td>0.007</td>
</tr>
<tr>
<td>7</td>
<td><strong>-0.286</strong></td>
<td>19</td>
<td>0.002</td>
</tr>
<tr>
<td>8</td>
<td>0.015</td>
<td>20</td>
<td><strong>-0.042</strong></td>
</tr>
<tr>
<td>9</td>
<td>-0.006</td>
<td>21</td>
<td>-0.008</td>
</tr>
<tr>
<td>10</td>
<td>0.006</td>
<td>22</td>
<td>-0.008</td>
</tr>
<tr>
<td>11</td>
<td>-0.004</td>
<td>23</td>
<td>-0.005</td>
</tr>
<tr>
<td>12</td>
<td>-0.004</td>
<td>24</td>
<td>-0.021</td>
</tr>
</tbody>
</table>

Values in bold are statistically significant at 5%
Conclusions

Studied Single Electricity Market of Ireland:

- Little interconnection with other systems (at least up to 2012)
- Compulsory pool system (comprehensive data)
- Generators have to bid marginal cost
- Doubling of wind installed in 4 years analysed

Findings:

- Small but negative effect of wind generation on Shadow Price
- Negative effect of change in wind on prob uplift $> 0$
- Negative effect of wind on uplift, conditional on uplift being positive
Future Work

Future work: analyse effect of wind on constraint payments to generators.