Renewable Sources, Technology mix, and Competition in Liberalized Electricity Markets: The case of Spain

USAEE 2010, Calgary

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USAEE 2010 Conference

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Outline of the presentation

- Motivation
- Literature
- The Model
- Contingent scenarios and possible market results
- Spanish case
  1. Descriptive statistics
  2. Analysis
- Conclusions and further research
Motivation

- The use and exploitation of energy sources is growing and will continue to do so in the near future.
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1. Is the electricity market ready to *incorporate* renewables?
2. Is the regulatory framework well-defined?
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Open Issues:

1. Is the electricity market ready to incorporate renewables?
2. Is the regulatory framework well-defined?
3. What about the short-run perspectives? and in the long-run?
Policy mechanisms to support renewable sources within EU members are focused mainly on financial instruments:

- Price-based systems (Germany, France, Spain and Denmark which apply feed-in tariffs).
Motivation, III

- Quota-based systems,

\[ Q_{Ra} + Q_{Rb} = \hat{Q} \]

Quota-based system


The model

- Two firms generate electricity by using two inputs: non-renewables sources, $F$; and renewables sources, $R$.
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- Firms minimize costs in each plant:
  
  Fossil plant \( \begin{align*}
    \text{MIN} & \quad c_F F + \Omega \\
    \text{s.t.} & \quad F^\alpha = q_i^F,
  \end{align*} \)
  
  Renewable plant \( \begin{align*}
    \text{MIN} & \quad c_R R + \Omega \\
    \text{s.t.} & \quad [R/\phi(e)]^\alpha = q_i^R,
  \end{align*} \)

  \( \phi(e) \in \mathbb{R} \) specifies technical maturity, with \( \phi(0) = 1 \), and \( \phi'(e) < 0 \).
The model, II

- Cost function: \( C_i(q_i) = c_F \cdot (q_i^F)^2 + c_R \cdot \phi(e) (q_i^R)^2, \ i = 1, 2. \)
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- Cost function: \( C_i(q_i) = c_F \cdot (q_i^F)^2 + c_R \cdot \phi(e) \cdot (q_i^R)^2, \quad i = 1, 2. \)

- The total amount of electricity produced: \( \sum_{j=F,R} \sum_{i=1,2} q_i^j = Q. \)
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Regulator incentives each kWh from renewables with \( 0 < \tau < 1; \) then total payment is \( \omega(1 + \tau). \)
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- Regulator incentives each kWh from renewables with \( 0 < \tau < 1; \) then total payment is \( \omega(1 + \tau). \)
- **Firms submit supply functions for each type**
  \( S_i(\beta_i) = \beta_i^F \omega + \beta_i^R \omega(1 + \tau), \ i = 1, 2. \) where \( \beta_i = (\beta_i^F, \beta_i^R), \ i = 1, 2. \)
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Market clearing condition \( \sum_{i=1,2} S_i(\beta_i) = D(\omega), \)

\[
\omega(\beta) = \frac{1}{1 \cdot p' + \sum_{i=1,2} \beta_i \cdot p'},
\]

where \( \beta = (\beta_1, \beta_2) \) and \( p = [1, (1 + \tau)]. \)
(β^{SN}_i, β^{SN}_j) is a SN equilibrium such that each firm is maximizing profits
β^{SN}_i ∈ \arg \max_{\omega_i} \pi_i(\beta_i) - C_h(\beta_i, \omega_i(\beta)), \text{ for } i, j = 1, 2, i \neq j.
### Definition

$(\beta_i^{SN}, \beta_j^{SN})$ is a SN equilibrium such that each firm is maximizing profits

\[ \beta_i^{SN} \in \arg \max_{\beta_i} S_i(\beta_i)\omega(\beta) - C_h(\beta_i\omega(\beta)), \text{ for } i, j = 1, 2, \ldots, i \neq j. \]

- Each firm chooses its profit-maximizing SN strategy, $\beta_i^{SN}$

\[ \max_{\beta_i} S_i(\beta_i)\omega(\beta) - C_h(\beta_i\omega(\beta)) \]

**Assumption:** normalize $c_R = 1 \implies c_F$ and $\phi(e)$ measures differences in marginal costs.

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The model, III

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- Equilibrium quantity and prices:
  \[
  \hat{q}_{i}^{F} = \hat{q}_{i}^{R}(1 + \tau) - \frac{\phi(e) - 4\tau - c_{F}}{4\theta}, \quad \hat{q}_{i}^{R} = \frac{\theta + 2\tau - c_{F}}{4\theta(1 + \tau)}, \quad \hat{\omega} = \frac{\phi(e) + c_{F}}{2\theta},
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Definition

\((\beta_i^{SN}, \beta_j^{SN})\) is a SN equilibrium such that each firm is maximizing profits \(\beta_i^{SN} \in \arg \max_{\beta_i} S_i(\beta_i)\omega(\beta) - C_h(\beta_i\omega(\beta))\), for \(i, j = 1, 2, \ldots, i \neq j\).

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\]

- Equilibrium profits:

\[
\hat{\pi}_i = \frac{(\phi(e) + c_F)(2\theta - \phi(e) - c_F)}{8\theta^2} - \frac{c_F(\phi(e) + 2\tau - \theta)^2}{32\theta^2} - \frac{\phi(e)(2\tau + \theta - c_F)^2}{32\theta^2(1+\tau)^2}
\]

\(\theta(\phi(e), c_F, \tau), \theta_{\phi(e)} > 0, \theta_\tau > 0, \text{ and } \theta_{c_F} < 0\)
Contingent scenarios and possible market results

Consider these three cases:

- **Scenario 1: Status quo**: $\phi(e) > c_F$.
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- **Scenario 2: Efficiency improvement to equal marginal cost:**
  
  $\phi(e) = c_F$.

General result: regardless the scenario considered the model states

1. $\frac{\partial}{\partial \tau} \left( \frac{b_q F_i}{b_q R_i} \right) < 0$; the ratio $\frac{b_q F_i}{b_q R_i}$ is decreasing in the subsidy.
2. $\frac{\partial}{\partial \tau} (b Q) < 0$; total electricity produced decreases with the subsidy;
3. $\frac{\partial}{\partial \tau} (b \omega) < 0$; wholesale price decreases with the subsidy.
Contingent scenarios and possible market results

Consider these three cases:

- **Scenario 1:** Status quo: $\phi(e) > c_F$.
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- **Scenario 3:** Renewables technical maturity above fossil sources: $\phi(e) < c_F$.

General result: regardless the scenario considered the model states:

1. $\frac{\partial (b_Q F_i b_Q R_i)}{\partial \tau} < 0$; the ratio $b_Q F_i / b_Q R_i$ is decreasing in the subsidy.
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**General result**: regardless the scenario considered the model states that,

\[ \frac{\partial}{\partial \tau} \left( \frac{b q_F}{b q_R} \right) < 0; \text{the ratio} \frac{b q_F}{b q_R} \text{is decreasing in the subsidy}; \]
\[ \frac{\partial}{\partial \tau} \left( b Q \right) < 0; \text{total electricity produced decreases with the subsidy}; \]
\[ \frac{\partial}{\partial \tau} \left( b \omega \right) < 0; \text{wholesale price decreases with the subsidy}. \]
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**General result**: regardless the scenario considered the model states that,

\[ \frac{\partial (\hat{q}_i^F / \hat{q}_i^R)}{\partial \tau} < 0; \] the ratio \( \hat{q}_i^F / \hat{q}_i^R \) is decreasing in the subsidy.
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**General result**: regardless the scenario considered the model states that,

1. \( \partial (\frac{\hat{q}_i^F}{\hat{q}_i^R}) / \partial \tau < 0 \); the ratio \( \frac{\hat{q}_i^F}{\hat{q}_i^R} \) is decreasing in the subsidy.
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3. $\partial(\hat{\omega}) / \partial \tau < 0$; wholesale price decreases with the subsidy.
Scenario 1

\[ \phi(e) = \frac{1}{1+e}, \quad c_F = \frac{3}{2} \text{ and } \tau \in \{0, 0.25\} \]

- Status quo: \( \phi(e) > c_F \). \( e = -\frac{1}{2} \implies \phi(-\frac{1}{2}) = 2 \)

| Table 1. Simulation for \( e = -1/2 \). |
|---|---|---|---|---|
| \( \pi_i^{SN} \) | \( (q_i^F)^{SN} \) | \( (q_i^R)^{SN} \) | \( Q^{SN} \) | \( \omega^{SN} \) |
| \( \tau = 0 \) | .085 | .165 | .124 | .578 | .422 |
| \( \tau = 0.25 \) | .089 | .140 | .125 | .530 | .405 |
Scenario 2

\[ \phi(e) = \frac{1}{1 + e}, \quad c_F = 3/2 \text{ and } \tau \in \{0, 0.25\} \]

- Equal marginal cost: \( \phi(e) = c_F \). \[ e = \frac{1}{c_F} - 1 < 0 \implies \phi\left(\frac{1}{c_F} - 1\right) = 3/2. \]

| Table 2. Simulation for \( e = \left(\frac{1}{c_F}\right) - 1 \). |
|-----------------|-----------------|-----------------|-----------------|-----------------|
|                | \( \pi_i^{SN} \) | \( (q_i^F)^{SN} \) | \( (q_i^R)^{SN} \) | \( Q^{SN} \) | \( \omega^{SN} \) |
| \( \tau = 0 \) | .085            | .150            | .150            | .600            | .400            |
| \( \tau = 0.25 \) | .089            | .123            | .149            | .544            | .381            |
Scenario 3

\[ \phi(e) = \frac{1}{1 + e}, \quad c_F = 3/2 \text{ and } \tau \in \{0, 0.25\} \]

- RES technical maturity above fossil sources: \( \phi(e) < c_F \).
- \( e \in \{0, 1/2\} \implies \phi(0) = \{1, 2/3\} \).

### Table 3. Simulation for \( e = 0 \).

<table>
<thead>
<tr>
<th>( \pi^S N_i )</th>
<th>( (q^F_i)^S N )</th>
<th>( (q^R_i)^S N )</th>
<th>( Q^S N )</th>
<th>( \omega^S N )</th>
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</thead>
<tbody>
<tr>
<td>( \tau = 0 )</td>
<td>.084</td>
<td>.127</td>
<td>.191</td>
<td>.636</td>
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<tr>
<td>( \tau = 0.25 )</td>
<td>.088</td>
<td>.097</td>
<td>.185</td>
<td>.564</td>
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</table>

### Table 4. Simulation for \( e = 1/2 \).

<table>
<thead>
<tr>
<th>( \pi^S N_i )</th>
<th>( (q^F_i)^S N )</th>
<th>( (q^R_i)^S N )</th>
<th>( Q^S N )</th>
<th>( \omega^S N )</th>
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</thead>
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<tr>
<td>( \tau = 0 )</td>
<td>.082</td>
<td>.103</td>
<td>.235</td>
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<td>( \tau = 0.25 )</td>
<td>.085</td>
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## Spanish case. Descriptive analysis

- Electricity traded by technologies,

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<tr>
<th>Special Regime</th>
<th>Thermal Distr. Pool</th>
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<th>NU</th>
<th>CB</th>
<th>CC</th>
<th>OF</th>
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<td>05</td>
<td>25,8</td>
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<td>06</td>
<td>6,1</td>
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<td>69,7</td>
<td>53,9</td>
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<td>274,5</td>
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<tr>
<td>08</td>
<td>0</td>
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<td>6,79</td>
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<td>43,5</td>
<td>82,0</td>
<td>4,39</td>
<td>279,8</td>
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</table>

Spanish case. Descriptive analysis, II

Iberdrola and Endesa are pivotal firms in generation.

<table>
<thead>
<tr>
<th>Firm</th>
<th>2002</th>
<th>2008</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>% hours</td>
<td>From RES</td>
</tr>
<tr>
<td></td>
<td>Hy</td>
<td>Non-hy</td>
</tr>
<tr>
<td>IB</td>
<td>42.5</td>
<td>40.1</td>
</tr>
<tr>
<td>Peak IB</td>
<td>72.5</td>
<td>71.8</td>
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<tr>
<td>Off-Peak IB</td>
<td>10.9</td>
<td>6.5</td>
</tr>
<tr>
<td>EN</td>
<td>23.4</td>
<td>7.2</td>
</tr>
<tr>
<td>Peak EN</td>
<td>12.3</td>
<td>11.6</td>
</tr>
<tr>
<td>Off-Peak EN</td>
<td>36.4</td>
<td>0</td>
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</tbody>
</table>
Iberdrola has larger renewable power generation than Endesa

Table 7. Generators’ Capacity (GW)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HY</td>
<td>5.2</td>
<td>5.3</td>
<td>8.5</td>
<td>8.6</td>
<td>1.8</td>
<td>1.8</td>
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<tr>
<td>RES</td>
<td>0.2</td>
<td>2.9</td>
<td>0.1</td>
<td>5.5</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Total RES</td>
<td>5.4</td>
<td>8.2</td>
<td>8.7</td>
<td>14.1</td>
<td>1.8</td>
<td>2.8</td>
</tr>
<tr>
<td>NU</td>
<td>3.6</td>
<td>3.6</td>
<td>3.3</td>
<td>3.3</td>
<td>0.7</td>
<td>0.7</td>
</tr>
<tr>
<td>CB</td>
<td>5.8</td>
<td>5.8</td>
<td>1.2</td>
<td>1.3</td>
<td>2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>OF</td>
<td>1.5</td>
<td>1.3</td>
<td>2.0</td>
<td>2.0</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>CC</td>
<td>1.4</td>
<td>2.4</td>
<td>3.2</td>
<td>6.0</td>
<td>2.1</td>
<td>4.0</td>
</tr>
<tr>
<td>Total FOSSIL</td>
<td>12.3</td>
<td>13.1</td>
<td>9.7</td>
<td>12.5</td>
<td>5.8</td>
<td>7.5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>17.7</td>
<td>21.6</td>
<td>18.4</td>
<td>26.6</td>
<td>7.5</td>
<td>10.3</td>
</tr>
</tbody>
</table>

Sources: Firms’ web pages, REE, and OMEL.
Islands not included. Provisional values for 2008.
Market shares in generation EN and IB

Table 8.- Market shares

<table>
<thead>
<tr>
<th></th>
<th>IB</th>
<th>EN</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>0.43</td>
<td>0.30</td>
</tr>
<tr>
<td>2008</td>
<td>0.25</td>
<td>0.20</td>
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</table>
### Table 9 - Summary statistics of variables

<table>
<thead>
<tr>
<th>Dep. Variable</th>
<th>Mean</th>
<th>Std. dev.</th>
<th>min</th>
<th>max</th>
</tr>
</thead>
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<td>29.51</td>
<td>18.97</td>
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<td>180.3</td>
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<tr>
<td>Indep. Variables</td>
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<td></td>
<td></td>
<td></td>
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<td>NU</td>
<td>6419</td>
<td>926</td>
<td>3176</td>
<td>7560</td>
</tr>
<tr>
<td>TH</td>
<td>13619</td>
<td>4082</td>
<td>1382</td>
<td>26539</td>
</tr>
<tr>
<td>HY</td>
<td>3522</td>
<td>2520</td>
<td>4.5</td>
<td>16450</td>
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<tr>
<td>RES</td>
<td>5916</td>
<td>2207</td>
<td>2151</td>
<td>17943</td>
</tr>
</tbody>
</table>

Source: OMEL, CNE and own calculations
### Spanish case. Analysis

<table>
<thead>
<tr>
<th>Table 9 - Summary statistics of variables</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dep. Variable</strong></td>
</tr>
<tr>
<td>SMP</td>
</tr>
<tr>
<td>Skewness 1.087  Kurtosis 5.597  Sktest Reject  J-B Test Reject  ADF test I (0)</td>
</tr>
<tr>
<td>Indep. Variables</td>
</tr>
<tr>
<td>NU</td>
</tr>
<tr>
<td>Skewness -0.737  Kurtosis 3.649  Sktest Reject  J-B Test Reject  ADF test I (0)</td>
</tr>
<tr>
<td>TH</td>
</tr>
<tr>
<td>Skewness 0.114  Kurtosis 2.735  Sktest Reject  J-B Test Reject  ADF test I (0)</td>
</tr>
<tr>
<td>HY</td>
</tr>
<tr>
<td>Skewness 0.987  Kurtosis 3.705  Sktest Reject  J-B Test Reject  ADF test I (0)</td>
</tr>
<tr>
<td>RES</td>
</tr>
<tr>
<td>Skewness 1.269  Kurtosis 4.984  Sktest Reject  J-B Test Reject  ADF test I (0)</td>
</tr>
</tbody>
</table>

Source: OMEL, CNE and own calculations
Behavior of the SMP depends on
Behavior of the SMP depends on

- Past values of the SMP: Existence of autocorrelation within the day
Behavior of the SMP depends on
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- Declared capacity of the plants the day before.
Behavior of the SMP depends on

- Past values of the SMP: Existence of autocorrelation within the day
- Declared capacity of the plants the day before.

Model:

\[
\ln SMP_t = \alpha + \sum_{\tau=1}^{23} \beta_\tau \ln SMP_{t-\tau} +
\gamma_1 K_{t-24}^N + \gamma_2 K_{t-24}^{TH} + \gamma_3 K_{t-24}^{HY} + \gamma_4 K_{t-24}^{RES} + \Phi \cdot REG_t + \varepsilon_t
\]
Step 1: OLS estimation. Ljung-Box test does not reject the hypothesis of the existence of arch-effects. A garch model can be fitted.
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Estimation results:

<table>
<thead>
<tr>
<th>Estimation from two alternative models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Nu</td>
</tr>
<tr>
<td>Th</td>
</tr>
<tr>
<td>Hy</td>
</tr>
<tr>
<td>RES</td>
</tr>
</tbody>
</table>

ARCH effects 1 24
Reg. Dummies NO YES
Log likelihood -55563 -59586

***Significant at 1%. * Significant at 10%
Conclusions and further research

- Fossil resources are scarce, produced at high prices, and cause environmental problems that make the actual electric technology mix unsustainable.

IEA predictions over renewable energy increments depend on country-specific policies. The OECD area is expected to lead the 'renewable sources revolution' by means of policy suggestions to the member states. The special regime must encourage trading renewable energy at the pool in order to increase efficiency. Increasing the share of renewable sources strongly depends on subsidies and technological innovations. Preliminary estimation results for the period 2002-2008 show how market prices are higher when the share of hydroelectricity is higher. Although result depends on controls.
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Further research: improve model predictions and empirical insights.
Thanks for attention

Comments are welcome,...