Estimating the Volatility of Electricity Prices: The Case of the England and Wales Wholesale Electricity Market

Sherzod Tashpulatov

CERGE-EI

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General Introduction  Liberalization of Electricity Industry

Fig. 1: Structure of a Network Industry before and after Liberalization

(a) Vertically Integrated Case

(b) Vertically Separated Case
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Fig. 2: Description of the Electricity Industry in Great Britain

Producers

National Power  PowerGen  AES  EdF

Network Infrastructure and Wholesale Market
(both operated by the National Grid Company in England and Wales)

Network Infrastructure

ELECTRICITY POOL

Retail Suppliers

Regional Electricity Companies (12 RECs)  Other Licensed Suppliers

Customers

Small Customers  "Franchise Market"  Large Customers  "Competitive Market"

England & Wales

Exporters

Small Customers  "Franchise Market"  Large Customers  "Competitive Market"

Scottish Power and Scottish Hydro-Electric

Scottish Nuclear Power

Other Licensed Suppliers
General Introduction  Liberalization of Electricity Industry

- The Key Question to Analyze Liberalization
  - Do liberalized markets drive price volatility?

- Case Study
  - Wholesale electricity market in England and Wales
General Introduction  Liberalization of Electricity Industry

- Motivation

Fig. 3: Daily Electricity Prices (April 1, 1990–March 26, 2001)
**General Introduction**  Liberalization of Electricity Industry

**Institutional Changes and Regulatory Reforms**

- **Creation of Wholesale Electricity Market**
- **End of Coal Contracts**
- **Start of Price-Cap Regulation**
- **End of Price-Cap Regulation**

<table>
<thead>
<tr>
<th>Regime 1</th>
<th>Regime 2</th>
<th>Regime 3</th>
<th>Pre-Regime 4</th>
</tr>
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<tbody>
<tr>
<td>April 1, 1990</td>
<td>April 1, 1993</td>
<td>April 1, 1994</td>
<td>April 1, 1996</td>
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</tbody>
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- **Restructure of Wholesale Electricity Market**
- **Divestment 1**
- **Divestment 2**

<table>
<thead>
<tr>
<th>Pre-Regime 4</th>
<th>Regime 4</th>
<th>Regime 5</th>
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<tbody>
<tr>
<td>July 1996</td>
<td>July 1999</td>
<td>March 26, 2001</td>
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- **Divestment 2**
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**Paper**  Estimating the Volatility of Electricity Prices

- Motivation

**Policy Importance**

- Price fluctuations:
  - uncertainty about revenues and costs
  - higher electricity prices for consumers

**Research Question**

- How did the institutional changes and regulatory reforms affect the dynamics of electricity prices during the liberalization process?

**Research Approach**

- stationarity and seasonality
- \(AR-ARCH\) model with a smoothly time-varying intercept term
Paper Estimating the Volatility of Electricity Prices

- Literature Review

- Crespo et al. (2004)
  AR, ARMA models: separate studies of each hour yielded better forecasts

- Guthrie and Videbeck (2007)
  30-min prices from the New Zealand Electricity Market (Nov. 1, 1996–Apr. 30, 2005)
  Half-hourly trading periods naturally fall into 5 groups, which can be studied separately using a periodic AR model

- Huisman et al. (2007)
  The Amsterdam Power Exchange (APX), the European Energy Exchange (EEX; Germany), and the Paris Power Exchange (PPX) for the year 2004
  Hourly electricity prices are treated as a panel in which hours represent cross-sectional units and days represent the time dimension. SUR is applied
Literature Review (cont.)

- **Conejo et al. (2005)**
  PJM interconnection data for the year 2002
  Dynamic modeling is preferred to seasonal differencing

- **Garcia et al. (2005)**
  $GARCH$ model outperforms a general $ARIMA$ model when volatility and price spikes are present

- **Bosco et al. (2007)**
  Daily prices from the Italian wholesale electricity market
  Periodic $AR-GARCH$ methodology
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- Seasonality: Time Domain Analysis

Fig. 4: Correlogram for Daily Electricity Prices
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- Seasonality: Frequency Domain Analysis

**Fig. 5: Periodogram for Daily Electricity Prices**
Estimating the Volatility of Electricity Prices

- Regression Model

\[
\text{price}_t = a_0 + \sum_{i=1}^{P} a_i \text{price}_{t-i} + z'_t \cdot \gamma + \varepsilon_t \tag{1}
\]

\[
h_t = \alpha_0 + \sum_{i=1}^{P} \alpha_i \varepsilon^2_{t-i} + z'_t \cdot \delta \tag{2}
\]

\[
\nu_t = \frac{\varepsilon_t}{\sqrt{h_t}} \sim \text{Generalized Normal Distribution}, \tag{3}
\]

where \( z_t \) is a vector of additional explanatory variables including the sine/cosine periodic functions and regime dummy variables.

- Methodological findings:
  - The sine/cosine periodic functions allow better modeling weekly seasonality
  - + and − shocks from the previous week are found to asymmetrically affect volatility
Estimating the Volatility of Electricity Prices

- Empirical Distribution

Fig. 6: *Density of $\hat{\nu}_t$ and the Normal Distribution*
Diagnostics of standardized residuals

Fig. 7: Ljung–Box Q-Test for Standardized Residuals $\hat{\nu}_t$ and $\hat{\nu}_t^2$
Results

Fig. 8: Impact on Price and Volatility Dynamics

(a) Mean Equation

(b) Conditional Volatility Equation
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- Contributions

- Methodological contribution
  - Application of the sine and cosine periodic functions allow better modeling weekly seasonality
  - + and − shocks from the previous week are found to asymmetrically affect volatility

- Policy contribution
  - The price-cap regulation and first series of divestments are found to result in opposite directions for the movement in the price level and volatility
  - Higher price and lower volatility levels are interpreted as an indication of possible tacit collusion
  - During the last regime period it was possible to simultaneously decrease prices and volatility
Thank You
The Fourier transform of a real-valued function $p(t)$ on the domain $[0, T]$ is defined as

$$F(i \omega) = \mathcal{F}\{p(t)\} = \int_0^T p(t) \cdot e^{-i\omega t} \, dt$$

$$|F(i \omega_k)| \approx \left| \sum_{t=0}^{T-1} p_t \cdot e^{-i\omega_k t} \right| = \left| \sum_{t=0}^{T-1} p_t \cdot (\cos \omega_k t - i \sin \omega_k t) \right| =$$

$$= \left| \sum_{t=0}^{T-1} p_t \cdot \cos \omega_k t - i \sum_{t=0}^{T-1} p_t \cdot \sin \omega_k t \right| =$$

$$= \left| (p_t, \cos \omega_k t) - i (p_t, \sin \omega_k t) \right| \rightarrow \max_{\omega_k}$$

where $\omega_k = \frac{k}{N-1} \cdot 2\pi$ and $k = 0, 1, 2, \ldots, N - 1$. 
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- Generalized Normal Distribution

Fig. 9: Generalized Normal Distribution for Different Values of the Shape Parameter $\beta$

Notes:
Generalized Normal Distribution is also known as Generalized Error Distribution: Error($\mu$, $\sigma$, $\beta$).
In our case we have $\mu = 0$ and $\sigma^2 = 1$. For the special cases of the shape parameter $\beta = 1$, $\beta = 2$, and $\beta \to +\infty$ we obtain Laplace, Standard Normal, and Uniform distributions, respectively.