A Regression Model of Natural Gas/Wholesale Electricity Price Relationship and Its Application for Detecting Potentially Anomalous Electricity Prices

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*The views set forth in this presentation are those of the authors and do not necessarily represent the views of the Federal Energy Regulatory Commission
Motivations

1. Estimate the effects of gas prices on wholesale electric prices in the Northeast region (New England, New York, PJM), and test whether the effect of gas prices on power prices has changed over time in the Northeast region.

2. Develop an initial screening tool (econometric model) for the detection of potentially anomalous electric pricing behavior/market outcomes.
Part I

Pricing Relationships between Natural Gas & Wholesale Electricity Price in the Northeast
As a starting point, we model electric price as follows:

Electric Price = f(Gas Price, Temperature, Seasonal Effects, Disturbances)
Data

- Sample period
  - New York: Year 2001 - 2003
- Electric price
  - Daily weekday bilateral spot peak price (source: Megawatt Daily)
- Natural gas price
  - Daily weekday bilateral spot price (source: Gas Daily)
- Average temperature
  - Daily average temperature (source: EarthSat)
- Electric/gas prices are inflation-adjusted using GDP deflator (base year: 1st quarter, 2004)
## Electric price, gas price, & temperature pairs

<table>
<thead>
<tr>
<th>Region</th>
<th>Electric Price</th>
<th>Gas Price</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>New England</strong></td>
<td>NEPOOL /Mass Hub</td>
<td>Algonquin City gate</td>
<td>Boston</td>
</tr>
<tr>
<td><strong>New York</strong></td>
<td>NYPP ZONE G</td>
<td>Transco Z6 NY</td>
<td>New York City</td>
</tr>
<tr>
<td><strong>PJM</strong></td>
<td>PJM-West</td>
<td>Transco Z6 Non-NY</td>
<td>Philadelphia</td>
</tr>
</tbody>
</table>
Electric Regions with Pricing Nodes On-Peak Prices ($/MWh)

- Prices 2004
- Prices 2003
- Percentage change
Regression Model Specifications & Estimation Method

Electric Price

\[ \text{Electric Price} = b_0 + b_1 \text{Gas price 2000} + b_2 \text{Gas price 2001} + b_3 \text{Gas price 2002} + b_4 \text{Gas price 2003} + b_5 T\text{mean} + b_6 T\text{mean}^2 + \text{Summer Dummy} + b_7 \text{Year 2000} + b_8 \text{Year 2001} + b_9 \text{Year 2002} + \text{Disturbances} \]

After removing significant outliers, the model is estimated applying an estimator that is robust to serial correlation & heteroskedasticity (Newey-West Estimator).
Regression Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>New_England</th>
<th>PJM</th>
<th>New_York</th>
</tr>
</thead>
<tbody>
<tr>
<td>gas_2000</td>
<td>5.9354***</td>
<td>3.2080***</td>
<td>5.7871***</td>
</tr>
<tr>
<td>gas_2001</td>
<td>5.9252***</td>
<td>4.0657***</td>
<td>8.7318***</td>
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<tr>
<td>gas_2002</td>
<td>6.9910***</td>
<td>4.8975***</td>
<td>5.4251***</td>
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<tr>
<td>gas_2003</td>
<td>6.2267***</td>
<td>4.4516***</td>
<td>5.4251***</td>
</tr>
<tr>
<td>tmean</td>
<td>-1.1859***</td>
<td>-1.4540***</td>
<td>-1.2317***</td>
</tr>
<tr>
<td>tmean²</td>
<td>0.0162***</td>
<td>0.0167**</td>
<td>0.0149***</td>
</tr>
<tr>
<td>dsummer</td>
<td>-7.6257***</td>
<td>-6.2656***</td>
<td>-3.8133**</td>
</tr>
<tr>
<td>year2000</td>
<td>6.9817</td>
<td>4.8380</td>
<td></td>
</tr>
<tr>
<td>year2001</td>
<td>3.9722</td>
<td>0.7598</td>
<td>-2.2457</td>
</tr>
<tr>
<td>year2002</td>
<td>-1.9715</td>
<td>-3.9747</td>
<td>-14.3497***</td>
</tr>
<tr>
<td>Constant</td>
<td>33.9725***</td>
<td>45.4450***</td>
<td>45.6413***</td>
</tr>
<tr>
<td>R²</td>
<td>0.71</td>
<td>0.63</td>
<td>0.74</td>
</tr>
<tr>
<td>N</td>
<td>1020</td>
<td>1005</td>
<td>736</td>
</tr>
</tbody>
</table>

legend: * p<.1; ** p<.05; *** p<.01
Findings

- The regression results indicate that the marginal effect of gas prices on wholesale electric prices in the Northeast has remained roughly constant over the last several years, with an exception of New York in 2002.
- The lower marginal effect of gas prices in PJM is likely to reflect the differences in generation mix in the region.
Part II

Detection of Potentially Anomalous Wholesale Electricity Prices

- A Case for Western Electricity Prices in 2005 -
Approach

- Take into account time-varying volatility
- Model serial correlation explicitly
- Estimate the model using 2003 – 2004 data
- Compare actual electricity prices with ex-post predicted prices for out-of-sample period to detect potential anomalies in 2005
The Model (GARCH (1,1))

\[
p_{t}^{Electric} = \beta_0 + \beta_1 P_t^{Gas} + \beta_2 T \max_t + \beta_3 T \max_t^2 + u_t
\]

\[
u_t = \rho_1 u_{t-1} + \rho_2 u_{t-2} + \rho_5 u_{t-5} + \epsilon_t
\]

\[
Variance \ (\sigma_t^2) = \omega + \theta \epsilon_{t-1}^2 + \lambda \sigma_{t-1}^2
\]
Electric price, gas price, & temperature pair

<table>
<thead>
<tr>
<th>Electric Price ($/MWh)</th>
<th>Palo Verde</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Price ($/MMBtu)</td>
<td>SoCal Border</td>
</tr>
<tr>
<td>Temperature (degrees F)</td>
<td>Phoenix</td>
</tr>
</tbody>
</table>
2004 Locational Natural Gas Prices

Pricing Point
Current Price
1-year price differential
This year - last year

- NW Sumas: $5.15, $0.46
- Malin: $5.35, $0.45
- PG&E Citygate: $5.75, $0.52
- SoCal Border: $5.51, $0.43
- El Paso San Juan: $5.18, $0.62
- Kern River Opal: $5.19, $0.88
- El Paso Permian: $5.34, $0.28
- Panhandle Tex-Okla: $5.45, $0.28
- AECO Hub: $5.04, $0.33
- Chicago Citygate: $5.85, $0.30
- Michigan City: $5.21, $0.22
- Tepco M-1: $5.42, $0.38
- Tennessee Zone 6: $5.64, $0.38
- Henry Hub: $5.85, $0.41
- Waha Hub: $5.38, $0.21
- Katy Hub: $5.67, $0.31
- Tetco M-1: $5.93, $0.38
- Columbia Pool: $6.14, $0.45
- Transco Zone 6 - NY: $6.81, $0.36
- Niagara: $6.20, $0.26
- Algonquin Citygate: $6.86, $0.34

The diagram illustrates the locational natural gas prices across various pricing points in the United States, showing the current prices and the 1-year price differential for this year compared to last year.
Dependent Variable: Palo Verde Electricity Price
Method: ML - ARCH (Marquardt) - Generalized error distribution (GED)
Included observations: 431 after adjustments

\[
GARCH = C(8) + C(9)*\text{RESID}(-1)^2 + C(10)*\text{GARCH}(-1)
\]

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>Std. Error</th>
<th>z-Statistic</th>
<th>Prob.</th>
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</thead>
<tbody>
<tr>
<td>C</td>
<td>35.44414</td>
<td>7.517003</td>
<td>4.715195</td>
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<tr>
<td>SOCAL_GAS</td>
<td>7.634210</td>
<td>0.477091</td>
<td>16.00160</td>
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<tr>
<td>PHOENIX_TEMP_MAX</td>
<td>-0.806452</td>
<td>0.152229</td>
<td>-5.297611</td>
<td>0.0000</td>
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<tr>
<td>PHOENIX_TEMP_MAX_SQ</td>
<td>0.005233</td>
<td>0.000897</td>
<td>5.836537</td>
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<tr>
<td>AR(1)</td>
<td>0.532615</td>
<td>0.050129</td>
<td>10.62488</td>
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<td>AR(2)</td>
<td>0.150017</td>
<td>0.051938</td>
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<td>AR(5)</td>
<td>0.180722</td>
<td>0.037386</td>
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<tr>
<td></td>
<td>Variance Equation</td>
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<tr>
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<td>-------------------</td>
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<tr>
<td></td>
<td>C</td>
<td>0.625941</td>
<td>0.343346</td>
<td>1.823061</td>
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<tr>
<td>RESID(-1)^2</td>
<td>0.191035</td>
<td>0.049480</td>
<td>3.860856</td>
<td>0.0001</td>
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<tr>
<td>GARCH(-1)</td>
<td>0.767920</td>
<td>0.059821</td>
<td>12.83686</td>
<td>0.0000</td>
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<tr>
<td><strong>GED PARAMETER</strong></td>
<td>1.465247</td>
<td>0.145364</td>
<td>10.07988</td>
<td>0.0000</td>
</tr>
</tbody>
</table>

R-squared 0.839905  
Adjusted R-squared 0.836093  
S.E. of regression 3.529652  
Durbin-Watson stat 1.775384
Deviations (Actual - Expected Electric Price) & Time-Varying Volatility at Palo Verde (March 19, 2003 - September 12, 2005)

Sample Period (2003 - 2004)

Out of Sample Period

Deviation ($/MWh)

Date

Deviation (Index - Estimated Price) — Garch +3 SD
Detecting Outliers (Price at Risk)

- If disturbance is normally distributed, 
  \( P(\text{deviation}>3\times\text{GARCH standard deviation}) = 0.135\% \text{ or less (0.35 day or less/250 days)} \)
- If we use Standardized Residuals without normality assumption, 
  \( P(\text{deviation}>3\times\text{GARCH standard deviation}) = 0.908\% \text{ or less (2.27 days or less/250 days)} \)
- As of September 12, 2005, we observed 2 days during which deviation (actual – predicted price) exceeded 3\*GARCH standard deviation (July 6, August 24)
GARCH Model's Standardized Residuals vs Normal(0, 1)
Next Steps

- Apply the GARCH model to the Northeast electric markets
- Explore and include other relevant explanatory variables to the model (e.g., oil price, generator availability, transmission constraints?)
- Model jump-diffusion behavior of electricity price?
- Any other suggestions for refining the model as a market-wide screening tool for the detection of potentially problematic electricity pricing behavior?