Seasonality and Weather Effects on Electricity Loads: Modeling and Forecasting

Christian Crowley and Frederick L. Joutz
Department of Economics and Research Program on Forecasting

http://www.gwu.edu/~forcpgm
Seasonality and Weather Effects on Electricity Loads: Modeling and Forecasting

Preliminary Results – Comments Welcome

Christian Crowley and Frederick L. Joutz
Department of Economics and Research Program on Forecasting
The George Washington University
Washington, D.C. 20052
(202) 994-4899
e-mail: crow@gwu.edu, bmark@gwu.edu

Acknowledgements: This research has been partially supported by an EPA-STAR Grant entitled, “Implications of Climate Change for Regional Air Pollution, Health Effects and Energy Consumption Behavior.” Hugh Ellis and Ben Hobbs from Johns Hopkins University are collaborating on the grant. Neil Leary provided information on North American local climate change and volatility data. All errors and omissions rest with the authors.
Objectives

• Examine the temperature effects on electricity loads within the PJM ISO
• Develop parsimonious specifications for hourly load models
• Test one and two day ahead forecasting capability of models
• Simulate the response to a 2°F increase in mean temperature
Objectives

• The research project focuses on short-term and long-term responses to changing temperature, its impact on generation and consumption technologies, and public health.

• Our focus today is only on short-run hourly consumption during the summer months.

• Our work is preliminary – we have a lot to learn and expect to benefit from the MetrixND User Meeting hosts and participants.
Progress and Learning

- Collected hourly load data for the control regions
- Collected hourly weather station data from NOAA
- Developed approach for correcting missing observations and outliers in weather data
- Developed a general-to-specific approach for modeling hourly demand

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
Progress and Learning

• Focus today is only on BG&E, Baltimore’s load region within PJM
• Data problems specifically with weather
Progress and Learning

• The Hourly Demand Model depends on:
  – Autoregressive components
  – Daily and Monthly Effects
  – Temperature and Temperature Squared
• We have estimated “cooling effect” elasticities
• We have performed forecast evaluations
• We have run a higher temperature simulation
BG&E Load Region

• In operation for over 100 years
• 1.1 million electricity customers
• 580,000 natural gas customers
• 2,300 square miles
• 1,200 miles of transmission lines
• 21,000 miles of overhead & ground distribution lines
• Traditional vertically integrated utility until July 1st, 2000
• A subsidiary of the holding company, Constellation Energy Group.

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
BG&E Load Region

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
BG&E Hourly Loads: July 2000

Refer to Table 2 of Handouts

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
Weather Data

- Hourly weather station data from Baltimore-Washington International Airport, WBAN#724060
- 29,184 total observations
- 868 missing observations (3% of total)
- 8,784 observations for June, July, August, and September in 1998, 1999 and 2000
- There are 155 missing observations (1.8%)
Temperature Sensitivity Variables

We constructed Cooling Degree Day variables for modeling purposes:

\[ CDD = \begin{cases} 
\text{Hourly Temperature} - 72 \\
0 & \text{for Temperatures below 72°F} 
\end{cases} \]
Refer to Table 2, 3, and 4 in Handouts

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
Refer to Table 2, 3, and 4 in Handouts

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
The General Load Model

\[
\log(\text{Load}_{ht}) = \beta_0 + \sum_{i=1}^{7} \beta_i \text{Day}_{iht} + \sum_{i=1}^{3} \delta_i \text{Month}_{iht} \\
+ \sum_{i=1}^{4} \alpha_i \text{Month}_{iht} \cdot CDD_{iht} + \sum_{i=1}^{4} \gamma_i \text{Month}_{iht} \cdot CDD_{iht}^2 + \phi(L) \cdot \log(\text{Load}_{ht}) + e_{ht}
\]

The autoregressive component includes the previous three hours and the same hour from the previous day:

\[
\phi(L) = \varphi_1 L + \varphi_2 L^2 + \varphi_3 L^3 + \varphi_{24} L^{24}
\]
Interpreting the Coefficients

• The electricity load in hour \( h \) on Fridays in July is captured by the expression
  \[
  \beta_0 + \beta_5 + \delta_1 + \alpha_2 \cdot \text{CDD} + \gamma_2 \cdot \text{CDD}^2
  \]

• The Friday effect comes from the \( \beta_5 \) parameter and the \( \delta_1 \) parameter captures the difference between July and June.

• The effect for a Tuesday in June is given by
  \[
  \beta_0 + \beta_1 + \alpha_1 \cdot \text{CDD} + \gamma_1 \cdot \text{CDD}^2
  \]

• The parameter \( \beta_1 \) represents the difference from Monday in June.
General to Specific Modeling Approach

• Goal is to explain a lot with a little
• The general model has 23 parameters to estimate
• We test 40 hypotheses on the deterministic variables on the temperature sensitivities, and both jointly – total 960 hypotheses
• Refer to Handout Table 8 for Description
• Refer to Handout Table 9 for Selection
General to Specific Modeling Approach

• Model Evaluation is based on:
  – Likelihood Ratio Statistics
  – Akaike Information Criteria
  – Schwartz Criteria

• Removal of deterministic effects for days and months reduces explanatory power.

• Level and Quadratic terms for CDD are important, but different on an individual monthly basis

• Symmetry found across months as well as for June/September and July/August
MStat Comparison – Hour 10

<table>
<thead>
<tr>
<th>Model</th>
<th>Coefs</th>
<th>Err DF</th>
<th>Std Err</th>
<th>AIC</th>
<th>BIC</th>
<th>Log-L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model0_10</td>
<td>23.00</td>
<td>1191.00</td>
<td>0.01</td>
<td>-8.62</td>
<td>-8.52</td>
<td>3536.52</td>
</tr>
<tr>
<td>Model40_10</td>
<td>19.00</td>
<td>1195.00</td>
<td>0.01</td>
<td><strong>-8.63</strong></td>
<td>-8.54</td>
<td>3533.29</td>
</tr>
<tr>
<td>Model41_10</td>
<td>17.00</td>
<td>1197.00</td>
<td>0.01</td>
<td>-8.62</td>
<td><strong>-8.55</strong></td>
<td>3529.84</td>
</tr>
</tbody>
</table>

• Version 3.0 of MetrixND allows the modeler to conduct the general-to-specific hypothesis tests that we did “by hand”

• The first line shows results for our General Model

• Other lines compare results for our Restricted Models 40 and 41
The Final Load Model

\[
\log(\text{Load}_{ht}) = \beta_0 + \sum_{i=1}^{6} \beta_i \text{Day}_{iht} + \beta_7 \text{Holiday}_t + \sum_{j=1}^{3} \delta_j \text{Month}_{jht} \\
+ \alpha \text{CDD}_{ht} + \gamma \text{CDD}_{ht}^2 + \phi(L) \cdot \log(\text{Load}_{ht}) + e_{ht}
\]

• The intercept captures Mondays in June
• Imposing symmetry across monthly CDD effects does not reduce the model’s explanatory power
• A close alternative suggested that there is a distinction between the June/September and July/August combinations
• Example: Hour 14 Model in Handout Table 11
Temperature or CDD Elasticities

- The hourly cooling degree day elasticity in month/season \( j \) is defined as

\[
E_{Chj} = ( \alpha_{hj} + \gamma_{hj} \times 2 \times MCDD_{hj} ) \times MCDD_{hj}.
\]

- Subscripts C, h, and j refer to cooling, hour, and month/season respectively.

- The M in front of MCDD terms indicates that degree day measures are evaluated at their mean values.

- Refer to Table 15 in Handouts.
Hourly Cooling Degree-Day Elasticity and Summer Loads

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
Forecast Comparison

• Compare Three Approaches:
  – Individual Hourly OLS Model Forecasts
  – Group OLS Forecasts
  – (Group) Neural Net Forecasts
• Estimate models from June-September 1998-1999 and June 2000
• Forecast July 2000 (31 one day ahead forecasts)
Comparison of MAD

MAD for BC, July 2000

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
Comparison of MAPE

MAPE for BC, July 2000

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
Comparison of RMSE

RMSE for BC, July 2000

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
Simulation

• Compare the effect of a 2°F increase on loads
• Focus on July 2000
• Predicted values calculated using actual temperature data
• Simulated values using actual temperature plus 2 degrees.

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
Average Change in Load by Hour
for a 2°F Increase in Temperature - July 2000

Hour of the Day

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
Percent Difference in Load for a 2°F Increase in Temp. - Hour 10

June 2000
Percent Difference in Load for a 2°F Increase in Temp. - Hour 15

June 2000
Conclusion

• Base-line study for estimating hourly impacts of cooling needs for one load region in PJM
• Forecast comparison – we could not distinguish between the different models
• CDD Elasticities were most pronounced in the late morning and late afternoon
Conclusion

• Simulation with temperature increased by 2°F in July 2000
• Biggest average hourly effect is 1% at Hour 10
• Between Hour 9 and Hour 15 the average effect 0.75% or more
• The Hour 10 effects range to 3.25%
Further Research

• Model Specification
  – Are Quadratic Temperature Effects Enough?
  – Cubic Temperature Effects?
  – Convert from natural logarithms to levels?

• Clean Weather Data from Weatherbank

• Other Weather Variables
  – Cloud Cover
  – Precipitation
  – Wind Speed
  – Other Seasonal differences

• Extend modeling efforts to other PJM load regions

“Seasonality and Weather Effects on Electricity Loads” Crowley and Joutz, GWU Sept. 02
Further Research

- MetrixND issues and ideas:
  - Version 3.0 is big improvement over 2.6
  - We relied on econometric package Eviews for many specification tests, because of programming requirements
  - Specification tests – compare with MSTAT
  - Elasticity estimates
  - Conversion from transformations to original series
  - Understand how to construct recursive group forecasts in MetrixND
  - Visual Basic for programming and testing large groups of models