Quantitative Modeling: The Next Step
A scalable electricity load and price model.

Executive Summary
This iteration of Morningstar's first energy-based quantitative model explores the improvements proposed in the first quantitative modeling white paper, "PJM Quant Model." The first stage of the model involved using a statistical approach to provide a forward load forecast, leveraging multiple data inputs including prices, market fundamentals, and environmental conditions. In this version of the model, the team used two zonal regions to test the model's efficacy. The regions used as the test area were PJM's PSEG zone and ERCOT's coastal zone.

In the last version, the improvements proposed as next steps were the following:
- Refining load forecast through regime-switching techniques and optimization approaches
- Converting load forecast into a day-ahead and real-time power price forecast
- Applying the methodology to lower levels within PJM (for example, zonal level, hub level)
- Extending the forecast benchmark against PJM's seven-day load forecast
- Expanding the methodology to other RTO/ISOs (for example, ERCOT, CAISO)

Improvements From Version 1
- Reduced mean absolute percentage error, or MAPE, in the load forecast
- Extension of the methodology into different regions, validating the scalability of the methodology
- Addition of a price forecast

Model Optimization Engine
During this phase of research, several optimization steps were tested with mixed results. The first piece included an optimization engine designed to determine the best model fit based on the optimal number of lags and the ideal information criterion for the vector autoregression, or VAR, model. While the computational demand was an order of magnitude greater than the original approach, the improvement of less than 0.25% in forecast accuracy did not justify pursuing this approach further. The second optimization approach employed a Lagrange multiplier to constrain the model's load forecast using weather forecasts. Like the automated optimization engine, the results showed minimal improvements and did not justify the additional computational expense.

The most promising improvement shifts the weather inputs forward by 24 hours, estimates the parameters, and calculates a 24-hour forecast. This forecast is then incorporated into a new model along with weather for the next 24 hours. A new VAR is estimated, and a new 24-hour forecast is calculated. This process is repeated until a seven-day forecast is assembled.
Seven-Day Forecast
Four different scenarios are analyzed using PJM’s PSEG region and ERCOT’s coastal regions for June and July, as outlined in Exhibit 1. For each region, four scenarios are run with the first split either shifting or not shifting the weather inputs. After the first split, one or seven VAR models are estimated to calculate the seven-day forecast.

Exhibit 1 Load Model Test Scenarios

PJM PSEG Back-Testing Results

Single Estimation Approach
As shown in Exhibit 2, the single estimation approach results in an average MAPE of 4.23% in the 24-hour load forecast and an average error of 7.05% in the 48-hour load forecast, an improvement from the errors shown in "PJM Quant Model" for the first iteration of the PJM RTO model. However, the errors vary significantly from day to day, being off as much as 29%, as on July 6 for the 48-hour forecast. The 24-hour forecast MAPE difference ranges between negative 1.0% and 15%. The seven-day forecast is not included in these charts because the historic seven-day forecasts were not available when these tests were performed. Morningstar will have PJM’s seven-day forecast history in the next phase of model development.
Daily Estimation Approach

Analyzing the results shown in Exhibit 3, the daily estimation approach represents an improvement from the first version of the model. The average MAPE difference between Morningstar's and PJM's models was 4.23% in the 24-hour forecast and 6.2% in the 48-hour forecast for June and July. However, the variance of the error is greater, beating PJM's model at times to missing by double-digit percentages. One reason for the wide discrepancy is the smaller geographic footprint of PSEG, which covers a very narrow sliver of New Jersey. To accurately forecast load in this smaller region, more data inputs or more history may be needed in training the model.

The MAPE difference between the two modeling approaches can be seen in Exhibit 4. The 48-hour forecast shows significant improvement, however, shaving 8% off the MAPE on certain days. On average, the daily estimation approach improves the model's output by 0.83% in the 48-hour forecast.
The day-ahead price forecast, which incorporates the load forecast model with shifted weather and a single estimation, is more accurate in the 24-hour forecast than the 48-hour forecast, as shown in Exhibit 5. Only a single estimation model was run for price. The model results are benchmarked against actual day-ahead price settles because a price forecast does not exist within PJM. The likely driver of this discrepancy is the accuracy in the model inputs. Additionally, the results rely on calculating a single estimation for the whole period instead of a daily estimation, which is likely to bear better results. This will be tested in the next iteration of the model using live inputs instead of using actuals to back-test the model.
ERCOT Coastal Back-Testing Results

Single Estimation Approach

Using the single estimation approach with shifted weather data to forecast ERCOT coastal load for June and July, the MAPE difference between Morningstar’s forecast model and ERCOT's internal model reveals mixed results, as shown in Exhibit 6. The 24-hour forecast performs better than the 48-hour and 168-hour forecasts, showing a MAPE difference between negative 2.0% and 6.9%. The average error over the period is 0.25% when benchmarked against ERCOT's internal model. The 48-hour forecast shows a slightly wider range between negative 3.0% and 9.0% with an average MAPE difference of 1.14%. Not surprisingly, the 168-hour forecast difference shows the greatest variation, between negative 2.8% and 14.1% with an average MAPE difference of 3.17%.

Exhibit 6: ERCOT Coastal Load 24-, 48-, and 168-Hour MAPE: Single Estimation Approach

<table>
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<tr>
<th>Forecast Date</th>
<th>24 Hour MAPE Diff</th>
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<tr>
<td>6/1/2018</td>
<td></td>
</tr>
<tr>
<td>6/8/2018</td>
<td></td>
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</table>

Source: Morningstar

Daily Estimation Approach

When looking at the performance of the model using the daily estimation approach, we see very promising results. Exhibit 7 shows the forward 24-hour, 48-hour, and 168-hour forecast error difference between our model and ERCOT’s load forecast. The Morningstar model MAPE is excellent through the first half of June, beating ERCOT’s forecast most days in the 24-, 48-, and 168-hour time frame. However, Morningstar’s model underperforms against ERCOT between June 15 and June 23 before improving at the end of the month. July’s results are a little more mixed, with wide disparities around the July 4 holiday lasting through the month, with a 0.0%-2.1% difference. The average MAPE difference is 0.6% in the 24-hour, 1.1% in the 48-hour, and 1.5% in the 168-hour forecast.
On average, the Morningstar model generally falls in line with ERCOT’s internal forecast. The focus on the next iteration of the model will be in improving the model’s output to more consistently fall below ERCOT’s internal forecast. Our focus in the next iteration would be to transfer the model into a live environment, where the team can assess the model performance in real time.

Comparing the MAPE differences shown in Exhibit 8 between a daily estimation forecast versus a single estimation forecast, the results using a daily estimation show better results. The 48-hour forecast MAPE range tightens with the daily estimation approach, moving in a range of 12.6% to 11.5%. The greatest improvement between the two approaches is in the 168-hour forecast, where the MAPE range narrows by 6.1% using a daily estimation. The MAPE in the 168-hour forecast is improved, with the maximum error seen in the single estimation process hitting 14.1% versus the 9.0% high when using the daily estimation approach, shown in Exhibits 6 and 7, respectively.
Exhibits 9 and 10 compare the seven-day forecast for June 3 and July 4, respectively. The MAPE on June 3 for the forward seven days comes in at 2.7% for the Morningstar model compared with ERCOT’s model of 4.0%. On July 4, the Morningstar model MAPE is 6.8% compared with the ERCOT forecast MAPE of 6.76%.

Looking closer at the results available on the July 4 run in Exhibit 10, two observations are worth noting. In hours 91 through 114, both Morningstar’s and ERCOT’s models overestimated the load compared with actual demand for this region. In both forecast models, the shape of the load curve is similar with a very clear daily peak, while actual load is significantly lower and showing a midday dip. Although the Morningstar model performs better than ERCOT’s model by around 2%-3%, both models miss the midday dip.
lull that can be seen in the actual demand. Future projects for this model include building an attribution engine to decompose and identify the drivers for any given forecast load.

Like the previous day's forecast, in hours 115-139, both the Morningstar and ERCOT forecasts overestimate demand. However, the Morningstar forecast outperforms ERCOT's forecast on two fronts. The Morningstar forecast comes in closer to the actual load between hours 116 and 142 with an average error of 5%, while ERCOT's forecast showed an average error of 15%. One area of future research will be to understand why the evening dip is captured in one day and not the previous day. We expect that the attribution engine in the next phase of this product's development will shed light on these issues.

**Exhibit 10** ERCOT Coastal Seven-Day Load Forecast (July 4)

![ERCOT Coastal Seven-Day Load Forecast (July 4)](image)

**Day-Ahead Price Forecast**

Like the PJM day-ahead price model, the ERCOT model uses shifted weather data and a single estimation. The test results show the day-ahead price forecast is more accurate in the 24-hour forecast than the longer 168-hour forecast, as shown in Exhibit 11. The model results are benchmarked against actual day-ahead price settles because a forward forecast for price does not exist within ERCOT. The MAPE in the 24-hour day-ahead price forecast ranges between 8.9% and 32.2%, achieving an average MAPE of 17.5%. The 48-hour forecast has a slightly wider error range between 8.1% and 41.5% for the test period. The average error for the test period was 19.1%. The 168-hour forecast has a slightly wider error range between 8.9% and 45.4% for the test period. The average error for the test period was 19.4%. In the next iteration, a daily estimation approach will be used instead of a single estimation. The daily estimation approach is expected to improve the model's output in a similar way to load forecasting. Additionally, an attribution analysis will be performed to determine the drivers of day-ahead price, which we expect will lead to additional data inputs for future tests.
Conclusion
The results from this iteration show considerable improvement from the initial tests conducted in the spring. The test cases from both PJM and ERCOT show that the basic framework can be applied to different geographies and zones, as well as forecasting price. In this version of the model, several cases were tested, which included shifting weather inputs, testing ideal number of components, and understanding the difference between using a single and daily estimation in predicting forward load. These tests also helped identify the next set of improvements to build and test.

The following items will be included in the next iteration of Morningstar’s load and price forecast model:
- Benchmarking seven-day forecast results against PJM’s seven-day load forecast
- Creating and testing a season-based regime switching module
- Testing the model’s efficacy in a real-time environment using forecast inputs
- Creating an attribution engine to load and price to derive model drivers
- Analyzing model accuracy using different historical periods to train the model
- Calculating a confidence interval for both load and price

Feedback
We actively seek feedback on model development from clients and prospects and would be interested in discussing the value of this work with commercial trading and analytics as well as to compare our results and approach with internal and external alternatives used by the industry. Contact Matt Hong or Michael O’Leary for additional comments or questions.

Products
Our experience in managing data suggests the model results could be made available to clients either as several data feeds or an analytic platform where customers can interact with the model directly. We welcome feedback and suggestions regarding the optimal mode to engage our customers with our model results.