Space Weather and the New York Wholesale Electricity Market: A Preliminary Analysis

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1. Introduction

It has long been understood that power grids are vulnerable to geomagnetically induced currents (GIC) that are the result of electric currents high in the atmosphere of Earth (at ionospheric altitudes). These are produced by geomagnetic storms and sub-storms as the magnetosphere interacts with disturbances in the solar wind. (e.g. Kappenman, 2000; Lanzerotti, 1979; Pirjola, 1983; Boteler, 1994). While some of the impacts of space storms such as the 1989 collapse of Hydro Quebec are fabled within the space weather community, little attention has been given to the economic costs of space weather.[1] Recently however, Forbes and St. Cyr (2003) have reported evidence that the market price on the PJM power grid over the period June 2000 through December 2001 was affected by space weather events. This paper examines whether these impacts are also present in the New York power grid.

The paper is organized as follows. Section 2 provides a brief overview of the New York market, whose data are employed in the paper's empirical analyses. Section 3 tests the hypothesis that adverse space weather increases the average price of electricity, *ceteris paribus*. Section 4 summarizes the paper and considers the direction of future research.

2. The New York Wholesale Electricity Market

The New York Independent System Operator (NYISO) manages the wholesale electricity market in New York. The NYISO was formed in 1998 as part of the restructuring of New York State's electric power industry. As of December 31, 2001, the NYISO had a peak load generating capacity of over 30,000 MW which makes it one of the 10 largest centrally dispatched electric power grids in the world.

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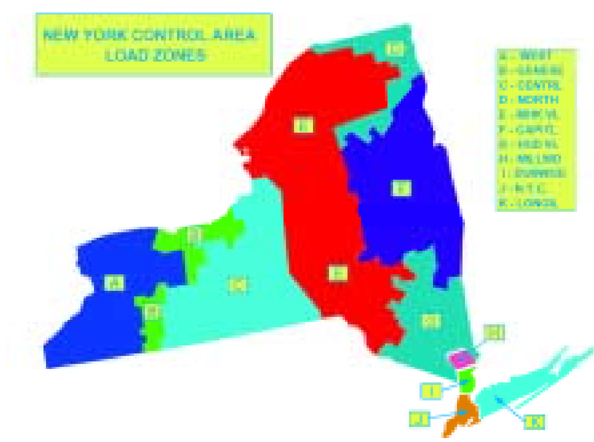
The NYISO is divided into 11 zones: The zones are Capital, Central. Dunwood, Gennese, Hudson Valley, Long Island, Millwood, Mohawk Valley, New York City, North, and West (Figure 1).

Figure 1. The New York Power Grid



Like the PJM, the NYISO allows the price of electricity to vary across zones, i.e., the NYISO uses locational marginal pricing. Prices will be equal across zones in the absence of transmission congestion and line losses but may differ by as much as a factor of ten or more when the transmission lines are congested. Unfortunately, relative to PJM, which is subjected to transmission congestion about 55 % of the time, the NYISO is congested almost 100 percent of the time. As a result of this differential in the incidence of congestion, the standard deviation in NYISO's zonal prices is more than twice PJM's.

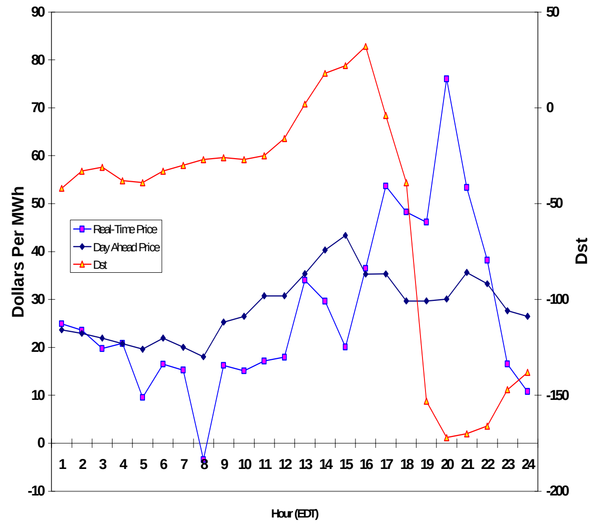
The NYISO operates two markets for electricity, a day-ahead market and a real-time market.[2] Real-time Locational Marginal Prices (LMPs) are calculated at five-minute intervals based on the actual operating conditions of the system. For this reason, the real-time market is probably the most important indicator of current operating conditions. Real-time prices are determined for each of the eleven zones and for the four neighboring regions that have interconnections with the NYISO (New England, Hydro Quebec, Ontario Hydro and PJM). Typically less than 10 % of energy transactions occur in the real-time market. The day-ahead market is a forward market that market participants can use to insulate themselves from the price volatility in the real-time market. These prices are calculated as of 11:00 a.m. of the previous day based on generation and energy transaction bids that were offered prior to a 5:00 a.m. deadline. As in the case of the real-time market, day-ahead prices are determined on an hourly basis for each of the eleven zones and the four neighboring regions that have interconnections with the NYISO.

3.Space Weather and the Real-Time Price of Electricity: An Econometric Analysis

In estimating the economic costs of space weather, Forbes and St. Cyr (2003) focused on the determinants of the outcome in the real-time market. Independent variables in their analysis included the day-ahead price for the hour in question, the utilization rate of the generators, measures of unexpected demand, unexpected generation outages, unexpected transmission constraints believed to be terrestrial in origin, and space weather. They hypothesized that adverse space weather increases the average price because it impedes the transmission of power from low cost to high cost zones. This hypothesized impact is consistent with the events of September 17, 2000 as depicted in Figures 2. As some readers may recall, the Earth experienced a significant geomagnetic storm on that day with the Dst index declining to –172 from –4 over the space of four hours (more negative values of Dst indicate a storm of greater intensity). Figure 2 suggests that the sharp increase in the real-time price in New York City, was associated with the storm.[3]

In this paper, the methodology employed by Forbes and St. Cyr (2003) is applied to the New York market. Unfortunately, data on generation utilization, outages, and real-time transmission constraints were not available. As a result, the full model that Forbes and St. Cyr estimated for the PJM cannot be estimated for the NYISO. A partial solution to this problem is to use systemwide load as a proxy for the utilization of the generators.

Figure 2. The Weighted Average Price of Electricity in New York City and the Value of the DST Index on September 17, 2000.



Having noted these shortcomings, the estimated equation is:

$$Ln(RtAvgPrice)_t = c + \alpha_0 Ln(DaAvgPrice)_t + \alpha_1 Load_t + \alpha_2 PosUnexpecteLoad_t + \alpha_3 NegUnexpectedLoad_t + \alpha_4 AdjDst_t \quad (1)$$

where:

Ln(RtAvgPrice$_t$)is the natural logarithm of the real-time system-wide load weighted average price for hour t;

Ln(DaAvgPrice$_t$) is the natural logarithm of the day-ahead system-wide load weighted average price for hour t;

$Load_t$ is the systemwide load (electricity delivered to consumers) for hour t. This variable is a proxy for the utilization of the generators;

$PosUnexpectedLoad_t$ = is the absolute value of the deviation between actual and expected day-ahead load in hour t multiplied by actual load in hour t when actual load exceeds expected load. It is zero otherwise;

$NegUnexpectedLoad_t$ = is the absolute value of the deviation between actual and expected load in hour t multiplied by actual load in hour t when actual load is less expected day ahead load. It is zero otherwise;

AdjDst is the absolute value of the negative values of the Dst index when Dst < 0. It is zero otherwise.

The dependent variable in equation (1) is the natural logarithm of the real-time price. The day-ahead price is also represented in terms of its logarithm. This specification was chosen following a preliminary analysis that indicated that the relationship between the two prices was not linear but could be represented as being linear in the logarithms.[4]

The data series on Dst was obtained from the World Data Center for Geomagnetism in Kyoto, Japan. All the other data were obtained from the NYISO web site.

Equation (1) was estimated using generalized least squares with corrections for both heteroskedasticity and autocorrelation. The estimation results are presented in Table 1. As expected, the coefficient on the day-ahead price is positive and highly statistically significant indicating that the average real-time price will be higher, the higher the day-ahead price. This is not surprising given that the day-ahead price represents the market's assessment of what the real-time price will be. The coefficient on *Load* is positive and highly statistically significant indicating that the real-time price is higher when Load is higher.

The coefficient on *PosUnexpectedLoad* is positive and highly significant indicating that higher than expected demand for electricity has a positive impact on the real-time price. In contrast, the coefficient on *NegUnexpectedLoad* is negative and statistically significant. These results suggest that there is an asymmetric price response to load forecasting errors. Underprediction of demand, i,e. forecasted load < actual load, leads to higher prices above and beyond the direct impact of higher load on price while overprediction of demand, i.e. forecasted load > actual load, results in a lower price above and beyond the direct effect of lower load on price. One possible reason for the asymmetry is that higher than expected demand will typically require the use of high cost peaking units while lower than expected demand can be accommodated by simply taking a generating unit offline.

Consistent with the hypothesis that adverse space conditions lead to higher prices, *ceteris paribus,* as well as the findings of Forbes and St. Cyr (2003) for the PJM, the coefficient on AdjDst is positive and statistically significant at the five percent confidence level.

Table 1
Estimation Results for Equation 1

Variable	**Estimated Coefficient**	**t-statistic**
C	0.576	5.06*
Ln(DaAvgPrice)	.268	5.54*
Load	0.120E-3	15.86*
PosUnexpectedLoad	0.113	2.76*
NegUnexpectedLoad	-0.110	12.39*
AdjDst	0.608	2.04**
Rho	0.742	19.32*
R-Squared	0.71	
Durbin-Watson Statistic	2.09	
Number of Observations	8666	
*Statistically significant at 1 percent. ** Statistically significant at 5 percent.		

4. Conclusion

Consistent with the findings of Forbes and St. Cyr (2003) for the PJM, this paper has found evidence of a space weather/market price relationship in the New York wholesale electricity market. Based on the parameter estimates, the model indicates that the real-time price was about 1 percent higher in 2000 as a direct result of space weather. This is less than one third the market impact reported by Forbes and St Cyr for the PJM. It is not clear why the impact is smaller. If anything, one might expect that the NYISO impact would be larger given that New York is at a higher geomagnetic latitude than PJM and hence more vulnerable to space weather events, *ceteris paribus*. It might be the case that the "quality" of the price signals are simply more robust in the PJM market as compared to the NYISO, i.e. that the real-time price is a better measure of operating conditions in the PJM as compared to the NYISO. Alternatively, Dst may be a poorer proxy for local geomagnetic conditions in the NYISO as compared to PJM. In any event, while the exclusion of the variables representing generation outages and transmission constraints suggest that this quantitative estimate should be intrepretated with more than the typical degree of caution; it is nevertheless significant that the space weather/market price relationship is supported by the data.

In terms of future research, the above noted data deficiencies need to be resolved. In addition, local magnetometer data are needed so as to ensure that the space weather variable accurately reflects the actual grid conditions. Dst is global index of geomagnetic conditions and thus it is probably a less than ideal measure.

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Endnotes

[1] On March 13, 1989, a space weather induced transformer failure on one of the main power transmission lines in the Hydro Quebec system led to a collapse of the entire power grid. Six million people lost electrical power for 9 or more hours .For more information on the 1989 collapse of Hydro Quebec, see Kappenman et. al. (1997).

[2] NYISO also operates markets for capacity credits, ancillary services, and financial transmission rights.
[3] Consistent with the view that the impact of space weather is largely unanticipated, observe that the day-ahead price does not appear to have been directly affected by the storm.