Space Weather and the Electricity Market: A Preliminary Assessment

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ABSTRACT

This paper considers the impact of space storms on the market for electricity. To accomplish this aim, an econometric model is both formulated and estimated that explains the difference between the day-ahead and real-time price of electricity for the PJM control area. Factors considered in the model include the level of generation utilization, unexpected demand, generation outages, unexpected transmission outages that are believed to be terrestrial in origin, and space weather. The preliminary results indicate the presence of space weather effects on the real-time price of electricity even after controlling for the other factors.

INTRODUCTION

It is well established that space weather storms can reduce the effective safe operating capacity of electric power transmission systems (Kapperman, 2000; Lanzerotti, 1979; Pirjola, 1983; Boteler, 1994). In this paper, the market impact is considered.

The paper develops the hypothesis that adverse space weather events can be expected to increase the level of price dispersion within a power control area. It is also hypothesized that adverse space weather events can be expected to increase the system-wide weighted average price within a control area. An econometric model to test the latter hypothesis taking into account that there are other determinants of price such as the demand for power, generation outages, etc. is formulated and estimated. The model focuses on explaining the difference between the day-ahead and real-time price of electricity. The day-ahead market is a market that allows participants to enter into transactions one day ahead of time while the real-time market is a market in which electricity is bought and sold in "real-time." The results are consistent with the formulated hypothesis that adverse space weather events increase the system-wide weighted average price.

THE PJM MARKET

The PJM has a peak load generating capacity of over 54,000 MW which makes it one of the largest centrally dispatched electric power grid in North America and the World .The PJM has over 8,000 miles of high-voltage transmission lines and 560 generating units. Its service area has a population of 22 million and includes all or part of Pennsylvania, New Jersey, Maryland, Delaware, Virginia, and the District of Columbia.

The PJM is divided into zones. In contrast to some power grids that use "postage stamp" pricing (such as Nordpool) , the PJM allows the price of electricity to vary across zones. The prices will be uniform in the absence of transmission constraints but may vary by a factor of 10 or more when there are constraints.

A MODEL OF SPACE WEATHER'S IMPACT ON THE ELECTRICITY MARKET

Consider an electricity grid with two distinct zones, zone 1 and zone 2. Assume the operator of the grid has instituted zonal pricing. Under this arrangement, prices can deviate across zones depending on the presence of transmission constraints. Assume that the demand and supply for electricity in each zone can be represented by the functions D_i and S_i, i = 1,2 as depicted in Figure1. Economic theory suggests that there will be price equality across zones in the absence of transmission constraints. The overall price in this case is determined by total supply, S_1, + S_2, and total demand, $D_1 + D_2$, as shown in Figure 1. In this case, the equilibrium price in both zones is P_3. At this price, zone one produces Q_1^S amount of electricity while only consuming Q_1^D amount of electricity. Zone two consumes Q_2^D while only producing Q_2^S. Observe that this solution entails the transmission of Q_1^S - Q_1^D amount of electricity from zone one to zone two. Space weather can impact the above solution by curtailing the transmission of power between the zones. For instance, suppose a geomagnetic storm induces the operators of the grid to reduce the flow of electricity from zone one to two to Q' (Figure 2). In this case, the effective demand for power in zone one is D_1' (equal to D_1 + Q'). Given zone one's supply of S_1, the equilibrium price of electricity in zone one will be P_1'. With respect to zone two, the effective supply with the transmission constraint is S_2'. Given zone two's demand of D_2, the price in zone two will equal P_2'.

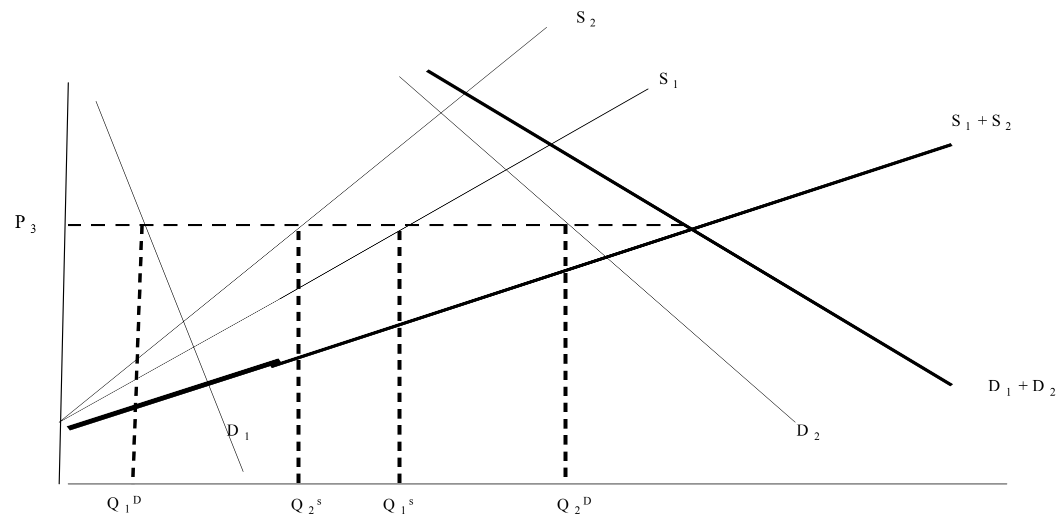

Figure 1. The Market Solution in the Absence of Transmission Constraints

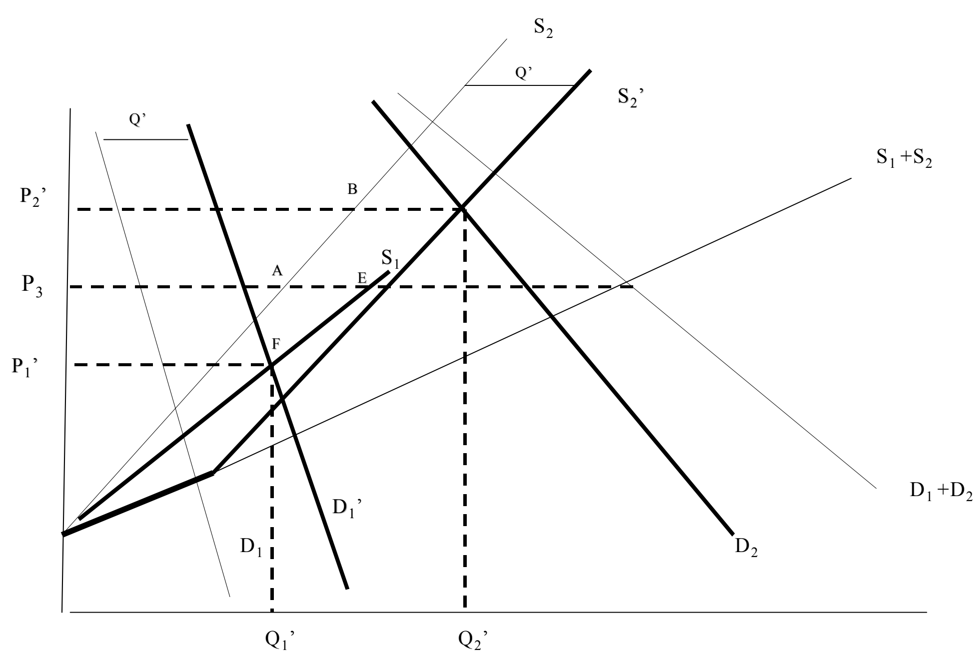

Figure 2. The Market Solution in the Presence of Space Weather Induced Transmission Constraints

Observe that the transmission constraint has led to price divergence across the zones. Also note that while the price in zone one has declined, the average price over the entire grid has increased since the output of the low cost zone has decreased (as represented by the movement from point E to F along S_1) while the output of electricity from the more costly zone, zone two, has increased (as represented by the movement from point A to B along S_2).

SPACE WEATHER AND THE REAL-TIME PRICE OF ELECTRICITY: AN ECONOMETRIC ANALYSIS

It was hypothesized above that adverse space weather conditions increase the deviation in prices across zones and also increase the system wide average price, *ceteris paribus*. This section reports on a test of the latter hypothesis using multivariate regression analysis. This methodology enables space weather's impact to be disentangled from the impacts of the other factors that affect price.

The average price in the real time market relative to the day–ahead market is hypothesized to be a function of

- **Expected Utilization.** Increases in expected utilization are hypothesized to increase the ratio of the real-time to day-ahead price.
- **The Day-Ahead Price.** Holding other factors constant, high day-ahead prices provide suppliers with the expectation that the real-time price will also be high. This expectation provides them with the incentive to bid more supplies into the real-time market. This of course reduces the real-time price relative to day-ahead price.
- **Unexpected Demand.** The real-time price of electricity can be expected to be quite sensitive to whether actual demand for electricity is less than, equal to, or greater than expected demand. The price impact of demand being higher than expected is hypothesized to be larger when utilization is high.
- **Unexpected Transmission Constraints that are Terrestrial in Origin.** Unexpected transmission constraints that are terrestrial in origin such as a malfunction in a transformer or congestion in a transmission interface impede the transmission of power from low to high cost zones, increasing the real-time price relative to the day-ahead price. The impact can be expected to be conditional on the overall level of load given that a particular constraint maybe more binding on the flow of electricity through the network as a whole when the aggregate level of flow through the network is high.
- **Unexpected Generation Outages.** Depending on the level of utilization, unexpected generation outages may increase the system-wide price. The price impact of an outage can be expected to be larger, the higher the level of capacity utilization.
- **Space Weather.** Like transmission constraints that are terrestrial in origin, space weather is hypothesized to impede the transmission of power from low cost to high cost zones and thus increase the average price over all zones. The impact can be expected to be conditional on the level of load, i.e., the price impact of a given space storm will be larger, the larger the level of load during the period of the storm.

More specifically, the regression equation is:

$$\begin{aligned}&\ln\_P\_ratio_i = c + \alpha_0 \ln\_DA\_P_i + \alpha_1 Un\exp\_Load_i + \alpha_2 \ln Utilization + \\ &\alpha_3 \ln Utilization * Un\exp\_Load_i + \alpha_4 GenerationOutage * \ln Utilization + \\ &\sum \beta_j TranmissionConstra\text{int}_{i\,j} * PJM\_Load_i + \delta\ SpaceWeather_i * PJM\_Load\end{aligned} \quad (1)$$

where

ln_P_ratio$_i$ is the natural log of the ratio of the system-wide real-time to day-ahead price in hour I
ln_DA_P$_i$ is the natural log of the day-ahead price in hour i;
Unexp_Load$_i$ = natural log of actual load to expected load in hour i;
lnUtilization$_i$ is the natural log of the estimated generation utilization rate for hour i;
TransmissionConstraint$_{i,j}$ is a binary variable representing whether there was a transmission constraint on the 500 kv transmission lines, 500 kv transformers, or a particular interface j in hour i. The variable has a value of one if j was constrained during hour i. It is zero otherwise;
GenerationOutage$_i$ is the increase in the estimated amount of capacity that is offline for noneconomic reasons;
PJM_Load$_i$ is the system wide level of electricity consumption within PJM in hour I
SpaceWeather$_i$ is a measure of adverse space weather conditions for hour i.. Specifically, is the absolute value of the negative values of the DST index. It is equal to zero if the reported value of DST is positive.

Equation (1) was estimated using generalized least squares with corrections for both heteroskedasticity and autocorrelation. The results are presented in Table 1. Consistent with the hypothesis formulated above, the coefficient on the variable SpaceWeather*PJM_Load, while small in absolute value, is both positive and statistically significantly different from zero. Most of the other coefficients also have the predicted sign and are statistically significant.

Table 1
Empirical Results for Equation 1

Variable	**Estimated Coefficient**	**t-statisitic**
C	2.483	18.84***
ln_DA_Price	-0.5193	20.32***
Unexp_Load	5.67598	6.48***
lnUtilization	1.27796	14.21***
lnUtilization* Unexp_Load	4.01141	2.79***
GenerationOutage*lnUtilization	247.340	2.74***
TransmissionConstraint_500kv_lines*PJM_Load	-0.10365E-5	0.43
TransmissionConstraint_500kv_Transformers*PJM_Load	-0.177947	0.17
TransmissionConstraint_Eastern_Interface*PJM_Load	0.172154	2.14**
TransmissionConstraint_Western_Interface*PJM_Load	0.261446E-6	1.77*
SpaceWeather*PJM_Load	0.45125E-7	4.09***
Rho	0.60	36.56***
R-Squared	0.4655	
Durbin-Watson Statistic	2.04	
Number of Observations	8752	
*** Statistically significant at .01 percent. ** Statistically significant at .05 percent.		

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