Solar Activity and Economic Fundamentals The Case of the Electricity Market in Texas:

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Kevin F. Forbes*

The Catholic University of America

O. C. St. Cyr
The Catholic University of America and NASA-Goddard Space Flight Center

1. Introduction

One of the most prominent economists of the 19th century was the English economist William Stanley Jevons. He was the co-developer of the neoclassical theory of consumer theory which literally transformed microeconomic theory by giving rise to such fundamental economics concepts such as marginal utility, marginal cost, and consumer surplus. His book, The *Coal Question*, which analyzed the possible consequences of energy resource depletion, arguably makes him the first energy economist.

Jevons is also known for his theory that business cycles were related to the sunspot cycle. His reasoning was that changes in sunspot activity affected crop output and prices that in turn affected overall economic activity. Unfortunately for Jevons' reputation, the evidence to support his theory was weak at best and the theory was eventually discredited, so much so that in a spoof on Jevons', the term "sunspot variable" in economics refers to a variable that has no effect on economic fundamentals.

The sunspot cycle had been discovered in 1843 by the German amateur astronomer Schwabe; hence it was rather new and in vogue when Jevons presented his business cycle theory in 1875. During this same period, researchers realized that disturbances in Earth's magnetic field (called "geomagnetic storms") could be statistically linked to this new sunspot cycle.

Similar to the economists contempt of "sunspots", physical scientists now understand that the sunspot cycle is neither a reliable quantitative measure, nor is it the physical driver of solar activity. Arguably, sunspots remain the best known public manifestation of our magnetically-variable star, but they are of little value to NOAA's forecasters of "space weather".

Technologists now recognize a multitude of societal impacts caused by solar variability. Foremost among the affected systems is the power grid, where electricity transmission and the operation of transformers can be severely impeded by geomagnetic storms.

Forbes and St. Cyr (2004) 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. But they only provided limited analysis of the impact of space weather on operating conditions. This has led some to wonder whether their results are analogous to Jevons' sunspots.

This paper examines whether space weather impacts are present in the ERCOT power grid. The focus is on the impact of space weather on operating conditions. The starting point of the paper is the documented evidence that geomagnetic storms can impair the performance of transformers. The paper examines the impact of this activity by drawing on data from the ERCOT power grid (the power grid that serves the vast proportion of Texas) over the period 1 May 2003 through 31 December 2003. This power grid is one of the few markets that releases data on what are known as "scheduling control errors." A positive scheduling control error (measured in MW) occurs when generators supply more electricity to the grid than scheduled. A negative scheduling control error occurs when the amount supplied is less than scheduled. Here we demonstrate through econometric modeling that geomagnetic storms can contribute to negative scheduling control errors. The impact of these scheduling errors on the deployment of

*Corresponding author address: Kevin F. Forbes, The Catholic University of America, Department of Business and Economics, Washington D.C. 20064. Email: Forbes@cua.edu

spinning reserves and the price of electricity in the balancing market are also examined.

2. The ERCOT Electricity Grid

The Electric Reliability Council of Texas, Inc. (ERCOT) is responsible for ensuring the reliability of approximately 85 percent of the state's electric load and 75 percent of the geographic land area in Texas. ERCOT serves seven million customers and oversees the operation of over 78,000 megawatts of generation and 38,000 miles of transmission lines in the State of Texas.

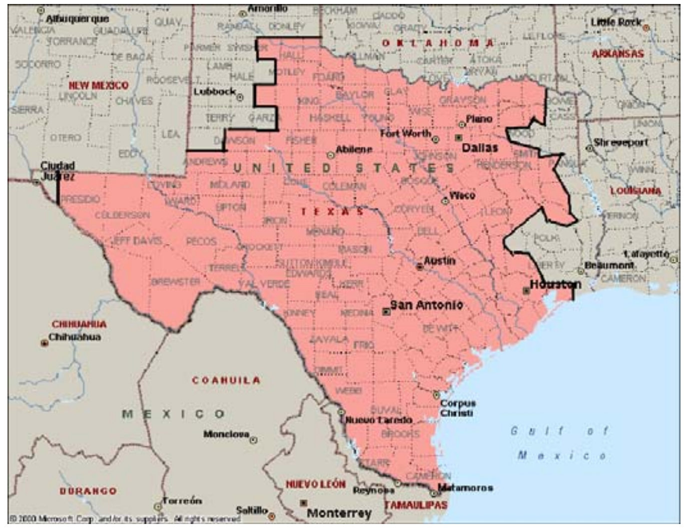
Approximately 63 % of the capacity in ERCOT is accounted for by natural gas. Coal/Lignite accounts for about 14 percent of capacity. Dual fired capacity (natural gas or oil) represents approximately 14 % followed by nuclear (6%) and renewable (1%).

The vast proportion of electricity (90-95 %) in ERCOT is traded via bilateral contracts. Prices in these agreements are considered confidential and thus are not known by ERCOT. However, the quantity of electricity agreed to is reported to ERCOT through the scheduling process.

While ERCOT does not concern itself with the contract terms of these base electricity supplies, it is charged with managing transmission congestion as well as ensuring that the overall market is balanced in terms of supply versus demand. The primary mechanism to accomplish these goals is through its balancing market that clears every 15 minutes. In this market, generators provide ERCOT with bids to adjust, either up or down, the quantity of electricity they supply to the grid. ERCOT starts with lowest price bid quantity and move up to higher price bids until total quantity expected to be required is obtained. The bid price of the last quantity expected to be taken sets the Market Clearing Price of Energy (MCPE) for that 15 minute interval. The market is not a real-time market. Instead, the market price is actually based on market conditions 20 minutes prior to real-time.

A key metric of the balancing market's performance is the extent to which generators follow the scheduling instructions established by the market. The difference between the amount of balancing energy uplifted on the grid and the amount scheduled is referred to as a balancing scheduling control error (BSCE). BSCE will be positive when generators uplift more energy than scheduled. It is negative when less energy is uplifted than scheduled.

Figure 1. The ERCOT Power Grid

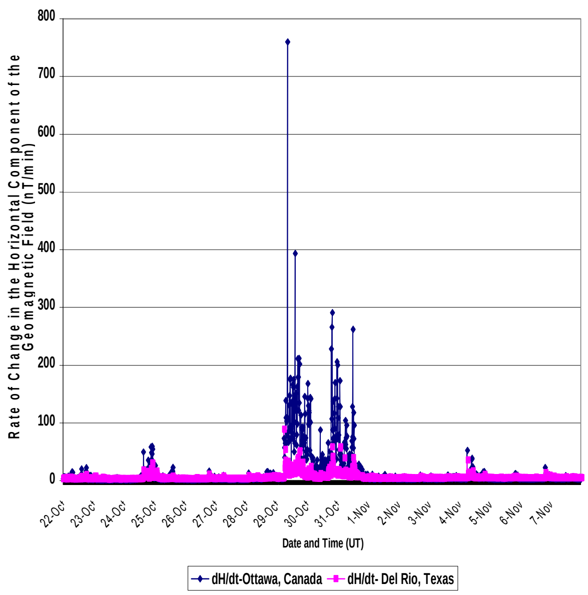


Source: ERCOT

3. Is Texas Impacted by Space Weather?

It is well established that the impact of space weather is more severe at the far northern latitudes. This is confirmed by inspection of Figure 2 which reports on dH/dt, the rate of change in the horizontal component in the geomagnetic field at both the Del Rio, Texas and Ottawa, Canada geomagnetic observatories over the period 22 Oct – 7 Nov 2003. Clearly, the impact of the late October 2003 storms in Texas was significantly less than in Canada. Yet, the impact of the storm in Texas was not insignificant in an absolute sense given that dH/dt exceeded 80 nT/min on 29 October 2003. While this level of geomagnetic activity is clearly dwarfed by the level recorded by the Ottawa station, it was powerful enough to leave its signature in the form of an aurora visible near Houston Texas (Figure 3).

Figure 2. The Rate of Change in the Geomagnetic Field: Del Rio Texas vs Ottawa Canada, 22 Oct – 7 Nov 2003



Data Sources: United States Geological Survey and the Geological Survey of Canada

Figure 3. Space Weather's Signature: An Aurora near Houston Texas, 29 October 2003

Photo by C. Ponder. Used with Permission.

4. The Determinants of Balancing Scheduling Control Errors

Possible determinants of balancing scheduling control errors (BSCE) include:

- **Forecast Errors.** BSCE is more likely when there is more balancing to be done, i.e. when there is an imbalance between the overall level of scheduled generation and load. This variable will be measured as the natural logarithm of the ratio of actual load relative to scheduled generation of each 15 minute period in the sample.
- **Hour-of-the-Day Effects**. Potomac Economics, a highly regarding consulting firm that provides consulting services to ERCOT, has noted the scheduling control errors are more likely during hours 6-7 and 22-23 LT. To account for these possible impacts, binary variables representing each hour of the day will be included as explanatory variables.
- **Idiosyncratic Scheduling Procedures.** Potomac Economics has also noted that most generators only alter their energy schedules hourly instead of every 15 minutes. The result can be systematic over- and under-scheduling. To account for this possible effect, binary variables representing the second, third, and fourth 15 minute period of each hour will be included as explanatory variables.
- **Day-of-the-Week Effects.** BSCE may be more likely during weekends because of reduced staffing levels. To account for this possible effect, binary variables representing Saturday and Sunday will be included as explanatory variables.
- **Load**. Periods of high load may be associated with large errors. To account for this possible impact, both load and load squared will be included as explanatory variables.
- **Changes in Load.** Errors may be larger during periods in which there are large changes in load. Specifically, when there are large changes in load, generation ramp constraints can cause a large quantity of energy to be unavailable to the market, i.e. negative

BSCE. To account for this possible effect, the change in load and the square of the change in load from the previous 15 minute period will be included as explanatory variables.

- **Ambient Temperature.** High ambient temperatures are known to degrade the performance of transformers which in turn can contribute to negative BSCE.
- **Geomagnetically Induced Currents** GICs are known to degrade the performance of transformers which in turn can adversely impact the uplifting of energy onto the grid thereby contributing to negative BSCE. GICs will be proxied by dH/dt.

5. Data

The sample period for this study is 1 May -31 December 2003. There are 22,160 observations. The temperature data is from the National Weather Service. Temperature is measured as the average of the hourly temperature reported at the DFW and Houston Bush Airports
GIC data was not available. GICs are instead proxied using geomagnetic data from USGS' Del Rio geomagnetic observatory in Del Rio, Texas (http://geomag.usgs.gov/observatories/Del_Rio/). Specifically, for each 15 minute market period, the rate of the change in the horizontal component of the geomagnetic field (dH/dt). was calculated using the one minute geomagnetic data reported by the Del Rio observatory. The descriptive statistics are reported in Table 1.

Table 1
Descriptive Statistics for dH/dt as Measured at the Del Rio Observatory, 1 May -31 December 2003

Measured in nanoTesla per minute
Sample Mean: 1.43
Minimum: 0
Maximum: 85
Standard Deviation: 2.1

6. Results for the BSCE Equation

BSCE was regressed on the independent variables using generalized least squares with corrections for both heteroskedasticity and autocorrelation. The estimation took into account that that the impact of both ambient temperature and dH/dt (the proxy for GICs) on BSCE might be subject to thresholds. In other words, each of these variables may need to attain a certain minimum level before it exhibits a marginal impact on BSCE. Another consideration deemed to be relevant is that the impact of GICs on BSCE might be cumulative in the sense that both current and lagged values of dH/dt may affect BSCE. A grid search was conducted to ascertain the threshold values for temperature and dH/dt along with the number of lags M that maximized the adjusted R^2. The estimation results indicate the following:

- The level of BSCE is critically affected by the level of load relative to scheduled generation.
- Positive changes in load contribute to negative BSCE
- Increases in temperature above the threshold of 16 degree Celsius contribute to negative BSCE.
- Increases in the rate of change in the horizontal component of the geomagnetic field above the threshold of 4.2 nT/minute contribute to negative BSCE.
- Evidence of nonlinearities and cumulative dH/dt impacts were also obtained.
- There is evidence of significantly larger values of BSCE on Sundays.
- There is evidence that BSCE varies both by hour and quarter hour.

7. Implications

Based on the estimated parameters, the predicted value of BSCE was calculated for every 15 minute period of the sample. It was first calculated with all of the independent variables equal to their historical values. It was then calculated with the variable dH/dt set equal to zero. The difference between these two series is the model predicted impact of dH/dt on BSCE. On average, the impact is approximately 3 MW per period. However, there are instances were the impact is large. Some of these instances are reported in Table 2.

Table 2

Date	Time	Estimated Impact of dH/dt (MW)	BSCE (MW)	Balancing Energy Deployed (MW)
30 May 2003	17:15	165	-389	2964
29 Oct 2003	17:30	340	-617	1028
30 Oct 2003	20:15	314	-533	2207
31 Oct 2003	12:45	296	-707	1500

8. Does it Matter? : The Case of Spinning Reserves

Does it really matter in an economic sense if BSCE is negative, zero, or positive? In answering this question, it is useful to consider that a nonzero value of BSCE indicates that the market has not achieved its goal of equating supply with demand. The case of positive BSCE is not particularly significant other than the fact that electricity is wasted. The case of negative BSCE is far more serious since at some point system frequency could drop below the point where ERCOT can keep the lights on. Fortunately spinning reserves can be deployed to prevent this from happening. In this light, it seems reasonable to suppose that negative BSCE, whether terrestrial or space weather in origin, could induce this deployment. To test this hypothesis, the number of MW of spinning reserves deployed for each 15 minute period was regressed on the following variables:

$PosBSCE_t$, the absolute value of $BSCE_t$ when $BSCE_t$ is positive. It is zero otherwise.

$SwNegBSCE_t$, the absolute value of the negative values of $BSCE_t$ that can be attributed to space weather based on the estimated parameters of the BSCE analysis discussed above. The variable is zero otherwise.

$TerrestrialNegBSCE_t$, is the absolute value of the negative values of $BSCE_t$ that cannot be attributed to space weather based on the estimated parameters of BSCE analysis discussed above. It is zero otherwise.

No spinning reserves were deployed for over 98 percent of the observations. The method of least squares can potentially lead to seriously biased estimates under these circumstances. To avoid this bias, the estimation employed the Tobit maximum likelihood procedure. The results indicate that the coefficients on TerrestrialNegBSCE and SwNegBSCE are both positive and statistically significant. These results suggest that negative BSCE, whether space weather or terrestrial in origin, contributes to the deployment of spinning reserves.

9. Is the Market Price Impacted?

The price of electricity in the balancing market can be expected to vary with load (LOAD), changes in load (ΔLOAD), scheduling controls errors, and the price of natural gas, the primary fuel used in the ERCOT grid. The natural logarithm of the balancing price was regressed on these independent variables using generalized least squares with corrections for both heteroskedasticity and autocorrelation. The estimation results reveal that the coefficient on the price of natural gas, LOAD, and ΔLOAD are positive as expected. Consistent with economic theory, the coefficient on PosBSCE is negative but is unfortunately statistically insignificant. The coefficients on TerrestrialNegBSCE and SwNegBSCE are both positive and statistically significant. These results suggest that negative BSCE, whether space weather or terrestrial in origin, contributes to higher prices in the balancing market.

10. Conclusion

The results of the analysis suggest that while sunspots may not impact economic fundamentals, solar induced geomagnetic storms do, at least in the electricity market in Texas.

Acknowledgments

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