

“Gaming” by Power Producers, Solar Storms, and “Loop” Electricity Flows: The Case of the PJM Power Grid

K. F. Forbes
The Catholic University of America
Washington, DC 20064 USA
Forbes@CUA.edu

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

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Introduction

- **In a well functioning market, the quantity of a commodity that is delivered to a buyer will not be systemically different from the amount that was scheduled to be delivered.**
- **Attainment of this property is especially important in electricity where the stability of a power grid requires that generation plus net electricity flows from other power grids be almost exactly equal to consumption at all times.**



Introduction

- **On alternating current transmission systems, the dominant form of electricity transmission, actual and scheduled electricity flows between two grids are seldom equal.**
- **This paper explores the ramifications and possible causes of these differences using data from the PJM power grid.**



PJM

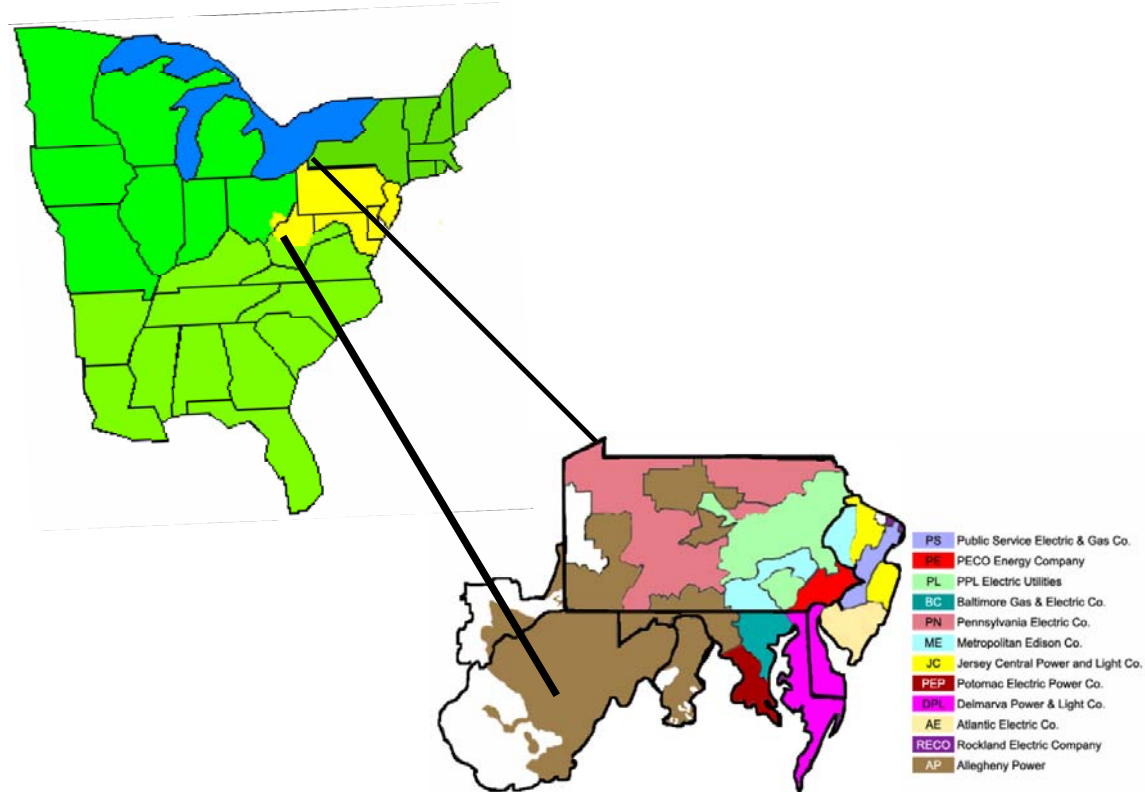
- **A regional electricity transmission organization which as of 30 April 2004 coordinated the dispatch of 76,000 megawatts of generating capacity over 20,000 miles of transmission lines.**
- **The sample period for this study is 1 April 2002 through 30 April 2004.**



PJM's Markets for Energy

- **PJM operates both real-time and day-ahead hourly markets for energy.**
- **Because of arbitrage considerations, the average day-ahead price is approximately equal to the real-time price.**

PJM's Geographical Footprint as of 30 April 2004



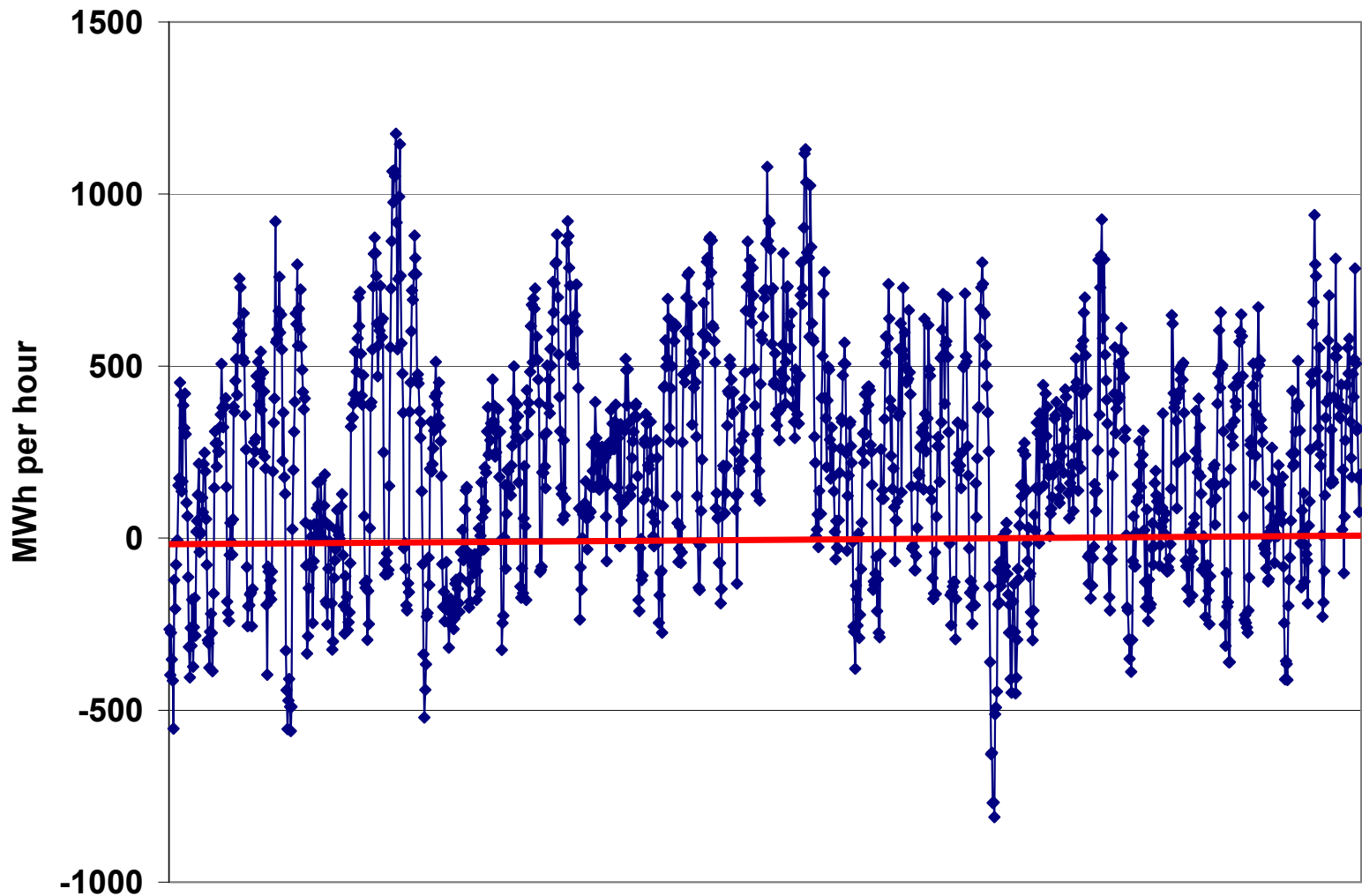


Loop Flows: What are they?

- **Over the sample period, PJM imported or exported power from the following grids: First Energy, New York, American Electric Power, Duquesne Light Company, and Virginia Power.**
- **At each interchange there were significant differences between scheduled and actual flows of electricity.**

These differences are known as “Loop Flows”

PJM's Loop Flows with New York, 1 June – 31 July 2002.

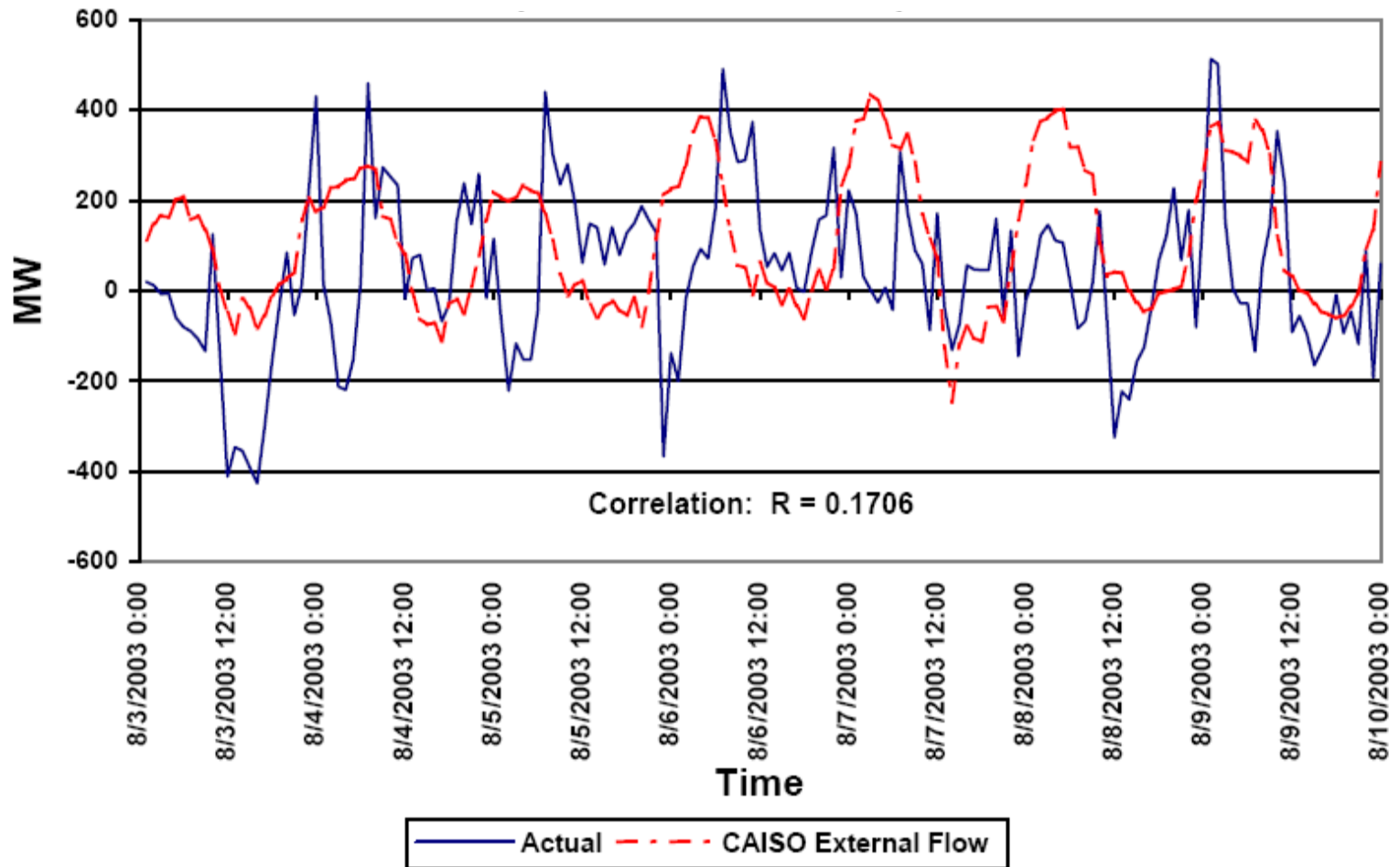




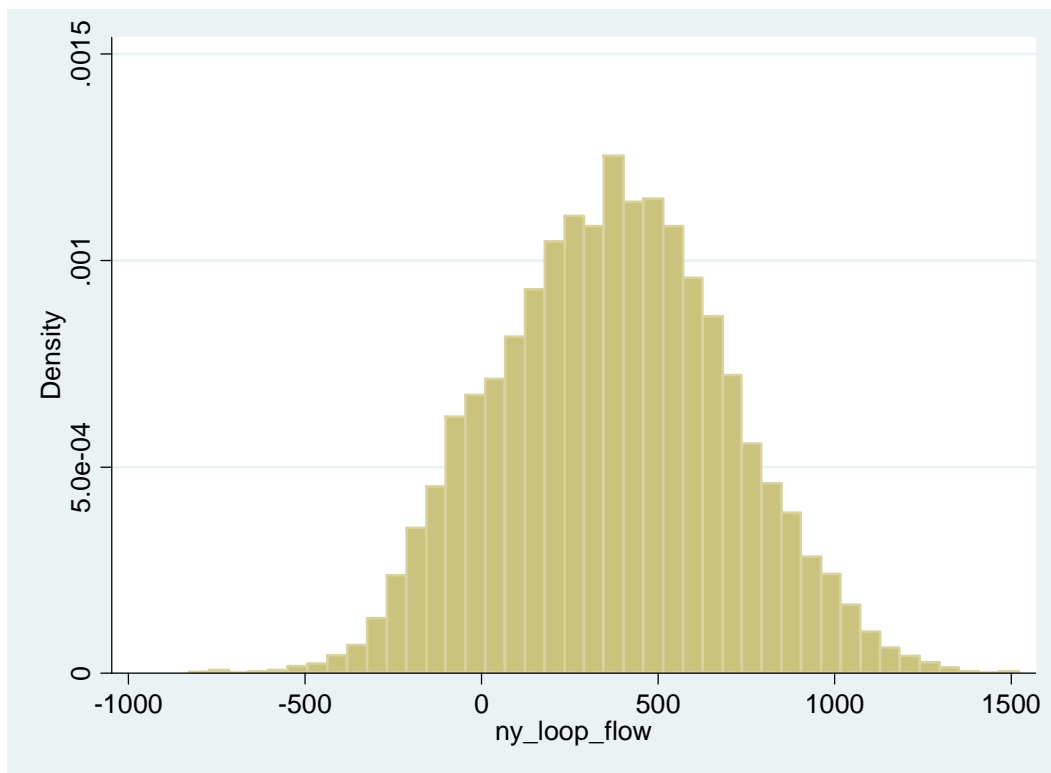
Loop Flows are Believed to be Difficult to Model

- **For example, the California ISO has found it be very challenging to model unscheduled flows at its Malin Intertie in Northern California**
- **Poor correlation with actual loop flow ($R=0.17$).**
- **Error in model of unscheduled flow sometimes exceeds the actual unscheduled flow**

Loop Flows at the Malin Intertie in Northern California



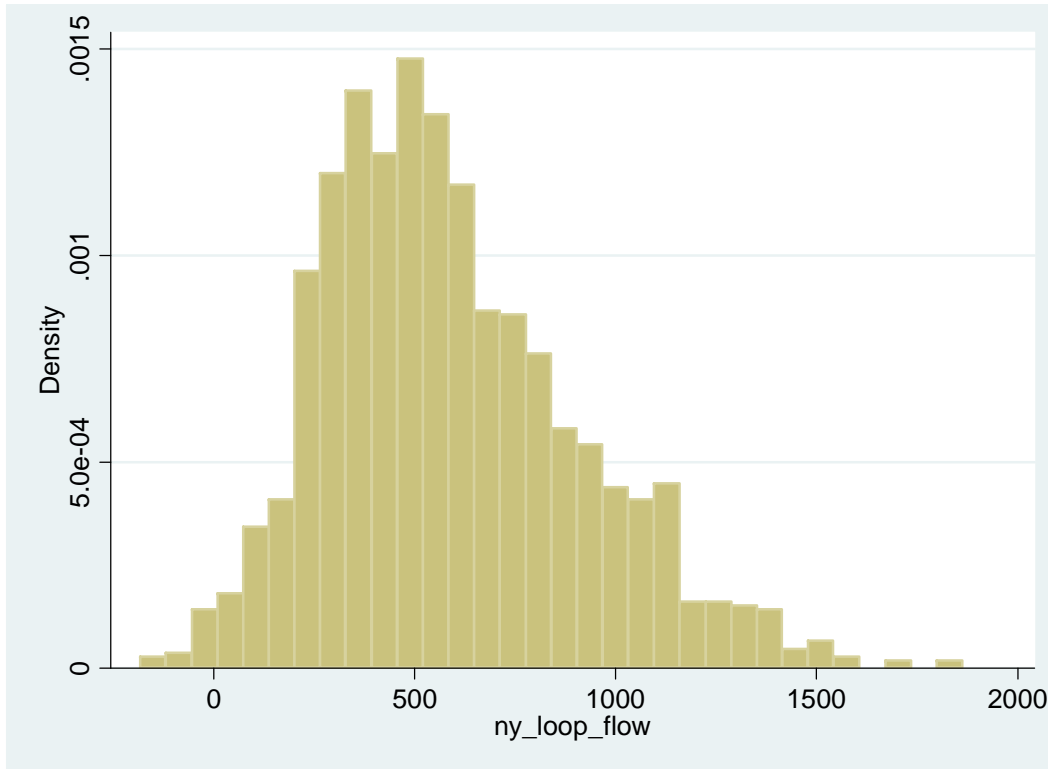
PJM's Loop Flows with the New York Power Grid During those Periods in which PJM was Scheduled to be a Net Exporter



Megawatt Hours Per Hour

When PJM was scheduled to be a net exporter, Average hourly net exports were 27 percent higher than scheduled

PJM's Loop Flows with the New York Power Grid During those Periods in which PJM was Scheduled to be a Net Importer from New York



When PJM was scheduled to be a net importer from New York, average loop flow exceeded average scheduled flow such that average hourly net exports were positive

Megawatt Hours Per Hour



Do Loop Flows Have Economic Consequences? : The Case of PJM's Loop Flows with New York

- **From economic principles, an unexpected change in electricity supply can be expected to affect the real-time price of electricity.**
- **Consistent with this expectation, a chi-square analysis indicates that the difference between PJM's real-time and day-ahead prices is statistically related with PJM's loop flows with New York. The p-value is 4.07E-154**



What Causes Loop Flows ?

PJM's Market Monitoring Unit has hypothesized that "gaming" by power producers contribute to Loop flows.

It believes that some producers schedule to deliver electricity to a particular interface only to actually deliver the electricity to another interface or another grid so as to take advantage of more favorable locational prices.



The Interface between PJM and New York

- **PJM and New York both establish Day-Ahead and Real-Time prices at their Interface.**
- **The two sets of prices are generally different.**
- **There is a clear incentive for an exporter to export more to New York when the price established by NYISO is higher than the price established by PJM.**



Geomagnetic Storms and Loop Flows

- **Power Grids are vulnerable to geomagnetic Storms because the power transmission grid acts as an “antenna” of sorts, picking up geomagnetically induced currents (GICs).**
- **These currents have the potential to induce transmission constraints which in turn may affect transmission flows.**

A Visualization of a Coronal Mass Ejection



Source: <http://sohowww.nascom.nasa.gov/spaceweather/lenticular/>



An Econometric Model of Loop Flows

- **The model examines the determinants of PJM's Loop Flows with the New York power grid.**
- **The sample will be restricted to those hours in which PJM was scheduled to be a net exporter to New York.**



Independent Variables in the Regression Equation

- **Scheduled transmission Flows**
- **Ambient temperature – included to reflect the fact that increases in temperature can degrade grid performance. Temperature is also a key driver of electricity demand.**
- **Binary variables to represent each hour of the day**
- **Binary variables to represent each month of the sample**
- **A price differential that can be “exploited”**
- **A proxy for geomagnetically induced currents**



The Proxy for Geomagnetically Induced Currents

In this study, we proxy GICs using data from the USGS operated geomagnetic observatory located in Fredericksburg Virginia.

The Estimating Equation

$$\begin{aligned} \text{NYLOOP} = & c + \Sigma a H + \Sigma b M + \alpha_1 \text{SchedFlow} + \beta_0 \text{TEMP} \\ & + \beta_1 \ln(\text{DA_P_NY}) + \beta_2 \ln(\text{DA_P_PJM}) \\ & + \beta_3 \ln(\text{DA_P_NY}) * \text{NY_P_Higher} \\ & + \delta \ln(\text{GIC}) \end{aligned}$$

Where H is a vector of binary variables representing the hour of the day

M is a vector of binary variables representing each month

SchedFlow is scheduled exports to New York

TEMP is ambient temperature

The Estimating Equation (Continued)

$$\begin{aligned} \text{NYLOOP} = & c + \Sigma a H + \Sigma b M + \alpha_1 \text{SchedFlow} + \beta_0 \text{TEMP} \\ & + \beta_1 \ln(\text{DA_P_NY}) \\ & + \beta_2 \ln(\text{DA_P_PJM}) \\ & + \beta_3 \ln(\text{DA_P_NY}) * \text{NY_P_Higher} \\ & + \delta \ln(\text{GIC}) \end{aligned}$$

DA_P_NY is the day-ahead price at the NY/PJM interface as established by the New York system operator

DA_P_PJM is the day-ahead price at the NY/PJM interface as established by PJM

NY_P_Higher is a binary variable that has a value of one if the day-ahead price established by New York is higher than the day-ahead price established by PJM

GIC is the proxy for geomagnetically induced currents

Results

- **The Coefficients β_1 and β_2 (the coefficients on the day-ahead prices) are statistically insignificant**
- **The coefficient β_3 (the coefficient on the Day-Ahead New York Price when it exceeds the PJM price) is positive and statistically significant at the one percent level.**
- **The coefficient on the natural logarithm of GIC proxy is positive and is statistically significant at the one percent level.**



Conclusions

- **Loop flows, at least in the case of PJM and New York, have economic consequences**
- **In the case of PJM and New York, a portion of the loop flows can be attributed to “gaming”**
- **A portion of loop flows can be attributed to Solar Activity.**
- **The results indicate that it should not be insurmountable to forecast loop flows. This could help make the goal of the “Smart Grid” a true reality**