Senior Project

Department of Economics

"Blowing Down Prices: An Analysis of Wind Generation and the ATSI Generation Hub Price"

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Abstract

This paper estimates the effect of wind generation on pricing in the American Transmission Systems Incorporated Generation Hub of the PJM regional transmission organization. Using a sample of 8759 hourly observations for the year 2013.Following a stationary AR(1) process, with $|p| < 1$*, I find there to be a $.08/MWH decrease in Locational Marginal Pricing for every 100 megawatt hours of wind generation, all else held constant.*

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Introduction

More than half of all states have put in place Renewable Portfolio Standards to promote generation from renewable sources (IEA).Ohio's RPS state that by 2025 at least 12.5 percent of the electricity sold by utilities must be generated from renewable sources, such as wind (Lawriter). These requirements support the expanding renewable energy production that is taking place in the U.S. and other countries around the world, as people search for alternatives to the finite supply of non-renewable sources. Global wind power capacity was 238 Gigawatts (GW) at the end of 2011, up from just 18 GW at the end of 2000, with an average growth rate of over 25% over the past five years (IEA). With this growing supply and concern for renewable energy production, the question arises of how large of an effect an increase in intermittent wind energy generation will have on the marginal costs in the competitive market? The hypothesis being that, in the short-run, it will decrease price through the Merit-Order-Effect. Past studies have looked at the Merit-Order-Effect in areas such as Germany and Texas. The purpose of this paper is to determine how renewable generation capacity affects the electricity price at the ATSI (American Transmission Systems Inc.) Generation Hub of the PJM (Pennsylvania Jersey Maryland) market, using time-series data to examine the effect that renewable generation has on the price of electricity. ATSI is the transmission subsidiary of First Energy Corp. ATSI ensures that electricity makes it from the generator to the customers of electric distributing companies. PJM is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of 13 states and the District of Columbia and who's primary task is to ensure the safety, reliability and security of the bulk electric power system (PJM).

Previous papers by, (Woo, Horowitz, and et al), examined the short term price changes associated from expanding renewable generation, in the Texas ERCOT area. This paper will do the same, for the PJM market, with a focus on the ATSI Generation Hub. There is currently a gap in the literature on renewable generation and electricity prices in the U.S., the most relevant studies examine Texas and the Pacific Northwest, but there is a lack of studies that look at short term price effects of wind generation for other Regional Transmission Organization (RTO) markets.

Literature Review

This section will go over past studies, which have laid the ground work for the application of a study on the affect that renewable generation capacity has on the electricity price. This section consists of empirical papers that examine the effect that renewable generation has on electricity price, starting with European examinations then a more local examinations of the state of Texas. Finally this section will examine the study that the rest of this paper will be replicating and how it can be applied to the PJM market.

The first article to be referenced is by (Gelabert, Labandeira, and Linares s59-s65). In this paper Galabert examines the electricity prices in Spain from 2005-2009. They use a multivariate regression model to estimate the average effect of a marginal change in the special regime, the small and renewable energy generators, on marginal electricity prices. (Gelabert, Labandeira, and Linares s59-s65) They constructed a model that examined the total mix of renewable generation, from different sources, to determine the effect that they would have on electricity prices. Their results showed that over the period from 2005-2009, the marginal cost of electricity, decreased by as much as 2 €/MWH, or roughly 4 percent of the base price, for every GWH of electricity produced by renewable sources.

The previous paper was cited by (Nicholson, Rogers, and et al), who laid the groundwork examination of the effect that wind generation has on the market price for electricity on the ERCOT market. Nicholson uses an ARMAX approach, an autoregressive–moving-average model with exogenous inputs, to determine that if wind generation in ERCOT is increased by 1 MWh between 7:00 pm and 8:00 am, the price in the Houston zone would decrease by 0.71¢/MWh. These results are repeatedly referenced by the next author, as the baseline for how wind generation should affect market prices.

The next three articles are the most relevant, as it pertains to the analysis that I conduct in the latter section of the paper. (Woo, Zarnikau, and et al b), use a two-stage regression analysis to study the state of Texas from 2007-2010. Their analysis takes into factor system load, price of gas, time and zonal dummy variables to determine their effects on the price of electricity. The results showed that a 1 GWH increase in wind generation has caused for there to be a $13/MWH to $44/MWH decrease in the price of electricity in the wholesale market.

The next paper supplies the model that I base my model off of. A second paper by, (Woo, Horowitz, and et al), examines the market price for electricity in the Texas ERCOT market. This time Woo uses a basic AR (1) model to examine the effect that increases in wind generation is having on the market price. His findings are in line with his past findings. Woo finds that a 100-MWH increase in wind generation reduces market price by $0.39/MWH in the Houston zone,$0.61/ MWH in the North zone,$0.32/MWH in the South zone and $1.53/MWH in the West zone. A price effect ranging from 2-9% off of the base price.

(Wurzburg, Labandeira, and Linares s159-s171), reference, (Woo, Horowitz, and et al), and apply his study to the entirety of the German-Austrian market. They find that day ahead electricity prices for Germany and Austria decrease by roughly 1 €/MWh for each additional expected GWh produced by renewable sources, a roughly 2% decrease in price for every GW of renewable generation produced.

The last paper, (Woo, Zarnikau, and et al), is an application, (Woo, Horowitz, and et al), that examines the level of the merit-order-effect, from wind generation, in the Pacific Northwest. The uses the same AR (1) approach to examine this area of the U.S. that is drastically different from Texas. Woo finds that a 100-MW increase in the average wind generation output results in a $0.096/MWH decrease in the market price for electricity. The most important part of the paper is that the study can be applied to areas with different characteristics and still produce consistent, yet different, results.

The papers referenced in this section are there to provide support to the analysis that I will be performing. Each paper examines the level of the effect of increases in wind generation has on the market price in their respective zones. They also provide consistent results from different estimation methods, from a two stage model to an AR (1). These papers support that conducting an analysis of the ATSI Generation Hub will be relevant and add to existing literature by providing information about an area that has not yet had this form of analysis applied to it, from a public standpoint. Private studies by organizations can't be accounted for.

Empirical Model

This paper draws upon the theoretical framework laid down by (Jensen, and Skytte 425-435), who propose that as opposed to non-renewable sources such as coal and gas, renewable sources such as wind and solar operate at zero variable costs. The only cost comes from the installation of the generation, a fixed cost, which in the market does not factor into the short-run marginal cost of the electricity. The idea, known as the Merit-Order-Effect, states that as the level of the low variable cost input enters the market it will displace the higher cost inputs and decrease the cost of the item and is the basis for how renewable generation and renewable generation programs affect the short-run marginal cost of electricity.

The price Y_t, which is the dependent variable in a linear regression model, is driven by a set of numeric variables, the load on the system (Load), the wind generation (WindGen), the Henry Hub natural gas price (HHP), the lagged price, Y_{t-1}, and a set of three time-dependent binary indicators that account for month of the year(M_{it}), day of the week(W_{jt}), and hour of the day(H_{kt}), with i=1… 11; j=1… 6; k=1… 23, respectively. Letting e_t denote a normally distributed disturbance term, e_t is assumed to follow a stationary AR (1) process with $|p| < 1$.

The model is written as:

$$Y_t = \alpha + \beta_1 Load + \beta_2 WindGen + \beta_3 HHP + \beta_4 Y_{t-1} + \beta_5 M_{it} + \beta_6 W_{jt} + \beta_7 H_{kt} + e_t$$

- **Y_t** is the hourly Locational Marginal Price at the ATSI Gen Hub for 2013.
- **Load** is the hourly load requirements for the ATSI zone. The load amount accounts for quantity demanded for the electricity market in the ATSI zone for a given hour. The hypothesis is that increasing demand will increase price: $\beta_1 > 0$
- **WindGen** is the hourly production of electricity that is attributed to wind generation in the PJM region. Theory states that increases in wind generation will lead to falling prices so I hypothesize that: $\beta_2 < 0$
- **HHP** is the hourly Henry Hub Price for natural gas. I hypothesize there to be a positive effect of increases in factor of production prices: $\beta_3 > 0$
- **Y_{t-1}** An increase in the lagged price will increase the current price. $B_4 > 0$

The binary variables capture the time dependent nature of electricity prices:

I = 1 (February)…11(December), j = 1(Saturday)…6(Thursday), k=1(1pm)…(11am).

Data

Data was collected from the Pennsylvania-Jersey-Maryland regional transmission organization and the U.S. Energy Information Agency websites(Table A). The data consists of 8760 observations from the American Transmission Systems Incorporated load zone in PJM from January 1st 2013 to December 31st of 2013. A description of the variables can be found in Table A in the appendix.

It needs to be addressed that there can be a negative price in this data set. Negative prices are a price signal on the power wholesale market that occurs when a high inflexible power generation meets low demand. Inflexible power sources can't be shut down and restarted in a quick and cost-efficient manner. In some circumstances, one may rely on these negative prices to deal with a sudden oversupply of energy and to send appropriate market signals to reduce production. In this case, producers have to compare their costs of stopping and restarting their plants with the costs of selling their energy at a negative price (which means paying instead of receiving money). (epexspot)

Empirical Results-Ordinary Least Squares

Results from the OLS estimation can be found in Table C and Table D of the appendix. The results imply that there is a $0.01/MWH decrease in the LMP for every 100MWH of wind generation, compared to the average price of $36.16/MWH, at the ATSI Gen Hub and is significant at the 99% confidence interval. This is in line with other studies that measure the merit-order-effect in the electricity market. The estimated effect for the load on the system is .001, implying that every MWH of load on the system increases price by .001/$. The parameter estimate for the lagged price is .9006, implying that the price from the previous period will increase price in the current period by 90% of the previous price. The parameter estimate for the Henry Hub Price was calculated to be .5636, in the model a $1 increase in the price of natural gas leads to a 56cent increase in the LMP at the ATSI Gen Hub. The binary variables accounting for hour of the day range from -$4.89 to $4.69 if the observation is taken at the corresponding hour. However the hours of 1am, 2am, 3am, 8am, 1pm, 3pm, and 9pm are not statistically significant in this model. The parameter estimates for the day of the week variables range from $1.14 to $.12, with Tuesday, Wednesday and Thursday not being statistically significant. Finally the estimates for month of the year range from -$.12 to $1.15 with the estimations for January, June, August and December not being statistically significant.

The model produces a R^2 of .9048, which is very high compared to the expected R^2 of past studies. The RMSE is relatively moderate at 4.66, with a mean of 36.16. It may be noted that with just a basic OLS there is no correction for serial-correlation, which may be affecting the error terms and parameter estimates in the model.

The results of a Durbin H test returned a value of 48.15, allowing me to reject the null that p=0, and conclude that there is very strong serial correlation between past observations and that OLS is not the best linear unbiased estimator.

Empirical Results-AR(1)

The results from the AR(1) regression can be found in Tables C and E in the appendix. After determining that OLS regression is biased and inefficient, the data was put through an Auto

Regression (1) that is assumed to be stationary, procedure to correct for the inadequacies of OLS regression. The model produced a R^2 of .9321, greater than the R^2 reported by the OLS regression, and a RMSE of 3.94. The RMSE is smaller than the RMSE from the OLS model, but with a mean of price at 36.16, I still interpret it as moderate. The statistically significant estimate for *p* is at -.8156, showing strong first-order negative autocorrelation. This validates the stationary assumption made for the AR (1) process.

The parameter estimate for wind generation was -.0895 and was statistically significant. That estimate implies that for every 100 MWH of wind generation, at any given hour of the day, in the PJM zone that the price of electricity at the ATSI Gen Hub decreases by $0.08/MWH, $0.07/MWH higher than the OLS parameter estimate. The parameter estimate for electrical load in the system is .0058 and is statistically significant. This is interpreted as every MWH of load on the system increases price by $.0058. The lagged price was statistically significant and reported a parameter estimate of .4701, implying that the current period price is affected by 47% of the previous period's price. The Henry Hub Price parameter estimate increases to 2.7997 and becomes statistically significant in the AR (1) model. The large increase in the estimate may be showing the importance of input prices on the cost of electricity, transitioning from 56% of the price of natural gas to 279% of the gas price having an effect on price. The binary variables estimates for hour of the day, in this model, ranged from -$2.13 to $5.75, but now 1pm, 7pm, pm, and 12am are not statistically significant. The parameter estimates for day of the week ranged from -$.53 to $2.83, with Tuesday, Wednesday and Thursday remaining insignificant. The range of parameter estimates for month of the year was -$.54 to $6.49, with January, June, Aug, and December remaining insignificant.

Conclusion

My results show there to be a \$0.08/MWH decrease in the ATSI Generating Hub price for every 100MWH of wind generation in the PJM zone. The results of my research are in-line with past results, but show that the effect that wind generation is much lower than the Texas area. This is most likely due to the amount of wind generation that comes out of Texas being larger than the wind generation in Ohio. The main point to take away from this study is that even though the impact from wind generation is lower, wind generation still has an effect on the short-run marginal costs of electricity. An interesting idea for future research would be to examine the effect that wind generation is having on the long run price. With the need for backup capacity for wind generation, you can't tell the wind when to blow, conventional production plants will need to be turned on for low wind production periods. This could lead to an overall increase in prices as these plants needing to be constantly restarted to make up for the short comings of wind generation.

There is much room for improvement. The results for all of the numerical variables in the AR (1) regression were statistically significant, but some of the binary variables were found to be insignificant. I would like to research further to see if the results are accurate or if there may be a way to correct the model to get significant results. The inclusion of data about the amounts of generation that come from other sources, such as nuclear and coal, along with their prices for the same hourly periods would add more explanatory power to the model. The addition of these variables would be predicted to reduce the estimate for how wind generation is effecting short term prices and bring it closer to the predicted value of zero. I would recommend to future researchers that they apply this analysis to other parts of the PJM market and if they have the means to acquire information on the amount of generation and their respective sources to provide more explanatory power to the model. I might be more informative to examine a larger period of time, before 2013 and to run the regression on lagged periods beyond just the last period and to determine if the price effect of wind generation is a constant across all periods or if it varies from one period to the next.

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APPENDIX

Table A: Variable Definitions, summary, and data sources		
Variable	Definition	Source
Load	Total consumption in thousands of megawatt hours by state.(7809.19, 126.15)	PJM.com
WindGen	Generation from wind sources in thousands of megawatt hours (1687.67, 1099.57)	PJM.com
LMPATSI	Wholesale Market prices for ATSI Gen Hub in dollars. (36.16, 15.08)	PJM.com
LMPLag	The price of the previous period in the ATSI zone(36.16, 15.08)	PJM.com
HHP	The Henry Hub natural gas price in dollars. (3.73, .32)	U.S. Energy Information Administration
Mon, Tues, Wed, Thurs, Fri, Sat, Sun	Dummy Variables for the day of the week the observation was taken on.	PJM.com
Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sept, Oct, Nov, Dec	Dummy Variables for the month of the year that the observation was taken on.	PJM.com
H1…H24	Dummy Variables for the hour of the day that the observation was taken on.	PJM.com
Note: The data are based upon ATSI and PJM zonal level observations from the most current available year.		

Table B

Variable Name	Number of Observation	Mean	Standard Deviation	Minimum	Maximum
WindGen	**8760**	**16.87**	**10.99**	**0**	**48.36**
LoadATSI	**8760**	**7809.19**	**1262.15**	**5003.45**	**13141.09**
LMPlag	**8759**	**36.16**	**15.08**	**9.90**	**329.97**
HHP	**8760**	**3.73**	**.0324**	**3.08**	**4.52**
LMPATSI	**8760**	**36.16**	**15.08**	**9.90**	**329.97**

Table C

Statistic	OLS	AR(1)
RMSE	**4.66**	**3.94**
R^2	**.9048**	**.9321**
Durbin H	**48.15**	**--------**

Table D		
Parameter Estimates-OLS		
Variable	**Estimate**	**t Value**
Intercept	-7.1739	-5.12
LoadATSI	0.00104	13.73
WindGen	-0.0164	-2.93
LMPlag	0.9006	200.98
HHP	0.5636	1.5
tues	0.3	1.6
wed	0.1412	0.75
thurs	0.1228	0.65
sat	0.6513	3.34
sun	1.1465	5.67
mon	0.4154	2.21
jan	0.0511	0.2
mar	0.5708	1.79
apr	1.155	2.7
may	1.0144	2.69
jun	0.2159	0.69
jul	0.55	1.94
aug	-0.1228	-0.46
sep	0.5382	1.87
oct	0.9128	3.06
nov	0.6451	2.23
dec	-0.0215	-0.05
h1	-0.3933	-1.09
h2	-1.1833	-3.24
h3	-0.5423	-1.47
h4	-0.0683	-0.19
h5	0.7156	1.95
h6	1.9445	5.39
h7	4.6989	13.32
h8	2.5578	7.34
h9	-0.1946	-0.56
h10	0.6847	1.98
h11	0.8179	2.37
h13	-0.224	-0.65
h14	0.6322	1.83
h15	0.3932	1.14
h16	0.8683	2.51
h17	1.5684	4.53
h18	1.2772	3.69
h19	-1.7203	-4.96
h20	-1.608	-4.65
h21	-0.1695	-0.49
h22	-3.5478	-10.23
h23	-4.8987	-14.04
h24	-2.5646	-7.25

Table E

Parameter Estimates-AR(1)

Variable	Estimate	t Value
Intercept	-40.8281	-7.68
LoadATSI	0.005861	25.6
WindGen	-0.0895	-5.22
LMPlag	0.4701	31.24
HHP	2.7997	1.89
tues	0.3944	0.71
wed	-0.2749	-0.52
thurs	-0.5311	-1.17
sat	1.9818	4.34
sun	2.8395	5.29
mon	1.0672	1.93
jan	0.2232	0.2
mar	3.226	2.46
apr	6.4918	3.81
may	5.6251	3.68
jun	1.4205	1.08
jul	2.6976	2.23
aug	-0.5415	-0.47
sep	3.1287	2.58
oct	5.0404	4.04
nov	3.5414	2.87
dec	0.1103	0.06
h1	3.4381	6.24
h2	3.5625	6.17
h3	4.1293	7.02
h4	4.4351	7.53
h5	4.6786	8.19
h6	4.6779	8.93
h7	5.7519	12.65
h8	3.8379	9.61
h9	1.1095	3.14
h10	0.9326	3.15
h11	0.6341	2.92
h13	-0.2031	-0.94
h14	0.5523	1.89
h15	1.046	3.06
h16	2.0705	5.48
h17	3.1382	7.75
h18	3.1404	7.35
h19	0.5861	1.32
h20	0.1317	0.29
h21	1.0081	2.2
h22	-1.4897	-3.19
h23	-2.1322	-4.41
h24	0.5357	1.04
p	-0.8156	-78.75