A Retrospective Analysis of the Impact of Wind Power Generation on Residential Natural Gas Prices in the United States

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Abstract

Heightened concern over the environmental impact and price volatility of natural gas has led to an increased demand for renewable energy. Wind energy is one of the fastest-growing sources of electricity and is the United States' top renewable energy source. As a substitute for natural gas, wind energy has a direct impact on the demand for natural gas and consequently, the price. Using data from the U.S. Energy Information Administration, the Bureau of Economic Analysis, and the U.S. NOAA, this paper determines a causal relationship between wind generation and natural gas prices because of the random component of weather. Employing an ordinary least squares regression with a fixed effect controlling for the month and state, I conclude that a one-percent increase in wind generation leads to a 1.80 percent drop in residential natural gas prices.

Keywords: Wind power generation; Natural gas prices; Renewable energy

I. Introduction and Motivation

With growing concern over carbon emissions, air pollution, and rising sea levels; wind power generation is playing a leading role in the transition to renewable energy. Wind energy has seen dramatic growth over the past decade, with capacity quadrupling since 2008. It is now considered America's top renewable energy source, contributing to 7% of the country's total electricity. As an environmentally sustainable alternative to coal and natural gas, wind saves 102 billion gallons of water every year and lowers annual CO_2 emissions the equivalent amount of 42 million cars. Supporting economic development, the wind industry employs 120,000 workers, delivers $1.6 billion in tax and lease payments, and is the most affordable type of new electricity (AWEA 2019). Since 2000, most new power generation capacity in the United States has come from natural gas and wind. Being wind's biggest competitor, the price of natural gas-fired generation is highly volatile and a key determinate in the demand for wind-generation (U.S. Department of Energy 2013).

The demand for natural gas is driven by three main factors: variations in weather, economic growth, and the availability and cost of other fuels (EIA 2020). Economic theory teaches that generally, increases in demand lead to higher prices and decreases in demand lead to lower prices. If the price of wind energy drops relative to natural gas prices, this incentivizes consumers to switch from natural gas energy to wind energy. Likewise, if prices of wind energy rise relative to natural gas prices, consumers would likely use more natural gas energy. As wind generation increases in supply, prices drop to reflect the new equilibrium level of consumption. Since the demand for natural gas depends on the cost of alternative fuels, it is expected that wind energy generation could have a significant impact on natural gas prices.

This paper aims to explore the extent of how the increasing market for wind power generation affects natural gas prices in the United States using a series of statewide data on net wind generation, residential natural gas prices, GDP, and average monthly temperature. The data is from the U.S. Energy Information Administration, the Bureau of Economic Analysis, and the U.S. NOAA over the period 2010 to 2020. Using an ordinary least squares regression analysis with a state and month fixed effect as my main specification, I extended the analysis to determine if GDP and temperature are alternative drivers of natural gas prices. With the market share of renewable energy ever increasing, understanding this relationship is vital.

II. Literature Review

Multiple studies have shown the impact of the demand for renewable energy on natural gas prices. This is often done through evaluating Renewable Portfolio Standards (RPS), policies that require electricity suppliers to increase their percentage allocation of renewable energy in their total supply portfolio. Wiser and Bolinger (2007) summarized the results from past RPS studies conducted by the U.S. Department of Energy's Energy Information Administration (EIA) as detailed in *Table 1*.

Table 1:

Summary of past EIA Renewable Portfolio Standard Studies (Wiser and Bolinger 2007)

Author	RPS/EE	Increase in US renewables TWh (% of total generation)	Reduction in US gas consumption Quads (%)	Gas wellhead price reduction $/MMBtu (%)
EIA (1998)	10%-2010 (US)	336 (6.7%)	1.12 (3.4%)	0.34 (12.9%)
EIA (1999)	7.5%-2020 (US)	186 (3.7%)	0.41 (1.3%)	0.19 (6.6%)
EIA (2001)	10%-2020 (US)	335 (6.7%)	1.45 (4.0%)	0.27 (8.4%)
EIA (2001)	20%-2020 (US)	800 (16.0%)	3.89 (10.8%)	0.56 (17.4%)
EIA (2002a)	10%-2020 (US)	256 (5.1%)	0.72 (2.1%)	0.12 (3.7%)
EIA (2002a)	20%-2020 (US)	372 (7.4%)	1.32 (3.8%)	0.22 (6.7%)
EIA (2003)	10%-2020 (US)	135 (2.7%)	0.48 (1.4%)	0.00 (0.0%)

All data is for 2020.
All dollar figures are in constant 2000$.
The reference case is from EIA Annual Energy Outlook (AEO) reference case
Calculated using data from EIA's national energy model (NEMS)

In short, the EIA found that if renewable energy generation increases, there is a significant decrease in gas consumption resulting in a modest reduction in wellhead prices. Wiser and Bolinger (2007) expanded on this finding and explored the reasonableness of the price-suspension effect and benchmarked this model against economic theory. They concluded the downward pressure of natural gas prices provided a significant benefit to consumers. Having 10% of the country's electricity come from renewable resources will translate into a 10% reduction in natural gas prices (Wiser and Bolinger 2007). Similar conclusions were reported by Barbose et al. (2016). Assessing RPS program's benefits and impacts on a national level, they found that complying with RPS obligations reduced natural gas prices by about $0.05 to $0.14/MMBtu. This translates into a total consumer savings of $1.3 billion to $3.7 billion based on 2013 prices (Barbose et al. 2016). Fischer (2010) extended this conversation to the electricity price-effect's impact on society as a whole using economic theory. She suggested that an RPS can act as both a subsidy for producers of renewable energy and as an implicit tax on producers of nonrenewable energy. Contradicting previous studies, Fischer found that the price impacts are ambiguous depending on whether the tax effect or subsidy effect dominates (Fischer 2010).

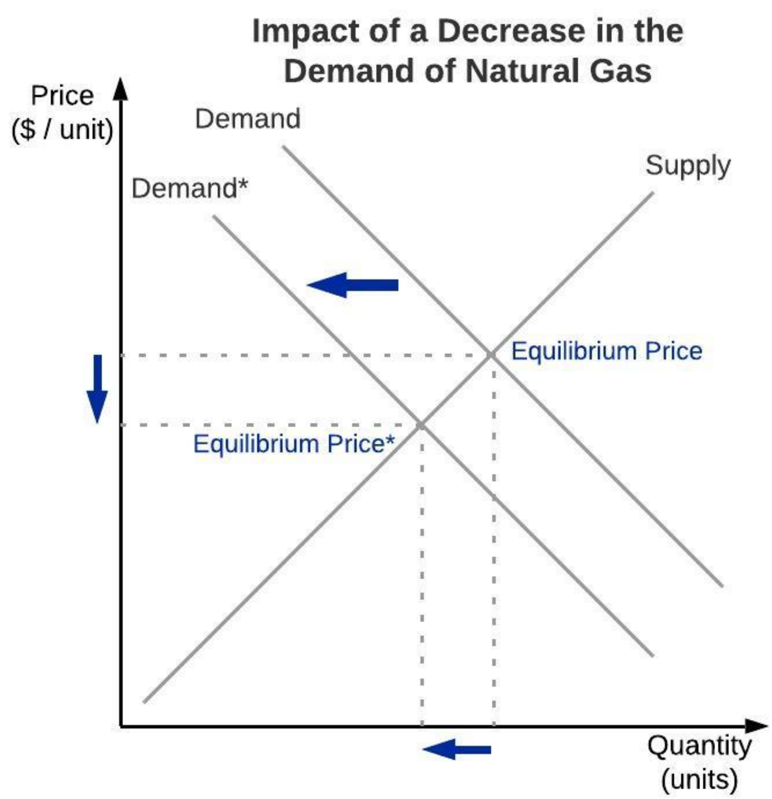
While the impact of renewable energy on natural gas prices has been studied extensively, less is known about the specific relationship between natural gas prices and wind energy. Berry (2005) examined whether wind energy proves to be an effective hedge for the price volatility of the natural gas market and in which conditions it proves to be the most beneficial. He concluded that not only does wind energy provide environmental benefits, but it can be successfully used as a hedge to manage risk from natural gas prices. The extent of the financial benefits depends on the availability of wind resources and on operating costs (Berry 2005).

Other researchers have explored the relationship between wind energy and natural gas in terms of environmental costs. McCubbin and Sovacool (2013) analyzed two wind farms and projected that, over the next two decades, the combined impact of both wind farms could lead to savings from human health and climate-related externalities as high as $4.48 billion. Although previous literature extensively evaluated renewable energy as a whole, there has been little discussion regarding which specific types of renewable energy sources are driving the downward pressure of natural gas prices. The following sections propose to build upon this research and provide an unexplored perspective of the strength of the relationship between residential natural gas prices and wind generation. Unlike previous research, this paper evaluates this effect on a month-by-month and state-by-state basis controlling for other factors that influence natural gas prices like GDP and temperature. Using data from 2010 to 2020, it takes an updated look on the previous studies, largely from the previous decade

III. Conceptual Model

Economic theory supports the notion that an increase in demand for wind energy will consequently decrease the demand for natural gas because they are substitute goods. This will cause an indirect effect on the price of natural gas, lowering it to reflect the new decreased level of demand illustrated in *Figure 1*.

Figure 1:



To examine the extent of the price change, I will test the research question: Does an increase in the net generation of wind decrease the average cost of natural gas? To explore this relationship, the null and alternative hypothesis are as follow:

$$H_0 : \beta_1 = 0$$

$$H_A : \beta_1 \neq 0$$

$$\beta_1 \; represents \; the \; regression \; coefficent \; on \; net \; generation \; of \; wind$$

IV. Empirical Strategy

To analyze the impact wind generation has on natural gas prices, I will use a series of three panel ordinary least squares (OLS) regressions as my main specification. The first regression will examine the impact of wind generation on natural gas prices with no fixed effects. The second will include a month and year fixed effect to eliminate biases from temporal factors that are common to all states. Building on the second, the third regression also includes a fixed effect for states to further control for factors that are specific to individual states and are assumed not to vary over the timeframe such as a population's sentiment to renewable energy, zoning laws, or the political system. I chose to focus post- 2010 to minimize the economic effects from the 2008 Financial Crisis. The logarithm of residential natural gas prices, wind generation, and GDP will be used to simplify the interpretation of the model by estimating the percentage effect of each variable. Due to some data points having zero wind generation, the data was adjusted upward by one so the logarithm could be taken. A causal effect can likely be determined because wind depends on nature which exhibits a strong random component. The three models are as follows:

$$\log(Gas\ Price_{it}) = \beta_0 + \beta_1 \log(Wind_{it}) + \beta_2 \log(GDP_{it}) + \beta_3 Temperature_{it} + \varepsilon_{it} \quad (1)$$

$$\log(Gas\ Price_{it}) = \beta_0 + \beta_1 \log(Wind_{it}) + \beta_2 log(GDP_{it}) + \beta_3 Temperature_{it} + \delta_m + \varepsilon_{it} \quad (2)$$

$$\log(Gas\ Price_{it}) = \beta_0 + \beta_1 \log(Wind_{it}) + \beta_2 \log(GDP_{it}) + \beta_3 Temperature_{it} + \delta_m + \gamma_s + \varepsilon_{it} \quad (3)$$

The variable $\log(Gas\ Price_{it})$ is the natural logarithm of the main outcome variable measured in the percentage change of dollars per thousand cubic feet. The variable $\log(Wind_{it})$ represents the natural logarithm of net generation for wind measured in the percentage change of thousand megawatt-hours. The natural logarithm of the statewide GDP measured in the percentage change of millions of chained 2012 USD is denoted by the variable GDP_{it}. The average monthly temperature per state in degrees Fahrenheit is $Temperature_{it}$. Lastly, the month and year fixed effect is δ_m and the state fixed effect is γ_s. The coefficients β_1 and β_2 will be interpreted as the percentage impact on residential natural gas prices from a one percent increase in wind or GDP, respectively. The coefficient β_3 will be interpreted as the percentage impact of one additional Fahrenheit of temperature on residential natural gas prices.

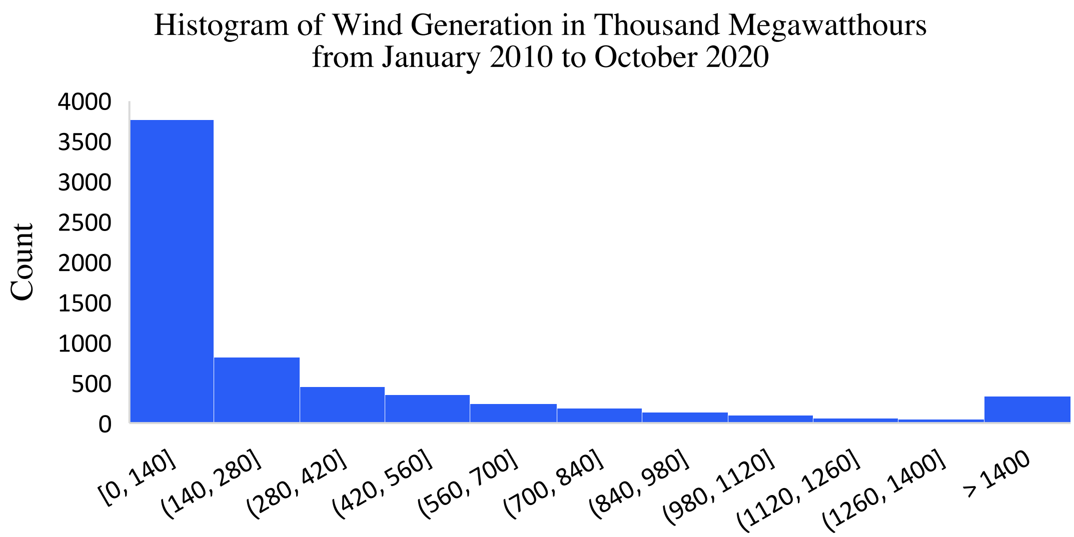
I hypothesize the regression models will show a negative relationship between natural gas prices and wind generation, consistent with previous literature. Unlike past studies that measured the impact of renewable energy generation on natural gas prices, I predict the results will be less substantial when focusing solely on wind generation. The previous studies lacked an exploration of the relationship between GDP and temperature on natural gas prices, which I expect has a significant impact on prices and, if included, could lessen the possibility of omitted variables bias. Economic theory states that a growing GDP produces inflation which pushes upward pressure on the prices of goods. Therefore, I presume the relationship between GDP and natural gas prices to be positive. The average monthly temperature is expected to have a negative relationship with natural gas prices. I predict prices to rise in the colder seasons and lower in warmer seasons. Although there are likely other variables that impact natural gas prices, the inclusion of fixed effects will control for all other factors that are specific to states and months.

Some drawbacks with time-series data that Beran (2018) suggests are the limitations imposed by a maximum sample size and the likelihood of incomplete observations. There is also the possible problem of data collection issues or correlation between states. To ensure the results aren't mistakenly interpreted, I assume that the data adheres to the following OLS regression assumptions summarized by Benchimol (2020): i) a normal distribution of residuals and strict exogeneity, ii) linear dependence, iii) homoscedasticity, iv) autocorrelation. I assume the large sample size of 6500 observations successfully meets the aforesaid conditions so I can move forward with the subsequent OLS regressions in R. R is used to perform the statistical computations because of its ability to effectively handle and graphically present data. Furthermore, being a popular computer language, it makes successive reproductions of the results easily accessible.

V. Description of Data

Similarly to EIA in their studies of RPS's effect on natural gas prices, I am using data from monthly survey reports collected by the U.S. Energy Information Administration (EIA), the Federal Energy Regulatory Commission (FERC), and the Office of Fossil Energy of the U.S. Department of Energy (DOE). I am narrowing my focus on the natural logarithm of residential prices to give a clearer picture of how the relationship affects everyday consumers. Likewise, the data on the natural logarithm of net generation for wind comes from the EIA compiled survey results from their Form EIA-826. *Figure A* illustrates the distribution of wind generation in our data set. The right skewed shape reveals the majority of data points have a net wind generation of less than 140 thousand megawatt-hours.

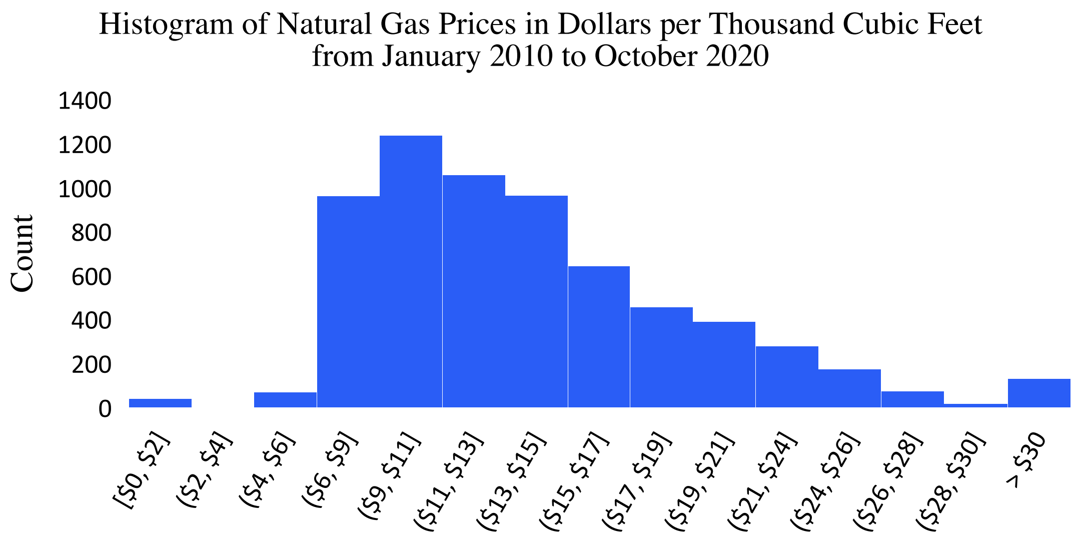
Figure A:



Notes: Based on data from the U.S. Energy Information Administration

Figure B demonstrates the histogram of residential natural gas prices in dollars per thousand cubic feet. Skewing to the right, the majority of data is in the $9 to $17 range with an average price of about $14. There are a few outliers with some prices under $2 and others reaching over $30.

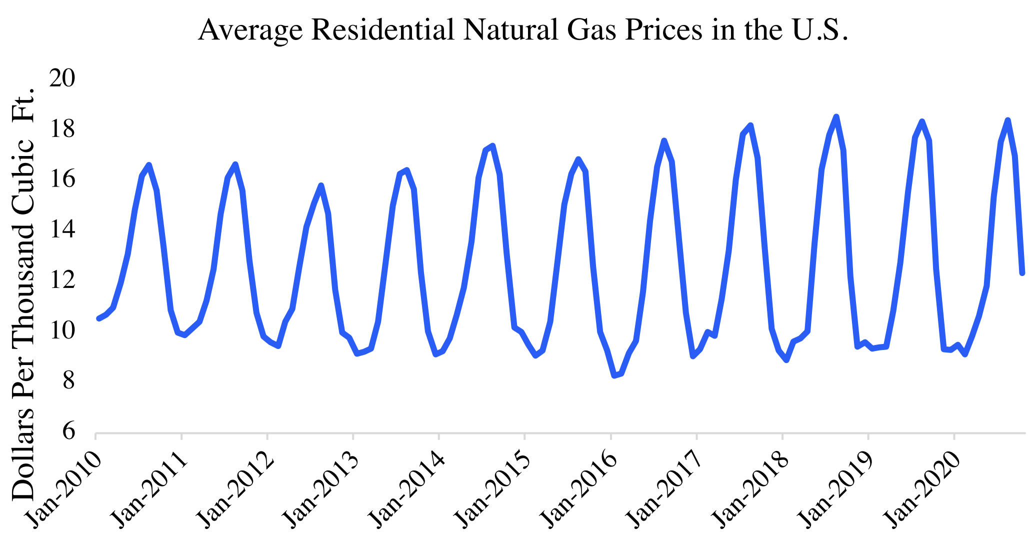
Figure B:



Notes: Based on data from the U.S. Energy Information Administration

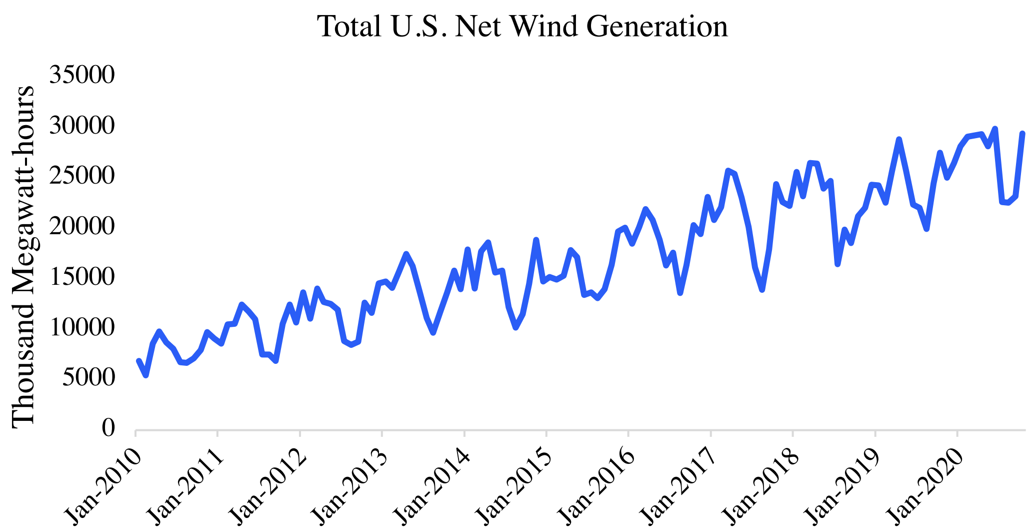
As illustrated in *Figure C* and *Figure D*, net generation of wind energy has been substantially rising over the years while gas prices have become slightly more volatile. The regression will let us measure if this is due to a relationship between the variables.

Figure C:



Notes: Based on data from the U.S. Energy Information Administration

Figure D:



Notes: Based on data from the U.S. Energy Information Administration

Including the additional variables GDP and temperature will let me further develop the causational relationship between wind generation and natural gas prices. Since GDP is a major indicator in the health of a state's economy, it could have influence on the prices of consumer goods including natural gas. Data for each state's GDP was collected from the United States' Bureau of Economic Analysis (BEA). The data is provided on the state level in quarterly intervals. To make it consistent with my model, I represented each month's GDP by its respective quarter. The variable temperature was included since natural gas prices are highly volatile and demand changes drastically based on the season. Data on each state's temperature was collected from the United States NOAA National Centers for Environmental Information climate divisional database.

The number of observations, mean, standard deviation, minimum, and maximum of the logarithmic adjusted variables are summarized *Output A*.

Output A: Summary Statistics for Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Gas Price	6500	2.545	0.443	0.000	4.106
Wind	6500	3.697	2.629	0.000	9.092
GDP	6500	12.199	1.032	10.169	14.862
Temperature	6500	51.833	19.328	-12.800	89.200

Notes: The variable Gas Price represents the log of natural gas prices. The variable Wind represents the log of net wind generation. The variable GDP represents the log of GDP. The variable Temperature represents temperature. Data from the U.S. Energy Information Administration, the Bureau of Economic Analysis, and the U.S. NOAA. Summary statistics represent the period from January 2010 to October 2020.

VI. Results

The following table summarizes the ordinary least squares regression results in R from regression equations 1, 2, and 3:

Output B: Summary Table of Coefficients from OLS Regressions 1, 2, and 3

	(1)	(2)	(3)
Variable	No Fixed Effects	Month/Year Fixed	Month/Year and State Fixed
Wind	-0.0362***	-0.0544***	-0.0180**
GDP	-0.0133**	0.0527***	-0.0563
Temperature	0.0075***	-0.0063***	0.0079***
constant	2.4518***	2.3078***	2.9577**
R-squared	0.1798	0.3838	0.6752
Obs	6500	6500	6500
df	6496	6475	6426

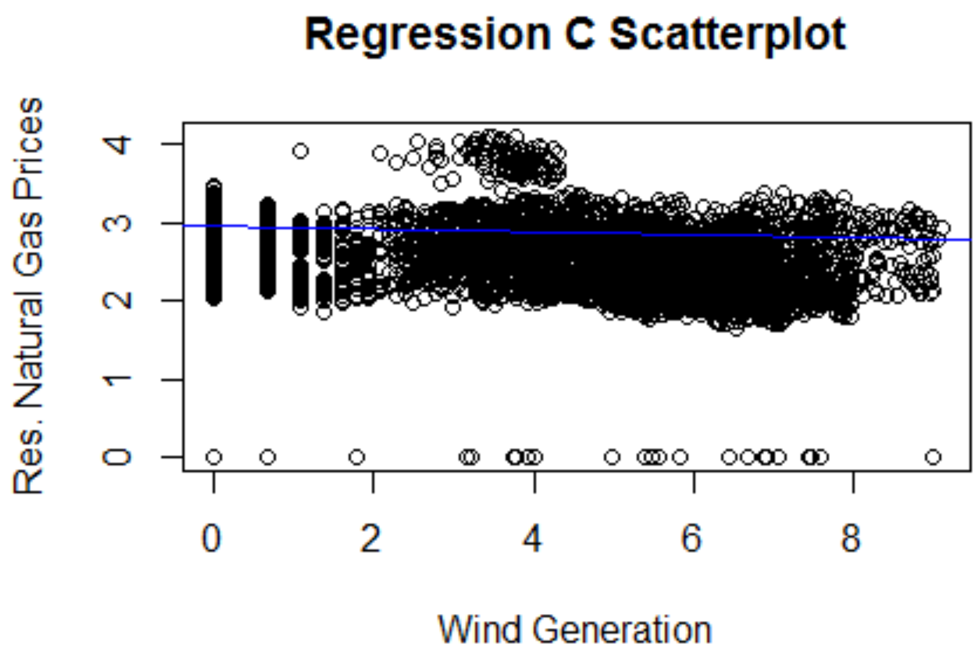
Notes: Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Column Variable represents the variables of the log of wind generation, the log of GDP, temperature, and the regression constant. (1) No Fixed Effects is the OLS regression coefficient with no fixed effects. (2) Month/Year Fixed are the OLS panel regression coefficients fixing the month and year. (3) Month/Year and State Fixed is the OLS panel regression coefficient fixing the month, year, and state. Data from the U.S. Energy Information Administration, the Bureau of Economic Analysis, and the U.S. NOAA. Panel length over the period from January 2010 to October 2020.

As hypothesized, net wind generation was significant in all three regressions at the 99.9% confidence level. I can reject the null hypothesis that the coefficient on wind is zero. In regression one, two, and three, the coefficient on wind is negative denoting that a one-percent increase in net wind generation is expected to decrease natural gas prices by 3.62%, 5.44%, and 1.80%, respectively. Typically, adding more fixed effects attenuates the size of the coefficient. This is pertinent in the lower coefficient in regression three versus the first regression with no fixed effect. The negative coefficient supports conclusions from previous literature that an increase in wind generation puts downward pressure on natural gas prices. In past EIA studies shown in *Table 1*, renewable portfolio standards reduced wellhead gas prices by an average of 8.10%. My results show less of an impact but this intuitive because the scope of renewable energy is a lot greater than exclusively wind energy.

In regression one, the variable GDP has a negative relationship with natural gas prices while regression two shows a positive correlation. Both are significant at the 99.9% level. Including the month and state fixed effects in regression three, GDP is insignificant at the 90% level, meaning I cannot conclude that a noteworthy relationship exists. With 100% confidence, I can say the variable temperature is significant among all three regressions. When controlling for month and state, a one-degree increase in Fahrenheit leads to a 0.79% increase in natural gas prices. The direction of the relationship differs from what was expected, anticipating a negative relationship across all three regressions. Typically, the increased demand for energy in colder seasons puts upward pressure on prices while the lowered demand in warmer seasons puts downward pressure. Yet, in regressions one and three it turned out to be a positive relationship, the explanation of which may be the subject of a future analysis.

Regression three has the highest R-squared value indicating the model explains 67.52% of the variability of the data around the mean. Shown in *Figure E*, it is clear that there is a moderately linear negative correlation between wind generation and natural gas prices.

Figure E: Scatter Plot of Regression C



Notes: Based on data from the U.S. Energy Information Administration

VII. Discussion

A greater understanding of the relationship between natural gas prices and wind generation is necessary to make informed policy decisions. Rapid growth in population, economics, and technology over the past 200 years has led to a climate crisis. Without significant change, greenhouses gases such as CO_2, CH_4, and N_2O will create irreversible, long-term changes in the earth's climate (McCubbin and Sovacool 2013). Cumulative lifecycle CO_2-equivalent emissions for natural gas-powered electricity can exceed 1100lbs/MW. In comparison, cumulative lifecycle CO_2-equivalent emissions for wind power range from 22-66 lbs/MWh (Weisser 2007; Hondo 2005). Policy recommendations that encourage wind energy have considerable environmental benefits which is necessary to combat the climate crisis.

My analysis concludes that wind energy is not only advantageous from an environmental perspective, but economically speaking, it translates into high costs savings. A Lazard (2018) analysis on the levelized cost of energy found that on average the unsubsidized cost for wind energy is between $29 and $56 per MWh. Natural-gas combined cycle is more costly at $41 to $74 per MWh. Increasing wind generation has the potential to reduce energy costs for consumers while simultaneously reducing natural gas prices. In 2019, the United States used 31 trillion cubic feet of natural gas, accounting for 32% of the total primary energy consumption (EIA 2019). The United States is still significantly reliant on natural gas, and the downward pressure wind energy has on prices can amount to substantial cost savings. Supporting policy proposals that increase usage of wind energy has clear future benefits both environmentally and economically.

VIII. Conclusion

Concerns about the environmental impact and price volatility of natural gas have grown over the past few decades and have led to a demand for alternative energy sources. Wind generation has been at the forefront of the clean energy movement, becoming the United States' top renewable resource. Using data from the U.S. Energy Information Administration, the Bureau of Economic Analysis, and the U.S. NOAA over the period from 2010 to 2020, I performed a series of three panel OLS regressions. Results from my analysis confirm that a one percent increase in wind generation decreases expected residential natural gas prices by 1.80% when controlling for a month, year, and state fixed effect.

This is in agreement with findings by Wiser and Bolinger (2007) and Barbose et al. (2016) that renewable energy is a substitute good for natural gas and an increase in renewable energy generation causes a decrease in natural gas prices. Due to the nature of the data, we can conclude causality. While wind generation behaved as expected, the results from GDP and temperature were ambiguous making them potentially intriguing variables of interest in future studies. With environmentally conscious decisions being a major topic of public discourse and policymaking, this paper supports the notion that an increased deployment of wind generation will benefit consumers in the form of lower natural gas prices.

Future research on the total cost advantages of wind energy would be beneficial to examine the application of my findings to specific policy proposals. There is debate over the practicability of the high initial infrastructure costs of wind energy. Analyses examining the net benefit of wind energy including indirect costs, such as the savings from decreases in natural gas prices, could further support the argument for increasing wind generation.

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