What's Powering Wind?
The Role of Prices and Policies in Determining the Amount of Wind Energy Development in the United States (1994-2008)

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> "Pop quiz: what source of power doesn't come out
> of the ground, doesn't burn and isn't radioactive?
> Hint: it contributed the most new electricity generation
> to the U.S. grid in 2008.
> The answer is wind power, the technology that
> has become synonymous with going green." (Walsh, 2009)

Purpose

This paper examines the influence of electricity markets and renewable energy regulations on the growth of wind energy development across the United States from 1994 through 2008. This time period encompasses the expansion of commercial scale wind development beyond states such as California, which participated in the nascent wind market in the 1980s. Since then wind energy production has grown into a more geographically dispersed and established industry. This paper contributes to existing literature on wind development by providing a theoretical and empirical framework to analyze the combined influence of both regulatory and market factors.

Other papers have focused on analyzing the efficacy of specific policies regarding renewable energy development. Several articles define the basic components of a Renewables Portfolio Standard (RPS) and include information on the evolution of RPS implementation across and within states (Langniss and Wiser, 2003; Rader and Norgaard, 1996; Wiser et al, 2007; Wiser and Barbose, 2007; Wiser, Porter, and Grace, 2004; Cory and Swezey, 2007) Overwhelmingly this literature has argued that RPS are effective in increasing renewables development. In addition to the work on RPS, Gouchoe, Everette and Haynes (2002) provide a case study of ten financial incentives across six states, including a list of recommendations for a better design of financial incentives. Their paper uses the same data source, the Database of State Incentives for Renewables & Efficiency (DSIRE) database, that I use in this analysis. (DSIRE, db) An important contribution of my work is the theoretical model and empirical analysis of the influence of regulations rather than a descriptive case study of these programs. Also, much of the existing literature focuses on a short time frame, while this paper includes a fifteen year time period.[1]

In addition to the literature that is focused solely on policy determinants, Bird et al (2005) provide descriptive work focused on both policy and market factors that are influencing wind energy development across states. They argued that state tax and financial incentives along with RPS are important policies to encourage wind development. In addition, they contended that lower costs for wind projects are due in part to technological improvements in wind turbines and in part to federal tax incentives including the Federal Production Tax Credit (PTC). They also maintained that high and volatile natural gas prices have led to increases in wind development by making wind more cost effective. (Bird et al, 2005, p. 1405)

Menz and Vachon (2006) extended the literature on wind energy development beyond a descriptive case study approach to an OLS analysis using multiple state policies. Their cross-sectional specification covered the time period from 1998 through 2003 across 39 states and included a binary indicator for each regulation and a control for wind potential. Some of their key findings were that RPS and mandatory green power option programs are positively related to increases in wind energy development. My work improves on their empirical analysis because it includes a panel specification that focuses on states with significant wind energy potential. I exclude states that have enacted renewables policies but do not have the resources to develop wind capacity.[2] Second, by including market controls the role of policies can be analyzed in the

[1] Due to limitations on some data a shorter analysis from 1998-2008 was also completed.

[2] Due to their limited number of observations, Menz and Vachon (2006) were not able to exclude state's that do not have sufficient wind potential for commercial wind production. (See (DOE, WPA) for information on each state's commercial scale wind development potential.)

context of existing market constraints. Lastly, my project expands the set of policies that are studied.[3]

Building on the work of Menz and Vachon (2006), Carley (2009) also provides an empirical analysis of the impact of renewable energy policies, including RPS. Her focus, however, is on renewable electricity generation rather than wind capacity. Sine and Lee (2008) also empirically examined the role of policies on wind energy development. However, their focus was on predicting the number of wind energy projects that were registered with the Federal Energy Regulation Commission (FERC) between 1978 and 1992. Though the authors' focused on the wind energy market, their goal in identifying the determinants of development in the early stages of the wind market are quite distinct from the focus of my project. It is interesting to note that they do find that state regulations generally had an impact in terms of wind development during the nascent years of the wind energy market. My project extends this analysis on the role of policies in the development of the wind industry beyond its initial establishment as a market, during a time of rapid expansion both within and across states. Overall, while there has been some descriptive work on the role of markets and policies in determining the amount of wind development in the United States and some empirical work on the role of regulations in wind development, this project is the first to synthesize the role that prices and policies played in influencing the growth of the U.S. wind industry during the time when it was expanding nationwide.

Background

Wind energy development is motivated by a complex set of factors. It is determined in part by the need to find renewable energy sources in the face of declining fossil fuel resources. It

[3] See the Data Section for a complete description of each renewable policy.

is also propelled by increasing concerns over climate change and the desire to implement energy production technologies that do not add additional carbon dioxide into the atmosphere. Due to the lower cost of wind compared with other renewable energy sources, particularly solar, wind has become the dominant non-hydrogen renewable energy source.

Wind is an abundant renewable energy resource in the United States. It is estimated that wind energy could supply 20% of the electricity in the United States. (Elliott, Wendell, and Glower, 1991, p. v) This estimate is derived from wind potential estimates produced by the Pacific Northwest Laboratory in 1991.[4] (Elliott, Wendell, and Glower, 1991) While these statistics are only theoretically feasible and are constrained by a set of assumptions including the absence of transmission limitations, they do demonstrate the abundance of wind resources in the United States. To emphasize the theoretically feasible supply of wind energy in the U.S., it is often noted that "the wind potential of just three states – North and South Dakota and Texas – could supply all the country's electricity." (Gipe, 1995, p. xiii-xiv) The impressive U.S. wind potential findings in this 1991 report are reinforced by a new 2010 wind potential study. The wind potential estimates in the new report exceed those presented previously due to improvements in wind technology. Due in part to this vast potential wind development has been increasing significantly in recent years.

<u>History of Wind Development in the United States</u>

Commercial wind development in the United States began in the 1980s. It was the first time in U.S. history that wind energy projects included multiple wind turbines sited together rather than implementing a single turbine at each site. (Gipe, 1995, p.13) It was during this time that the notion of a wind farm developed. The impetus for wind development was the same as

[4] Wind potential calculations indicate the amount of wind that a state or region is theoretically capable of producing under a specific set of assumptions.

that for all renewable energy, a “scramble to develop alternative energy after the oil embargoes of the 1970s.” (Gipe, 1995, p.2) This initial commercial wind development in the 1980s was limited to a few states, primarily California.[5] The mid-1980s represented the first peak in wind development This peak however pales in comparison to the growth in wind capacity that has been seen since then. [6,7]

The growth of wind energy development in the United States since the 1980s has been a tale of two decades. A lull in the early 1990s was followed by a period of significant increase in wind capacity additions beginning in the late 1990s.[8] (AWEA, projects db) By 2000, wind projects were dramatically increasing in size compared with their 1980s counterparts. Total wind capacity was also increasing, by 2003 U.S. wind energy capacity had maintained an average annual growth rate of 24.5 percent for the previous five years and as of 2005 the United States was the worldwide leader in wind capacity additions. (WPO, 2003, p.2) This trend continued through 2008, which proved to be a record year. “Wind installations in 2008 were not only the largest on record in the U.S., but were more than 60% higher than the previous U.S. record, set in 2007.” (WPO, 2008, p. 3)

While wind projects have been sprouting up throughout the United States, the increase in U.S. wind capacity is not matched by a correspondingly dramatic increase in terms of renewable electricity production from wind. Wind power in 1999 provided less than 1% of total U.S. electricity. (GWEMR, 1999, p. 1) This remained true though 2006 and by 2008 wind generated

[5] According to the AWEA projects database Minnesota had one small wind project, < 1 MW in 1987. All other wind projects prior to 1992 were in California.

[6] The 1980s peak coincided with the expiration of federal energy tax credits in 1985 and California state energy tax credits which also expired in the mid-1980s.

[7] Capacity, measured in megawatts, is the amount of power that a wind turbine is capable of producing. (Gipe 1995, p.9) To determine a state’s capacity, individual turbine capacities are first summed for each wind project and then the project wind capacities are added to determine a state and year wind capacity measure.

[8] Wind capacity in this paper is measured in two different ways, wind capacity additions and cumulative wind capacity. Wind capacity additions are the megawatts of wind capacity that are added in each state and year. Cumulative wind capacity is the total available wind capacity for each state and year.

only 1.25% of the nation's electricity. (WPO, 2006, p. 1; AWEA, AWIR, p.2) Despite this small increase in the percentage of total electricity generated from wind, it has made inroads in terms of new generating capacity. From 2000 to 2004 wind contributed only 4 percent of all new electricity generating capacity in the United States (Wiser and Bolinger 2009, p. iii) Since then there has been a steady rise. In 2005, wind's contribution increased to 12 percent. For 2006, it rose again to 18 percent. (Wiser and Bolinger 2009, p. iii) Subsequently, for 2007 and 2008, the rise was dramatic, in 2007 and 2008 wind accounted for 35 percent and 42 percent of new electricity generating capacity. (Wiser and Bolinger 2009, p. iii) In fact, 2008 was the fourth consecutive year when wind power was second only to natural gas in terms of electricity generating capacity added. (Wiser and Bolinger 2009, p. iii)

To understand the factors that are leading to this increased development I provide a theoretical framework which models a robust set of policy and market factors which may have influenced wind development. This framework includes both sides of the wind energy market, wind producers and wind energy consumers.

Theoretical Framework

I base the theoretical framework on the standard economic supply and demand model. In this case, the supply side is determined by wind producers who provide the available wind energy for wind generated electricity, while the demand side is driven by electricity producers who demand renewable electricity.

Supply

The supply side focuses on a profit maximizing wind developer such that firms produce the profit maximizing level of wind energy for wind generated electricity. For the *j-th* producer:

$$q_j = g(x_j, y_j) \qquad (1)$$

Wind energy for wind generated electricity output, q_j, is expressed as a function of wind inputs, including wind capacity, x_j, and an additional composite input, y_j, that includes direct wind project inputs such as capital and labor. The output is determined by a production function that varies across firms. For the *j-th* profit maximizing producer:

$$\pi_j = \mathrm{p_w g(x_j, y_j)} - (\mathrm{w_c} - \mathrm{R_c} - \mathrm{FI_c})\mathrm{x_j} + (\mathrm{w_y} - \mathrm{R_y} - \mathrm{FI_y})\mathrm{y_j} \quad (2)$$

Output price, p_w, is the price received for the sale of the wind generated electricity to electricity producers. Given the small influence of wind producers in the electricity market, producers will take this price as given. Input costs for capacity and other project inputs, w_c and w_y, are influenced by a set of regulations, R, and financial incentives, FI that are designed to increase wind capacity by reducing costs. Regulations and financial incentives can be directly focused on increasing wind capacity, R_c and FI_c, or on indirectly increasing wind capacity by providing direct incentives for capital and labor inputs for wind project development, R_y and FI_y. Producer j develops some level of wind capacity $J \leq N$, where N is the total wind potential available.

Solving the standard profit maximizing model leads to some important implications regarding the role of input costs and prices. It can be shown that:

Wind Capacity: $\frac{\partial \mathrm{x_j}}{\partial \mathrm{w_c}} < 0, while\ \frac{\partial \mathrm{x_j}}{\partial \mathrm{w_y}} <> 0,\ \frac{\partial \mathrm{x_j}}{\partial \mathrm{R_c}} > 0, while\ \frac{\partial \mathrm{x_j}}{\partial \mathrm{FI_c}} > 0$

Composite development good: $\frac{\partial \mathrm{y_j}}{\partial \mathrm{w_y}} < 0, while\ \frac{\partial \mathrm{y_j}}{\partial \mathrm{w_c}} <> 0,\ \ \frac{\partial \mathrm{y_j}}{\partial \mathrm{R_y}} > 0, while\ \frac{\partial \mathrm{x_j}}{\partial \mathrm{FI_y}} > 0$

Wind capacity will decrease as costs increase and increase as regulations or financial incentives that promote renewables development increase. The influence of other costs and regulations is not clear in this case. A similar case is found for the composite good. In addition, it can be shown that in terms of prices, an increase in the price for wind generated electricity will lead to either a direct increase in wind capacity or an increase in development inputs or both, but the specific influence is not known given the standard profit maximization assumptions.

Demand

The demand side for wind generated electricity is determined by electricity producers demand for renewable electricity. For the *k-th* electricity producer :

$$Q_k = f(P_w, Q_e, P_c\ , P_{ng}, T) \tag{3}$$

The quantity of wind generated electricity, Q_k, that is demanded is a function of the price of wind generated electricity, P_w, the total quantity of electricity produced, Q_e, the price of substitute fuels, coal, P_c, and natural gas, P_{ng}, and the preferences of consumers for renewable electricity, T. The quantity varies by state, *i*, and year, *t*. Electricity producer *k* consumes some level of wind energy for wind generated electricity $K \leq M$, where M is the total wind energy that has been produced.

Assuming that wind generated electricity is a normal good, I expect that increases in P_w will lead to decreased demand for wind generated electricity. Given that wind generated electricity is a component of total electricity, increases in Q_e are expected to lead to increases in demand for wind generated electricity. Under the assumption that wind generated electricity and electricity generated from traditional fuels are substitutes, I expect an increase in either P_c or P_{ng} to lead to increases in demand for wind generated electricity. Lastly, I anticipate that an increase in preferences for wind generated electricity, T, will lead to increased demand.

Reduced Form

The reduced form approach that I present below allows me to estimate the relationship between wind capacity and the relevant independent variables without necessitating a measure of the price of wind generated electricity.[9] The reduced form of the model, for a given level of wind potential is:[10]

$$Wind\ Capacity_{Supply_{it}} = \alpha_1 + \alpha_2 P_{w_t} + \alpha_3 W_t + \alpha_4 R_{it} + \alpha_5 FI_{it} + \epsilon_{it}$$

$$Wind\ Capacity_{Demand_{it}} = \beta_1 + \beta_2 P_{w_t} + \beta_3 Q_{e_{it}} + \beta_4 P_{c_t} + \beta_5 P_{ng_{it}} + \beta_6 T_{it} + \varepsilon_{it}{}^{11,12}$$

where, in equilibrium:

$$Wind\ Capacity = \frac{1}{(\alpha_2 - \beta_2)}[(\alpha_2\beta_1 - \alpha_1\beta_2) + \alpha_2\beta_3 Q_{e_{it}} + \alpha_2\beta_4 P_{c_{it}} + \alpha_2\beta_5 P_{ng_{it}} + \alpha_2\beta_6 T_{it} - \alpha_3\beta_2 W_t - \alpha_4\beta_2 R_{it} - \alpha_5\beta_2 FI_{it}]$$

where, based on the theoretical model:

$$\alpha_2 > 0, \alpha_3 < 0, \alpha_4 > 0, \alpha_5 > 0$$

$$\beta_2 < 0,\ \beta_3 > 0,\ \beta_4 > 0, \beta_5 > 0,\ \beta_6 > 0$$

Based on the equilibrium equation, this implies that the expected coefficient on W_t is negative, increases in wind project costs will lead to decreases in wind capacity. The expected coefficients on the remaining variables, $Q_{e_{it}}$, R_{it}, FI_{it}, $P_{c_{it}}$, $P_{ng_{it}}$,and T_{it} are positive. Increases in the quantity of electricity, prices of substitute fuels, renewable energy regulations and financial incentives, and preferences for renewable energy will all lead to increased wind capacity.

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[9] The annual price or electricity by state is available from the Energy Information Association (EIA), the statistics arm of the U.S. Department of Energy (DOE), but the price of wind generated electricity is not separately tracked by the EIA annually over this time.

[10] In the empirical analysis, wind potential will be included as a control through the construction of the dependent variable. The dependent variable that is analyzed is the annual states wind capacity divided by the state's wind potential.

[11]Where P_{w_t} = Price of Wind generated electricity/Renewable Electricity; W_t= Project costs; R_{it} = Regulation; FI_{it} = Financial Incentives; $Q_{e_{it}}$= Quantity of electricity produced; P_{c_t} = Price of Coal; $P_{ng_{it}}$= Price of Natural Gas; T_{it} = Tastes

[12] For the analysis, I use annual coal prices rather than annual state coal prices so that the analysis focuses on the overall influence of coal prices on electricity including states for which no state coal prices are available, such as California.

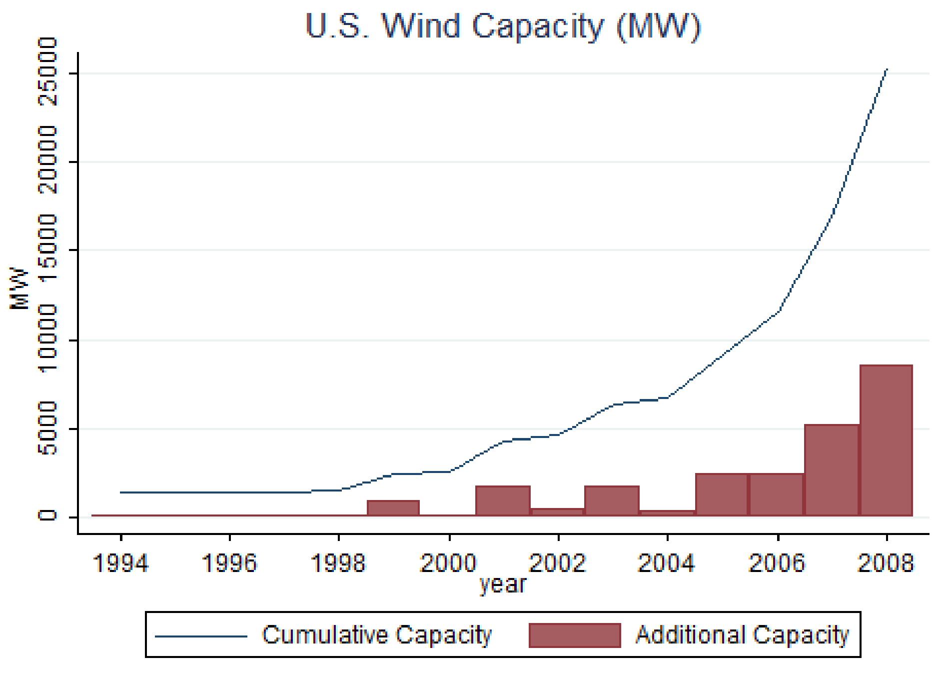
Data

To complete the analysis, my project uses data from three main categories. First wind measures, both wind potential and wind capacity, second renewable energy policy indicators, and third relevant electricity market factors. I discuss each of these categories and the corresponding constructed variables in more detail below. The goal of this paper is to determine the wind development impacts of both financial incentives and regulations after controlling for a variety of market factors that may have influenced wind development. The time period for this analysis covers the years 1994 through 2008, a period of rapid growth in wind development and also a time of rapid change in terms of both the regulatory environment and energy market.

While the dramatic rise in commercial scale development did not occur until about 1998, 1994 represents the first year when a state other than California implemented projects of greater than 1 MW with the exception of two projects in Hawaii in the 1980s.[13] (AWEA, projects db) Given that other states were participating in commercial wind development prior to 1998, I feel that it is important to consider prior years when commercial scale wind was beginning its expansion across the United States. Figure 1 demonstrates the marked 1998 increase in wind development and its more marginal rise beginning in 1994.

[13] See Figure 1 for a graph of U.S. Wind Capacity from 1994 through 2008.
Commercial scale development began in Hawaii in 1985, in Iowa in 1992 and prior to 1985 in California. Hawaii and Alaska are excluded from this analysis, which focuses on the contiguous United States do to availability of wind potential estimates.

Figure 1: U.S. Cumulative Wind Capacity and Added Capacity by Year



Source: (AWEA, projects db)

In addition to determining the time frame for analysis, it is also important to establish the sample states for inclusion in the analysis. For this project, the wind potential of a state was the determining factor. Wind potential is a set of measures that provide information on the amount of wind that a state would be capable of producing. A key reason that wind potential was a constraining factor in sample definition is that the policies that I analyzed are not wind specific, they are focused on renewables generally. In particular, states with RPS, but with zero wind potential are excluded from the analysis. While RPS in these states may influence renewables development generally, it would not be expected to lead to increases in wind generating capacity within the state.[14]

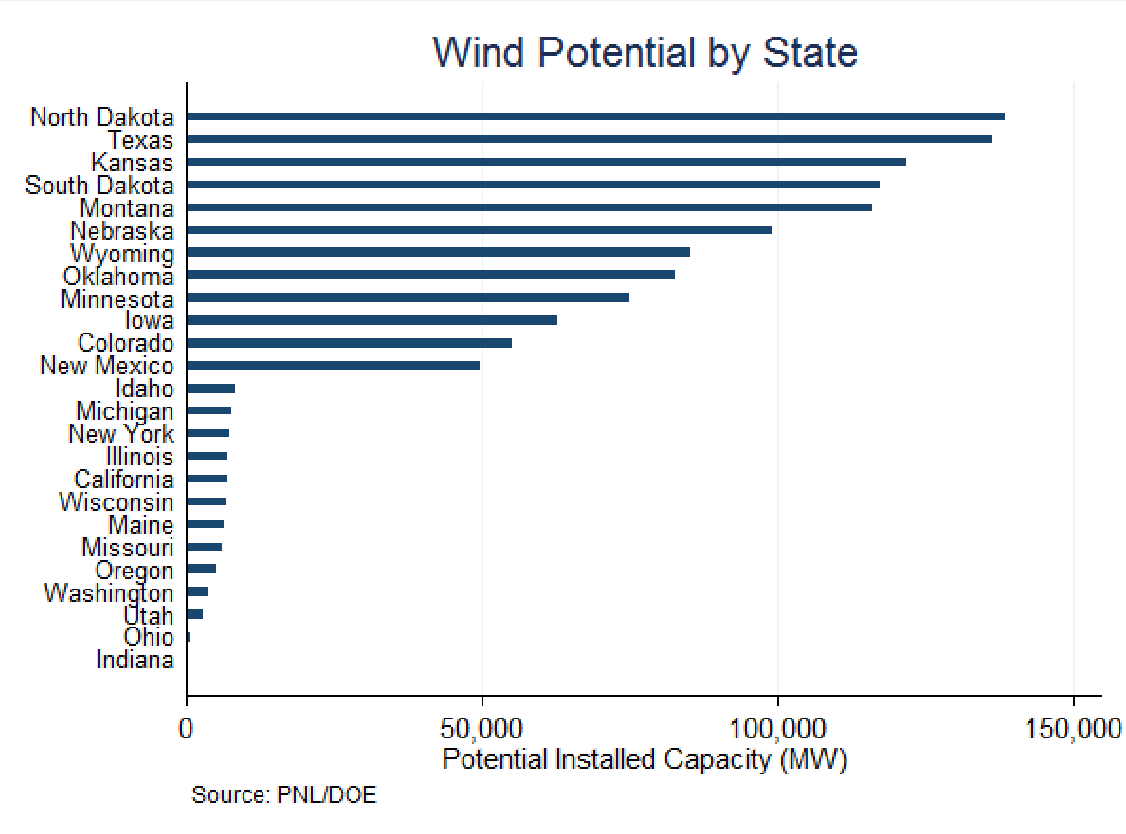
[14] The cross-state impacts of RPS programs are not analyzed in this paper. While some RPS do allow for the importation of wind development from other states, this analysis focuses only on within-state impacts.

To construct the sample, I used two measures of wind potential. First, I used the measure of wind potential constructed in 1991.[15] (Elliot, 1991, p. B-1) Second, I use the updated 2010 wind potential measurements constructed by NREL. (NREL, AWS) The two measures differ based on technological and land use assumptions.[16] They provide different wind potential ratings for each state. I used the information from both wind potential studies for my project to identify which states would be included in the sample. The sample of states is based on the top 20 states using the 1991 and 2010 wind potential ratings. Due to overlap this led to a sample of 25 states, which are the same states as the top 25 states using the 2010 potential ratings. Figure 2 contains the wind potential rankings by state for the sample states using the 1991 potential information.

[15] The 1991 measure was for the contiguous U.S., excluding Hawaii and Alaska.

[16] For instance, the 1991 measure was constructed at 50m due to the availability of wind technology at the time, while the 2010 measure was constructed at 80m.
The 1991 measure that I used was developed by the Pacific Northwest Laboratory under a scenario that all areas with class 3 or higher wind resources were developed. Further, certain lands that were unlikely to be developed were excluded such as lands that were protected due to environmental concerns, in certain urban, forested, or agricultural setting. This is referred to as scenario 3. (Elliott, 1991, p. B-1)

Figure 2: Wind Potential by State



There are two wind potential measures for the 1991 and 2010 models, potential installed capacity in megawatts and potential annual generation in gigawatt-hours. "The 'Installed Capacity' shows the potential megawatts (MW) of rated capacity that could be installed on the available windy land area, and the 'Annual Generation' shows annual wind energy generation in gigawatt-hours (GWh) that could be produced from the installed capacity." [17] (NREL, AWS) For the analysis, I used the potential installed capacity by state because it is measured in megawatts which corresponds to the wind capacity variable that is also measured in megawatts.

After establishing a sample time period and set of states, the most critical data for analyzing wind development over this time period is a measure of wind development. For this

[17] The installed capacity calculations are based on an assumption of 5 MW/km^2 of installed capacity. The top 25 states in terms of both measures were identical.

paper, I use added wind capacity by state and year for each state.[18] At its most disaggregated level, wind capacity is a measure in megawatts (MW) of the capacity rating of each turbine installed at a wind project. I collected the data for this research primarily from the AWEA wind projects database.[19] The AWEA projects database reports wind capacity as a cumulative project capacity. The number reported is the turbine rating, the capacity rating of each turbine, multiplied by the number of turbines for each project. Using this information, I constructed a state-year added capacity measure for use in the dependent variable.[20]

In addition to wind capacity, I use 1991 wind potential to construct the dependent variable. The dependent variable is equal to the state-year wind capacity variable divided by the state wind potential. This provides a measure of the relative wind capacity in a state as compared with its overall wind resource allotment.[21]

Regulations and Financial Incentives

After the construction of the dependent variable for this analysis, I constructed the regulatory variables, regulations and financial incentives. This data set was based largely off of information collected in the Database of State Incentives for Renewables & Efficiency (DSIRE)

[18] The current measures of wind potential are for the 48 –contiguous states only and therefore Hawaii and Alaska are excluded from this analysis.

[19] The AWEA contains commercial scale wind projects, generally over 100 kW. "Commercial scale wind refers to wind energy projects greater than 100 kW. Typically, the electricity is sold rather than used on-site. This category can include large arrays of 100 or more turbines owned by large corporations or a single locally-owned wind turbine greater than 100 kW in size." (Windustry)

[20] To create this variable, I began with data provided by the DOE through NREL for the time period from 1999 through 2008 using data from the Global Energy Concepts (DNV-GEC) database which is jointly maintained by the AWEA and made publicly available through AWEA as the AWEA projects database. The database provided by the AWEA contains information prior to 1999 and for the purposes of my project the added wind capacity measure was constructed for the years from 1994 to 1998 so that a fifteen year sample is available for analysis. This constructed five year sample was then appended to the state-year cumulative capacity measures as presented by NREL. There are some discrepancies in the cumulative capacity information that is constructed prior to 1999 as detailed in Appendix A, Table A2.

[21] I also constructed an indicator for wind potential over time, wind potential interacted with year indicators, to control for the potentially disparate impacts of wind potential on states over time.

database.[22] From this database, I used only those regulations and financial incentives that focused on wind projects over 100 kW and that had been implemented prior to the end of 2008.[23] I restricted this set of data to include State Loan Programs and State Grant Programs from the set of state financial incentives.[24] In addition, I included the following state regulations, State Green Power Purchasing/Aggregation (GPA), Renewables Portfolio Standards[25] (RPS), and Mandatory Green Power Option Programs (MGPP). In addition to these state specific measures, I also constructed a measure of the Federal Production Tax Credit (PTC).[26]

To supplement the regulation information provided in the DSIRE database, I used data from the Green Pricing, Utility Programs by State information that is provided by the Department of Energy, Energy and Efficiency Program to construct a Green Power Purchasing Option Programs (GPP) indicator.[27] I include details on the sample data that I used to construct measures for each of these policies in Tables 1-5. Below I provide a detailed description of each policy.

State Loan and Grant Programs

The state grant and loan programs in this analysis were those that provided financial support for the development of commercial scale wind projects. The programs were not generally wind specific and instead targeted increases in renewable energy in their respective

[22] The copy of the DSIRE database that my project for this analysis contained updates though August 2009 and was obtained in September 2009 as an MS Access database. The database "is a comprehensive source of information on state, local, utility, and federal incentives and policies that promote renewable energy and energy efficiency. Established in 1995 and funded by the U.S. Department of Energy, DSIRE is an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council." (DSIRE)
[23] If a financial incentive or regulation expired in a given year, it was coded as active for that year. If a financial incentive or regulation began in November or December of a given year, it was coded as active for the following year. I coded all other financial incentives as active in the year in which they were implemented.
[24] Given the limited number of programs, I combined both state grant and loan programs into a single variable for the purposes of this analysis.
[25] I verified all information on Renewables Portfolio Standards using information from Wiser and Barbose (2008).
[26] Information on the Production Tax Credit in the DSIRE database was supplemented using information from Wiser, Bolinger, and Barbose (2007).
[27] See (Green Power Markets).

states through financing options that were intended to make the projects more attractive to developers.[28] The loan programs generally offer below market interest rates for funding of renewable development, while the grant programs provide funds outright to encourage renewables projects.[29]

An example of a loan program is Iowa's Alternative Energy Revolving Loan Program (AERLP), which provides loans for the construction of renewable energy production projects in Iowa. The program began in 1996 with a limit of $1 million dollars per organization and a 20 year maximum term per loan which was interest free for 50% of the loan with the remainder provided by a lender at a market rate. (DSIRE, Iowa) The program continues presently and was expanded in 2009. An application is required, the deadlines for application vary by the size of the project. This loan program has been successful. "As of March 2009, the AERLP had provided loans of more than $11.4 million in support of 88 renewable energy projects." (DSIRE, Iowa)

Using information for each state, I constructed three indices for state loan and grant programs. The first is an indicator variable, indicator index, that is set to one in the years in which the first loan or grant program was enacted in a given state. The second, the sum index, is the sum of the active loan or grant programs in a given year for each state. And the third, the years from index, is the number of years from the first active loan or grant program in each state.[30] Table 1 contains information on the years in which a state or loan program became

[28] The terms of the loan and grant programs varied, but all required an application and award process for the projects. The inclusion of a project in this sample is restricted only by the years in which the programs were active, but not by whether wind or other developers utilized the programs or whether the programs were successful.
[29] It should be noted that states that offer financial incentives to encourage wind project development generally structure their policies so as to allow the use of the financial incentives in conjunction with the federal PTC, so that the implementation of these policies is not exclusive but rather complementary. (Wiser, Bolinger, and Barbose ,2007, p. 10-11)
[30] All variables are zero in years in which no program has started and are set to zero once a program or in the case of the sum index, all programs have expired.

active and expired by state. It is clear from Table 1 that there is considerable variation in the timing of the implementation of these programs.

Table 1: State Loan and Grant Programs by Year Effective

Year Effective	**State**	**Program**	**Expiration**
2002	California	State Loan Program	2003
2007	Colorado	State Grant Program	
1996	Iowa	State Loan Program	
1983, 1989, 1994, 2007	Minnesota	State Loan Program	
1989	Missouri	State Loan Program	
2001	Montana	State Loan Program	
2004	New Mexico	State Grant Program	2005
2001	New York	State Loan Program	
1999	Ohio	State Grant Program	
2002	Ohio	State Loan Program	2007
1980	Oregon	State Loan Program	
1988	Texas	State Loan Program	
2002	Wisconsin	State Grant Program	

Source: DSIRE database
Note: The table includes expiration dates only if they are within the sample time frame. (Prior to 2009)

Green Power Purchasing Option

In addition to offering financial incentives states have implemented regulations that support the development of renewable energy. GPP are a popular program across states. These programs offer consumers the opportunity to increase the amount of renewable electricity that is generated through payment of an additional fee on their utility bill. The amount of the fee and the specific rules of the programs vary, but the additional funds are utilized to provide an offsetting amount of renewable energy generation in the amount of the customer's overall energy use. While not a direct purchase of renewable energy, the programs are designed to increase the overall amount of renewable electricity generation.

These programs are implemented by utilities and therefore each state can have multiple programs starting in different years providing variation for analysis. One example, in Colorado in 1997 the Public Service Company of Colorado, the state's largest utility, offered a green pricing option to its customers. The consumers could buy 100 kilowatthour (kWh) blocks of renewable energy for a premium of 2.5 cents per kWh. (Green Power Markets) Other programs were subsequently offered in Colorado by other utilities.

To encourage the development of GPP programs states have also stepped in and mandated that utilities offer a green power option to their customers. These Mandatory Utility Green Power Option (MGPP) programs are also analyzed in this paper to determine the potentially disparate impacts of state programs directed at utilities and utility programs offered directly to consumers. Table 2 presents a list of the total number of active GPP offered by utilities in each state along with a list of states that have implemented mandates requiring that utilities offer these programs.[31]

Table 2: Green Power Purchasing Option Programs

Year GPP Programs Effective	State	Total GPP Programs	Mandatory Utility Green Power Option
1997, 1999, 2000(2), 2003, 2004(3), 2006, 2008	California	10	
1997(2), 1998, 1999(3), 2007, 2008	Colorado	8	2007
2001, 2002, 2003(2)	Idaho	4	
1997, 2000, 2003, 2005	Illinois	4	
1998, 2000, 2001	Indiana	3	
1998, 2000(2), 2001(2), 2003(5), 2004(2), 2006(1)	Iowa	13	2004
2000(2), 2004, 2005, 2007	Michigan	5	
1998(3), 1999, 2000(2), 2002(5), 2003(1)	Minnesota	12	2001
2000(2), 2003, 2007	Missouri	4	
2000, 2001, 2002(2), 2003(2)	Montana	6	2003
2001, 2002	Nebraska	2	
1999, 2001, 2003(2), 2005	New Mexico	5	2003
1999, 2000, 2002	North Dakota	3	
2000, 2001, 2003, 2007, 2008	Ohio	5	
2003(2), 2004(2)	Oklahoma	4	
1999(2), 2000, 2001, 2002(5), 2003(3), 2004, 2005, 2007(3)	Oregon	17	2007

[31] Note: Mandates do vary in terms of which utilities are required to provide a green power option. For some states, the mandates focus on all Investor Owned Utilities (IOUs), for others the requirement only affects utilities of a certain size, i.e. with a customer base over some minimum number of individuals.

Year GPP Programs Effective	State	Total GPP Programs	Mandatory Utility Green Power Option
2000, 2001, 2002	South Dakota	3	
1997, 2000, 2001, 2005, 2006	Texas	5	
2000, 2001, 2003, 2004, 2005	Utah	5	
1999(2), 2000(2), 2001, 2002(8), 2003(2), 2005, 2007	Washington	17	2001
1996, 1997, 1998, 1999, 2000, 2001, 2002	Wisconsin	7	
1999, 2000(2), 2001, 2003, 2006	Wyoming	6	

Source: Green Power Markets and DSIRE db

Note: Kansas, Maine, New York do not have Green Power Option Programs.

Note: The table includes expiration dates only if they are within the sample time frame, prior to 2009, no Green Power Purchase Option Programs expired during that time frame.

For this analysis, I constructed three separate variables for the GPP. The indicator, sum, and years from indices. In addition, I constructed indicator and years from indices for the MGPP.

Renewables Portfolio Standards

It is clear from the Table 2 that utility GPP programs are prevalent across states. Another widely discussed and popular state program is the Renewables Portfolio Standard (RPS). Fundamentally, an RPS is a requirement that the utilities in a state produce a certain amount of electricity using renewable energy sources. The amount of electricity generation that must be supplied from renewables varies in percentage and in the year of required implementation. See Table 3 for detailed information.

Table 3: RPS Goal by State and Year of Goal Implementation

State	**Mandate/Goal (Percentage of Electricity Generated from Renewable Energy)**	**State**	**Mandate/Goal (Percentage of Electricity Generated from Renewable Energy)**
California	20% by 2010	Montana	15% by 2015
Colorado	20% by 2020	New Mexico	20% by 2020
Illinois (Optional)	(5% by 2010 and 15% by 2020)	New York	24% by 2013
Illinois	25% by 2025	North Dakota (Optional)	10% by 2015
Iowa	105 MW by 1999	Oregon	5-25% by 2025
Maine	30% by 2000	South Dakota (Optional)	10% by 2015
Michigan	10% by 2015	Texas	5880 MW by 2015
Minnesota[a]	825 MW by 2002	Utah (Optional)	20% by 2025
Minnesota (Optional)	10% by 2015	Washington	15% by 2020
Minnesota	25-30% by 2020-2025	Wisconsin	10% by 2015
Missouri (Optional)	11% by 2020		

a: This RPS legislation was focused only on Xcel Energy. It is scheduled to expire in 2010. The mandatory RPS does not apply to Xcel Energy until 2010.
Source: DSIRE database and Wiser et al 2007 p. 7

In addition to this variation, across states these policies vary in their requirements for implementation of intermediate renewable mandates prior to the reaching of the final goal and by the mix of renewables that are required. Additionally some states require newly developed renewable generation, generally put into production after 1999 and some require that the generation take place within the state while others do not. (Wiser et al 2007, p.6)

Despite the variation in implementation, given the common focus of these policies, for this analysis the RPS will be treated as a single policy instrument. An exception will be made for those RPS that are not mandated. I expect that the impacts on wind development from a legally mandated RPS requirement will be stronger than for those in which the percentage of renewable electricity generation is an optional standard for utilities.

RPS are widely touted as critical factors for renewable energy development and in particular wind energy development. (RPS 2007, p.2, WPO 2005, p.2) This general finding is noteworthy given that the design and components contained in each RPS vary across states and time. It is also a strong conclusion given that RPS are often non-binding constraints since the year for the implementation of the final renewable generation requirement is outside the sample time frame.[32]

For this analysis, I constructed separate variables for optional RPS and mandatory RPS by state and year of adoption. See Table 4 for information by state on the implementation of RPS.

[32] Some states have instituted mandatory interim requirements which may have been binding over the sample time frame.

Table 4: Renewables Portfolio Standards

Year Effective	State	Program	Expiration
2003	California	Renewables Portfolio Standard	
2005	Colorado	Renewables Portfolio Standard	
2001	Illinois	Optional Renewables Portfolio Standard	
2007	Illinois	Renewables Portfolio Standard	
1983	Iowa	Renewables Portfolio Standard	
2000	Maine	Renewables Portfolio Standard	
2008	Michigan	Renewables Portfolio Standard	
1995	Minnesota	Renewables Portfolio Standard[a]	
2001	Minnesota	Optional Renewables Portfolio Standard	2007
2007	Minnesota	Renewables Portfolio Standard	
2007	Missouri	Optional Renewables Portfolio Standard	
2005	Montana	Renewables Portfolio Standard	
2003	New Mexico	Renewables Portfolio Standard	
2004	New York	Renewables Portfolio Standard	
2007	North Dakota	Optional Renewables Portfolio Standard	
2007	Oregon	Renewables Portfolio Standard	
2008	South Dakota	Optional Renewables Portfolio Standard	
1999	Texas	Renewables Portfolio Standard	
2008	Utah	Optional Renewables Portfolio Standard	
2006	Washington	Renewables Portfolio Standard	
1999	Wisconsin	Renewables Portfolio Standard	

a: This RPS legislation was focused only on Xcel Energy. It is scheduled to expire in 2010. The mandatory RPS does not apply to Xcel Energy until 2010.

I used the date enacted for the RPS as the basis for analysis. Additionally, I constructed two variables to represent both optional and mandatory RPS, the indicator index and the years from index. While RPS like any regulation is not stagnant, a more in depth investigation of the changes in RPS over time is left for future work. Table 4 presents RPS by state and year of implementation for the 25 states included in the sample.[33]

[33] The years listed are the years when the RPS was enacted. For some states there may be several years between the date the RPS is enacted and the date in which utilities are required to use produce electricity from renewables. It is expected that the enactment of an RPS could spur development to meet future goals even if the RPS mandates are not binding.

State Green Power Purchasing/Aggregation

Another program that has been implemented by states is the Green Power Purchasing Programs (GPA), which outline specific goals for the state government in terms of renewable energy use. Table 5 includes a list of states that have implemented such programs.

Table 5: Green Power Purchasing/Aggregation

Year Effective	**State**
2007	Illinois
2007	Indiana
2005	Iowa
2003	Maine
2001	New York
2006	Wisconsin

Source: DSIRE database
Note: The table includes expiration dates only if they are within the sample time frame. (Prior to 2009)

One example of a GPA is from the state of Illinois. "In January 2007, the State of Illinois established a goal for state agencies to purchase 3% of their power from renewable sources by the end of 2007, 4% by the end of 2008, and 5% by the end of 2009." (DSIRE, IL) These programs provide a direct incentive for renewables development by mandating that the government go green. For the purposes of this analysis, I will focus only on state level purchasing programs, however the implementation of these programs extends beyond the state to both municipal governments and the federal government. A more detailed analysis of the impacts of all green power purchasing programs and their relationship with other state renewables programs will be completed in future work.

Given the lag between enactment of legislation and implementation, for the purposes of this analysis, the effective date of legislation is used for analysis as opposed to the enacted date. I constructed two variables to represent GPA programs, the indicator index and the years from index.

Federal Production Tax Credit

Along with state regulations and financial incentives, this paper also analyzes the PTC. In addition to RPS, the PTC is often cited as critical for wind development. The PTC is an inflation adjusted business tax credit that applies to electricity generated from commercial wind projects for the first ten years after they are developed and reduces the cost of producing wind by about a third.[34] (Wiser, 2007) The goal of the PTC is to offset energy credits already in place for other energy sources due to the environmental and energy security benefits of wind energy. (Wiser, Bolinger, and Barbose, 2007, p.2) The credit was originally created under the Energy Policy Act of 1992, but has been allowed to expire several times since its inception. (Wiser, Bolinger, and Barbose, 2007, p. 1-2) Its lapses over the years are correlated with decreases in wind capacity additions and are often blamed for those declines. In 2005 the AWEA argued "that the current 'on-again, off-again' status of the credit is hobbling project development and the industry as a whole." (AWEA, EoWE, p. 4)

For the purposes of this analysis, I constructed a binary PTC variable with a 1 indicating that the PTC was active for a given year and a 0 indicating that it had lapsed for some time during the year. One exception to this construction is that although the PTC was allowed to lapse in 1999, the impacts of this lapse are conventionally attributed to 2000 due to the lag time for development. I followed this convention in this paper. Therefore, I constructed the PTC indicator variable with a zero for the years 2000, 2002, and 2004.

Market Factors

After the construction of the policy indicators, I constructed the variables to measure the electricity market impacts. I collected total electricity generation information from annual state data provided by the Energy Information Association (EIA) from 1998-2008 as the measure of

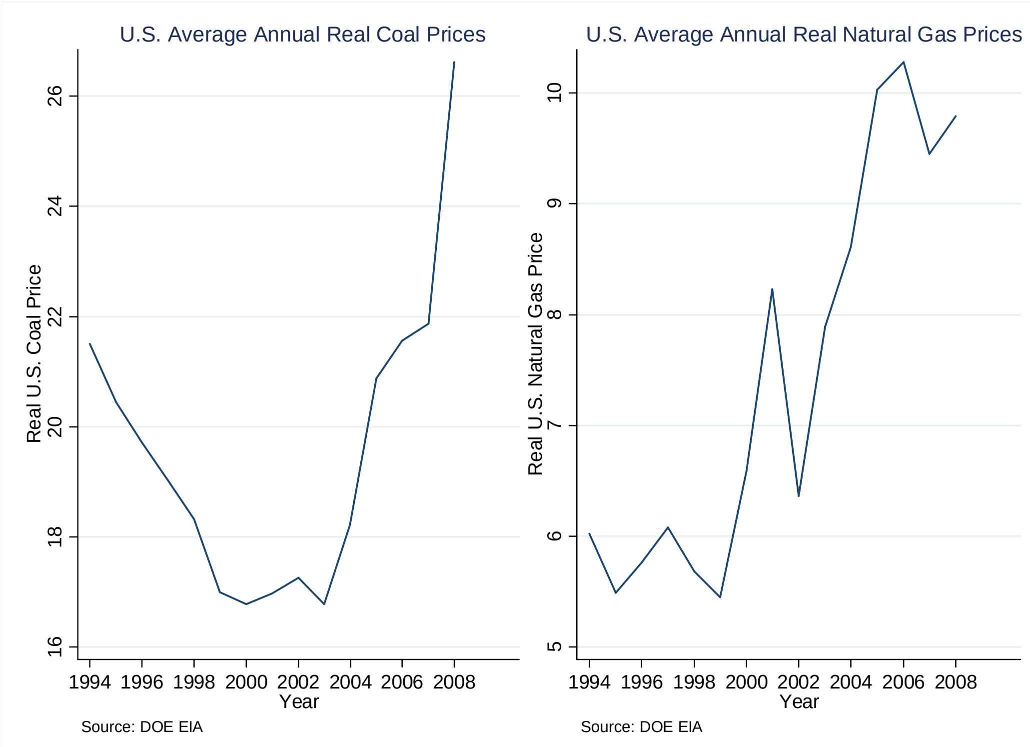
[34] The initial credit was 1.5c/kWh and was directed towards wind plants that were to come online between 1994 and the middle of 1999. By 2007, the value of the tax credit had increased to 2.0 c/kWh due to inflation adjustments.

total quantity of electricity produced. (REA, 2000 – 2008) I also constructed price variables for natural resources used in electricity generation, natural gas and coal.[35] To construct the natural gas price measure, I collected data by state and year of commercial natural gas price from the EIA. (EIA, Gas Price) For coal prices, I constructed an annual measure due to the fact that information on the average price of coal delivered to electric utility plants by state was not available for all states.[36] (EIA, Coal Price) Natural gas and coal are substitute goods in terms of fuel for electricity production. Increases in prices of these substitute goods would be expected to lead to increases in demand for alternative fuel sources, including wind. Also, the volatility of natural gas prices is an oft cited reason for increases in renewables development generally. (WPO, 2005, p. 4) Figure 3 contains average annual real resource prices for the United States.

[35] All prices and well costs are real prices, in chained (2000) U.S. dollars, calculated by using gross domestic product price deflators from the EIA.

[36] For states in which coal is not delivered or used in electric utility plants, the price information is missing. These states include California, Idaho, Maine, and Washington. For Washington the price data is missing from 2001 through 2008.

Figure 3: Electricity Fuel Prices

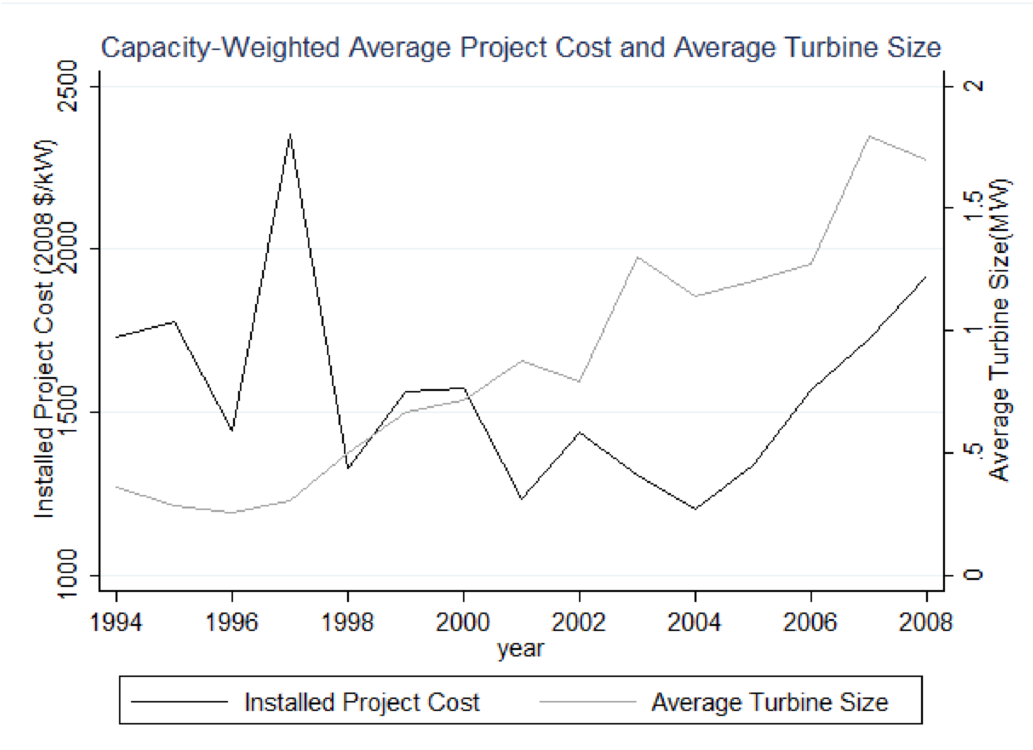


The graph above demonstrates that over this time period, from 1994-2008, prices have been increasing for the United States for both resources. This upward trend in the price of fossil fuels could be motivating electricity producers to look for alternative fuel sources. This analysis will test the impact that these rising resource prices are having on wind development.

Wind Costs and Turbine Size

As far back as 1989, cost estimates for wind power have been estimated to be in line with conventional sources and were predicted to fall further. (Gipe, p. 226) The AWEA argued in 2002 that the "cost of wind power at efficient wind farms has declined to a range that is close to competitive with several forms of conventional power and less expensive than nuclear." (GWEMR, 2002, p.7) This is consistent with the argument put forward by Wiser (2007) that declining costs since 1994 combined with the PTC lowers the cost of wind by about 1/3, making wind a cost effective source of energy. (Wiser, March 29, 2007) The decline in costs is shown in Figure 4.[37]

Figure 4: Project Costs and Turbine Size



Source: Turbine Size- AWEA projects database, Cost – Berkeley Labs email from Mark Bollinger 03/10

Costs have had an overall decreasing trend until 2008 when prices began to rise above the 1994 levels. Average costs were approximately $3500 per kilowatt in 1985 and had fallen to just over $1700 per kilowatt by 1994. By 2008, the average costs had increased to just over $1900 per kilowatt, still only approximately 55% of the 1985 costs. (Wiser and Bolinger, 2009, p. 33) Due to these significant changes, falling costs are expected to play a role in the amount of wind capacity that is added.[38]

[37] The project costs in the graph above include "turbine purchase and installation, balance of plant, and any substation and/or interconnection expenses." (2008 Market Report, p. 33)

[38] In addition to direct costs, financing and transmissions costs may also play a role in wind capacity additions. I do not include direct measures of financing or transmissions costs in the analysis, but I do include year indicator variables to control for the overall influence of year specific variations. While not a precise measure of changes in these costs, the year indicators broadly include factors that influence wind capacity in each year.

These costs declines have been caused in part by technological improvements in turbine design. Figure 4 shows that turbine size has been increasing over this time period and taller towers and larger blades both lead to increases in production. (AWEA, EoWE, p. 1) This is due to the fact that wind speeds are higher as the distance from the ground is increased and larger blades have a larger swept area. (AWEA, EoWE, p. 2) The increases in size of the individual turbines and the addition of larger numbers of turbines per project also lead to decreased marginal costs. (AWEA, EoWE, p.2) This significant ramping up of turbine sizes is expected to also play a role in determining wind capacity changes. I constructed two variables, both annual measures, of average project costs and average turbine size.

League of Conservation Voters Scores

The last factor that I have postulated will influence demand for wind generated electricity is consumer tastes. According to the theoretical framework, states with higher demand for renewable energy will have higher levels of renewable development generally and wind specifically. The League of Conservation Voters (LCV) scores provide a rating for each state's Federal Senate and House delegation based on how the state's Senators and Representatives voted on key environmental legislation in the previous year. (LCV, Score) The relevant legislation is determined by experts from environmental organizations. The score is constructed on a 0 to 100 scale for each legislator with 0 indicating that the legislator voted against environmental legislation and a higher score indicative of a more environmentally friendly legislator. The legislators scores are then averaged across a state's legislative delegation in the Federal Senate and House by year. My analysis uses these indicators of the overall environmental friendliness of a state as an indicator of the willingness of a state's population to demand wind development. It is expected that states with higher LCV scores will have additional wind development.

Empirical Framework

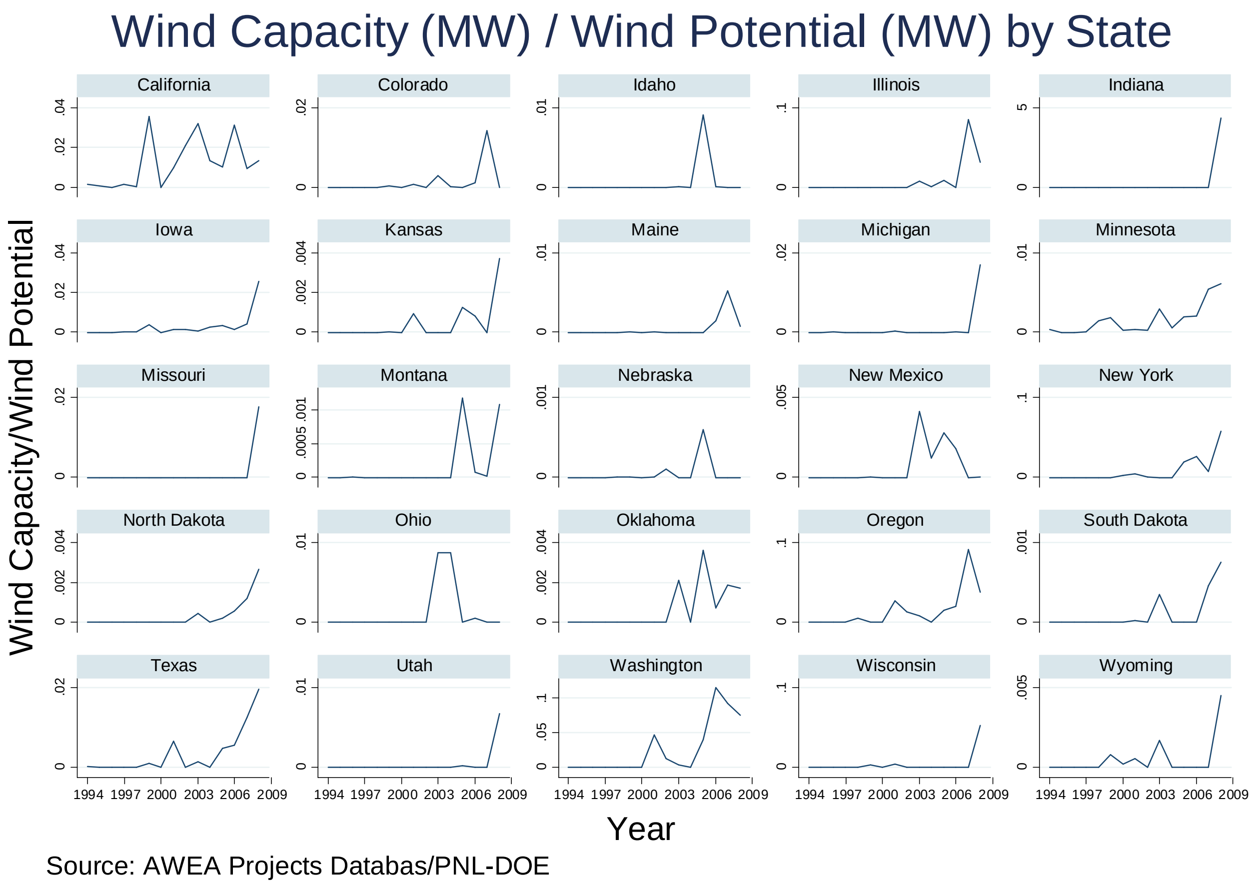
Based on the theoretical framework, I focus the empirical analysis on measuring the influence of renewable energy policies on the growth in added wind capacity after controlling for market factors and state wind potential. The 25-state sample covers the time period from 1994 through 2008.[39] This panel allows for the identification of impacts from the policy variables, that change at most annually at the state level. Given the distribution of the dependent variable a random effects Tobit model was used.[40] Y_{it} is censored at zero with approximately 40 percent of the observations at zero. See Figure 5 for a depiction of the dependent variable over time by state.

[39] Indiana is excluded from the results. Due to a wind potential of only 30 MW, and an installed capacity in 2008 of four times that amount, Indiana is an outlier. The wind potential measure increased significantly under the 2010 model. To avoid this anomaly in the wind potential data the regressions are run without Indiana.

The analyses were also run using electricity prices as an indicator of the influence of the electricity market, the results regarding the market and policy variables were consistent in magnitude and sign to those presented here. The electricity price variable was not consistently statistically significant.

[40] I include a linear regression in Appendix A, Table A3 for comparison. Also, the pooled Tobit regression specification was tested against the random effects Tobit regression and the random effects Tobit regression was found to provide a better fit. Fixed effects Tobit was also considered, however, the fixed effects Tobit specification is known to be biased. For robustness, I ran linear fixed effects and random effects regressions and used a Hausman test to determine if the more efficient random effects model was consistent with the fixed effects model. The results indicate that the linear random effects model is consistent.

Figure 5: Dependent Variable – Added Wind Capacity / Wind Potential by State



The specification of the model is:

$$Y_{it} = \propto + \beta_1 Q_{e\,it} + \beta_2 P_{c\,t} + \beta_3 P_{ng\,it} + \beta_4 T_{it} + \beta_5 W_t + \beta_6 R_{it} + \beta_7 FI_{it} + \varepsilon_{it}$$

where Y ~ (0, ¥)

and $\varepsilon_{it} = \gamma_i + \mu_{it}$

where *i* = state and *t* = year. Y_{it} represents the annual state wind capacity per state wind potential.

The main regression results are presented in Tables 6-8, which vary based on the regulatory variables that are included. Tables 6 and 6a present results for the sum index, Table 7 includes findings for the indicator index, and Table 8 provides results for the years from index.

Table 6: Tobit Random Effects: Regulations and Market Influences

	Regulatory and Financial Incentive Indicators: Sum of Active Programs	
Dependent Variable: Annual State Wind Capacity / State Wind Potential	**(1) Full Sample**	**(2) Full Sample with Year Indicators**
State Grant and Loan Program(s) [a]	**-0.00369****	**-0.00363****
	(-2.130)	(-2.059)
Green Power Purchasing/Aggregation	0.00584	0.00449
	(1.303)	(1.002)
Optional Renewables Portfolio Standard	0.00358	0.00246
	(0.837)	(0.573)
Renewables Portfolio Standard	**0.0101*****	**0.0104*****
	(2.708)	(2.765)
Utility Green Power Option(s) [a]	**0.00240*****	**0.00227*****
	(5.961)	(5.031)
Federal Production Tax Credit	**0.00932*****	**0.00220**
	(3.131)	(0.203)
Commercial NG Price ($/Mcf)	**0.00135***	**0.00206***
	(1.827)	(1.834)
Real Coal Price	-0.000108	-4.78e-05
	(-0.197)	(-0.0229)
Net Electricity Generation (Thousands of Kilowatthours)	**3.23e-08****	**3.09e-08***
	(2.014)	(1.855)
Capacity-Weighted Average Project Costs ($/KW)	5.04e-07	2.30e-05
	(0.104)	(0.663)
LCV Score (Senate)	4.47e-05	3.17e-05
	(1.066)	(0.689)
Constant	-0.0355***	-0.0724***
	(-4.294)	(-3.597)
σ_u (State specific standard deviation)	0.00381*	0.00421**
	(1.919)	(2.129)
σ_e (Observation specific standard deviation)	0.0154***	0.0149***
	(15.91)	(15.80)
ρ	0.0579	0.0739
Observations	360	360
Pseudo R-squared		
Number of States	24	24

Note: asymptotic z-statistics in parentheses, *** p<0.01, ** p<0.05, *p<0.1. ρ is the percent contribution to the total variance of the panel-level variance component. σu: panel-level standard deviation; σ_e: standard deviation of e_it.
a: These indices are the sum of active GPP programs and State Grant and Loan Programs in each state.

Overall, the findings in Tables 6 through 8 indicate that the regulatory influences of the PTC, RPS, GPP, and MGPP on wind capacity are consistently positive and statistically significant.[41] In addition, the coefficient on Optional RPS was consistently not significant. This result is not unexpected for the Optional RPS, since it is a voluntary program. These findings are discussed in more detail below along with the remaining policy indicators that demonstrated some statistical significance. In terms of electricity market factors, there was some evidence of significance for several measures, however, there is some variability in the individual results. The market factors will be discussed in more detail below. [42]

Renewables Portfolio Standard

To begin the discussion of the regression results, I focus on two of the most widely known and discussed renewable regulations, RPS and the PTC. The AWEA has consistently advocated for RPS as an important regulatory mechanism for supporting the growth of wind energy. The literature has generally supported the supposition that RPS lead to additional renewable energy development. (Langniss and Wiser, 2003; Wiser, Porter, and Grace, 2004; Wiser and Barbose, 2008; Menz and Vachon, 2006). Counter to the largely descriptive literature on renewable energy development, Carley (2009) finds that in terms of renewable electricity generation, RPS are not statistically significant predictors. The results in this paper support the

[41] MGPP sum index is correlated with the GPP sum index at .66. Due to this colinearity, the variables are not included in the same regression. The coefficient on the MGPP program, not shown in Tables 6 and 6a, was also positive and statistically significant at the ten percent level if included without the GPP programs.

[42] In addition to the market variables presented in the analysis, I also analyzed average turbine size as an indicator of technological progress and it was consistently not statistically significant. Also, to determine if there was a disparate influence of wind potential over time, I analyzed a year-wind potential interaction, it was consistently not statistically significant. Lastly, I ran all of the analysis with an alternate dependent variable constructed with 2010 wind potential measures, the magnitude and sign of the coefficients was consistent with the results presented here.

work that argues for RPS in positively influencing renewable energy development, in this case wind development.[43]

The results in Tables 6a and 7 demonstrate that the probability of wind development occurring increases by between approximately 24 and 33 percent after the implementation of an RPS. In addition, given that wind development has occurred, the expected megawatts of wind capacity per megawatt of wind potential increased by between approximately 0.3 and 0.5 percentage points.

[43] The results regarding RPS were robust to the inclusion of year indicators. See Table 20, column 2 for results including year indicators.

Table 6a: Tobit Random Effects: Regulations and Market Influences - Sum Index (Marginal Effects)

	Regulatory and Financial Incentive Indicators: Sum of Active Programs	
Dependent Variable: Annual State Wind Capacity / State Wind Potential	**(1) Full Sample: Probability of Wind Development**	**(2) Full Sample: Expected Increase in Wind Capacity Relative to a State's Wind Potential Given That Wind Development Has Occurred**
State Grant and Loan Program(s) [a]	**-0.0828****	**-0.00100****
	(-2.102)	(-2.120)
Green Power Purchasing/Aggregation	0.139	0.00175
	(1.246)	(1.180)
Optional Renewables Portfolio Standard	0.0837	0.00103
	(0.811)	(0.788)
Renewables Portfolio Standard	**0.239*****	**0.00306****
	(2.678)	(2.427)
Utility Green Power Option(s) [a]	**0.0539*****	**0.000652*****
	(5.652)	(5.909)
Federal Production Tax Credit	**0.188*****	**0.00229*****
	(3.581)	(3.461)
Commercial NG Price ($/Mcf)	**0.0303***	**0.000366***
	(1.837)	(1.835)
Real Coal Price	-0.00242	-2.93e-05
	(-0.197)	(-0.197)
Net Electricity Generation (Thousands of Kilowatthours)	**7.25e-07****	**8.77e-09****
	(1.995)	(2.013)
Capacity-Weighted Average Project Costs ($/KW)	1.13e-05	1.37e-07
	(0.104)	(0.104)
LCV Scores (Senate)	0.00100	1.21e-05
	(1.063)	(1.068)
Observations	360	264
Number of States	24	24

Note: asymptotic z-statistics in parentheses, *** p<0.01, ** p<0.05, *p<0.1.
a: These indices are the sum of active GPP programs and State Grant and Loan Programs in each state. For other programs, only one program was active in each state.

Table 7: Tobit Random Effects: Regulations and Market Influences – Indicator Index (Marginal Effects)

	Regulatory and Financial Incentive Indicators: Year of Initial Implementation	
Dependent Variable: Annual State Wind Capacity / State Wind Potential	**(1) Full Sample: Probability of Wind Development**	**(2) Full Sample: Expected Increase in Wind Capacity Relative to a State's Wind Potential Given That Wind Development Has Occurred**
State Grant and Loan Program [a]	-0.0918	-0.00121
	(-1.341)	(-1.341)
Green Power Purchasing/Aggregation	0.177	0.00246
	(1.554)	(1.434)
Mandatory Utility Green Power Option [a]	0.114	0.00154
	(1.189)	(1.154)
Optional Renewables Portfolio Standard	0.0629	0.000840
	(0.608)	(0.596)
Renewables Portfolio Standard	**0.328*** **	**0.00472*** **
	(4.189)	(3.489)
Utility Green Power Option [a]	**0.271*** **	**0.00367*** **
	(4.716)	(4.413)
Federal Production Tax Credit	**0.174*** **	**0.00231*** **
	(3.511)	(3.398)
Commercial NG Price ($/Mcf)	0.0263	0.000347
	(1.524)	(1.533)
Real Coal Price	0.00806	0.000106
	(0.692)	(0.692)
Net Electricity Generation (Thousands of Kilowatthours)	5.62e-07	7.42e-09
	(1.107)	(1.115)
Capacity-Weighted Average Project Costs ($/KW)	-2.26e-05	-2.98e-07
	(-0.215)	(-0.214)
LCV Scores (Senate)	0.00102	1.34e-05
	(0.941)	(0.947)
Observations	360	360
Number of States	24	24

Note: asymptotic z-statistics in parentheses, *** p<0.01, ** p<0.05, *p<0.1.

a: This index is an indicator of the first year for each effective program in each state and year for GPP and state grant and loan programs.

Table 8 demonstrates that these results are unexpectedly diminishing over time. These findings are in contrast with those of Carley (2009) who found that the there was no initial effect of an RPS on renewable electricity generation generally, but that its influence was increasing over time.

Table 8: Tobit Random Effects: Regulations and Market Influences (Marginal Effects)

	Regulatory and Financial Incentive Indicators: Years from Initial Implementation	
Dependent Variable: Annual State Wind Capacity / State Wind Potential	**(1) Full Sample: Probability of Wind Development**	**(2) Full Sample: Expected Increase in Wind Capacity Relative to a State's Wind Potential Given That Wind Development Has Occurred**
State Grant and Loan Program [a]	0.00297	3.92e-05
	(0.572)	(0.572)
Green Power Purchasing/Aggregation [a]	**0.0975*** **	**0.00129*** **
	(3.362)	(3.339)
Mandatory Utility Green Power Option [a]	**0.0469** **	**0.000619** **
	(2.150)	(2.166)
Optional Renewables Portfolio Standard [a]	0.0133	0.000175
	(0.558)	(0.556)
Renewables Portfolio Standard [a]	**-0.0156***	**-0.000205***
	(-1.682)	(-1.663)
Utility Green Power Option [a]	**0.0474*** **	**0.000625*** **
	(4.390)	(4.390)
Federal Production Tax Credit	**0.175*** **	**0.00232*** **
	(3.363)	(3.278)
Commercial NG Price ($/Mcf)	**0.0352** **	**0.000464** **
	(2.052)	(2.042)
Real Coal Price	-0.0201	-0.000265
	(-1.506)	(-1.508)
Net Electricity Generation (Thousands of Kilowatthours)	**7.70×10^{-7}***	**1.02×10^{-08}***
	(1.706)	(1.711)
Capacity-Weighted Average Project Costs ($/KW)	4.54×10^{-06}	5.98×10^{-08}
	(0.0425)	(0.0425)
LCV Scores (Senate)	**0.00168***	2.22×10^{-05}
	(1.689)	(1.698)
Observations	360	360
Number of States	24	24

Note: asymptotic z-statistics in parentheses, *** p<0.01, ** p<0.05, *p<0.1.
a: This index is an indicator of the number of years from initial implementation for each type of regulatory program and financial incentive in each state and year except the Federal Production Tax Credit.

Given that the binding constraints for the implementation of each RPS are outside of the time period of analysis, I expected that the effectiveness of the RPS would increase rather than decrease in the years subsequent to its implementation. In fact, the influence of the RPS is diminished in the years after its implementation. The magnitude of the negative influence in each year after implementation is approximately 1.5 percentage points, significantly smaller than the initial positive influence of the RPS. This indicates that long term role of the RPS in influencing continued wind development after its initial year of implementation is debatable. The total long term influence cannot be determined until after the mandatory renewable energy requirements of the RPS become binding. The information in Table 3 shows that generally this will occur in the next five to ten years. While the initially positive influence of the RPS is strongly demonstrated in these results, the fact that this influences diminishes in the years after implementation make it difficult to conclude whether the long term role of the RPS will be positive or not. The final conclusions hinge on the long term influence of the RPS as they become binding constraints.

Federal Production Tax Credit

The AWEA often argues for the importance of the PTC in influencing wind development (AWEA, EoWE; GWEMR 1999). The literature has generally supported this viewpoint, arguing that the lapses in the PTC lead to decreases in wind development. (Bird et al, 2005; Harper, Karcher, and Bolinger, 2007). Evidence of correlation between the total amount of wind capacity that is added in the United States and an active PTC are clear from Figure 2. The findings in this paper support the supposition of the AWEA and others regarding the significance of the PTC in influencing added wind capacity. The coefficient on the PTC is consistently positive, and statistically significant.

The results in Tables 6a, 7, and 8 demonstrate that the probability of wind development occurring increases by between approximately 17 and 19 percent with an active PTC. In addition, given that wind development has occurred, the expected megawatts of additional wind capacity per megawatt of wind potential increased by approximately 0.2 percentage points.

Green Power Purchasing Option Programs and Mandatory Green Power Option Programs

The role of RPS and the PTC are not the only widely discussed renewables programs, in addition, GPP programs are widely popular. The results in Table 7 show that after a state implements a GPP program, the probability of wind development increases by 27 percentage points. In addition, given that wind development has occurred, a GPP program increases the expected megawatts of wind capacity per megawatt of wind potential by 0.4 percentage points. Table 6a shows that these findings are supported by the results for the GPP sum index. The results in Table 6a demonstrate that the probability of wind development increases by approximately five percentage points after each GPP program is implemented in a state. In addition, for each program that is implemented, the expected megawatts of added wind capacity per megawatt of wind potential increases by 0.07 percentage points.[44] Table 8 shows that the findings are robust to the inclusion of the alternate, years from, index. For each additional year after the implementation of a GPP program, there is an approximately five percentage point increase in the probability of wind development. In addition, given that wind development has occurred, there is an expected increase in the megawatts of added wind capacity per megawatt of wind potential of approximately 0.06 percentage points.

Given the fact that multiple GPP programs are often implemented in a single state, it is not possible to entirely separate out the effects of additional programs from the influence of the initial program in the specifications in Table 8. The fact that the significance of the GPP

[44] The findings regarding the GPP sum index are robust to the inclusion of year indicators. For the GPP indicator index, however, the statistical significance is diminished to less than ten percent if year indicators are included.

programs is robust for both the GPP sum and GPP years from indices does demonstrate the important influence of these programs on increasing wind development.

The expected positive influence of the GPP programs has led some states to mandate their implementation by utilities. Tables 7 and 8 demonstrate the positive and statistically significant influence of the MGPP programs. The magnitude of the influence of the MGPP index is less in terms of its initial influence as demonstrated in Table 7, but after its implementation, its continued yearly influence is as strong as that of the GPP programs as demonstrated in Table 8. Given the role of the MGPP in generating GPP programs, it is not surprising that the influence is stronger in the years after the implementation of a MGPP than it is in its initial year of implementation. Clearly, these programs, which allow for the direct implementation of consumer demand for renewables, have played an important role in increasing wind capacity across states.

<u>Green Power Purchasing/Aggregation Programs</u>

The last policy that I analyze are green power purchasing mandates for state governments. The findings in Tables 6 and 7 show that the implementation of a GPA program does not have a statistically significant influence on wind development. The findings in Table 8, however, indicate that for each year after the implementation of the GPA program, there is a positive and statistically significant influence on wind development. States with a GPA will on average have an increased probability of wind development of approximately 10 percentage points. In addition, for each year after the GPA program is adopted, there will be an increase in the expected megawatts of wind capacity per megawatts of wind potential of approximately 0.01 percentage points. This positive influence over the longer term could point to either a delay in the adoption of the renewable energy to meet the goals of the GPA or influence of the state GPA on municipalities leading to municipal GPA implementation. Future work will focus on analyzing additional GPA programs.

Electricity Market Factors

The regression results in Tables 6 through 8 indicate the significance of various market factors, including natural gas prices, and the total net electricity generation. The findings, however, are not robust to the inclusion of the alternate policy indices. Interestingly, taken together, the market factors are consistently jointly statistically significant. This indicates that there is an overall influence from the electricity markets after controlling for the regulatory environment.

League of Conservation Voters Scores

The final factor that was considered was the role of consumer preferences for renewables development. As an indicator of consumer preferences by state, I analyzed LCV scores for both the state Senate and House. The state Senate score was consistently positive indicating that a higher environmentally friendly state legislative delegation leads to additional wind capacity, however, it was generally not statistically significant.[45] The limited influence of the LCV scores could indicate that preferences are not a main factor in determining wind development. Forthcoming work will analyze the role of alternative preference measures to determine if the lack of statistical significance is due to the choice of indicator variable.

Conclusion

The findings in this paper demonstrate that both renewable energy regulations and the electricity market influence added wind capacity increases in the United States. The

[45] The House LCV score was statistically significant at the ten percent level for both the sum and indicator indices, but not for the years from index. The magnitude of the coefficient was consistently not economically significant. For a ten percentage point increase in the index, the probability of wind development increased by two percentage points.

implementation of the PTC, an RPS or a GPP program, either by a utility or a state mandate for utilities, increased added wind capacity relative to a state's wind potential. The influence of the GPP is increasing in the years after implementation, while for an RPS the effect diminishes in the years after initial implementation. State GPA programs also positively influenced wind development, while State Loan and Grant programs were ineffective.

In terms of market factors, although no single electricity market indicator was consistently statistically significant, taken together the electricity market did have a statistically significant influence on wind development. As expected, given the measures included, the influence was positive. Also, consumer preferences, as measured through LCV scores, did not prove to be a significant factor in increasing wind development.

This paper demonstrates that while renewable energy regulations are not universally significant in influencing wind development, they are having a positive influence in the wind market. The implementation of the PTC, an RPS or GPP programs in particular, lead to increased added wind capacity.

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Appendix A

Table A1: Summary Statistics

	Added Wind Capacity (MW)	Wind Capacity (MW) / Wind Potential (MW)	Net Generation of Electricity (Thousands kWh)	Real Commercial NG Price ($/Mcf)	Real U.S. Coal Prices ($/Short Ton)
Mean	336.4659	0.00367642	81919.81	7.397992	19.29364
Median	53	0	49470.85	7.41	18.21
Standard Deviation	724.2453	0.0129579	82052.47	1.972993	2.98338
Maximum	7113	0.1144652	405492.3	13.42	26.62
Minimum	0	0	6136.605	0	16.78

	LCV score Senate	LCV score House	Capacity-Weighted Average Project Costs ($/KW)	Average Turbine Size (MW)	Year and Wind Potential (GW) interaction
Mean	44.53409	40.95455	1471.997	1.087104	1.01×10^{08}
Median	47	40.5	1439.52	1.1412	5.80×10^{07}
Standard Deviation	33.27896	25.8661	210.5465	0.401866	9.91×10^{07}
Maximum	100	100	1915.41	1.795789	2.78×10^{08}
Minimum	0	0	1202.76	0.496061	819180

Note: All of the summary statistics in the Table above are for the 24 state sample.

Table A2: Discrepancy between Cumulative Measures

State	Discrepancy (MW)	Percentage of 1999 Level Attributed to the Discrepancy
California	59	3.7%
Iowa	5	2%
Nebraska	1	33%
Texas	6	3.3%

Table A3: Linear Models

Dependent Variable: Annual State Wind Capacity / State Wind Potential	**Fixed Effects Specification**	**Random Effects Specification**
State Grant and Loan Program(s) [a]	-0.00356	-0.00403
	(-0.776)	(-1.058)
Green Power Purchasing/Aggregation	0.00651	0.00541
	(0.896)	(0.735)
Optional Renewables Portfolio Standard	0.00508	0.00746
	(0.971)	(1.143)
Renewables Portfolio Standard	0.00140	-0.00165
	(0.369)	(-0.312)
Utility Green Power Option(s) [a]	**0.0127***	**0.00680***
	(2.042)	(1.871)
Federal Production Tax Credit	**0.00333****	**0.00320****
	(2.772)	(2.117)
Commercial NG Price ($/Mcf)	**0.00245***	**0.00227***
	(1.963)	(1.737)
Real Coal Price	8.18e-05	0.000389
	(0.102)	(0.527)
Total Quantity of Electricity Generation	0.000270	0.000383
	(0.775)	(1.251)
Capacity-Weighted Average Project Costs ($/KW)	-5.20×10^{-08}	2.37×10^{-08}
	(-0.444)	(1.636)
LCV Score (Senate)	1.86×10^{-06}*	1.92×10^{-06}*
	(1.969)	(1.902)
Constant	9.63×10^{-05}	8.57×10^{-05}
	(1.275)	(1.434)
Observations	360	360
R-squared	0.288	
Number of States	24	24

a: These indices are the sum of active GPP programs and State Grant and Loan Programs in each state.