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The effects of renewables portfolio standards on renewable energy generation.

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Abstract

Renewable energy as a share of total electricity generated has been increasing in recent years. According to The Energy Information Administration (EIA), half the installed capacity for electricity generation in 2017 came from renewable energy. Thirty-eight states have enacted policies to encourage or require some of their generated electricity to come from renewable sources. Renewables Portfolio Standards (RPS) have varying requirements and objectives among the states, but the overall objective is to diversify the ways electricity is generated and reduce emissions of greenhouse gases. A state fixed-effects panel data model is used to estimate the effects of an RPS policy on renewable electricity generation. Results show that states which enacted mandatory RPS policies experienced an increase in the share of total renewable energy generation of about 1.08 percentage points. States which enacted voluntary policies experienced a larger increase in renewable energy generation relative to those with mandatory polices, about 1.9 percentage points. States implementing voluntary polices also see larger effects on the share of wind generation.

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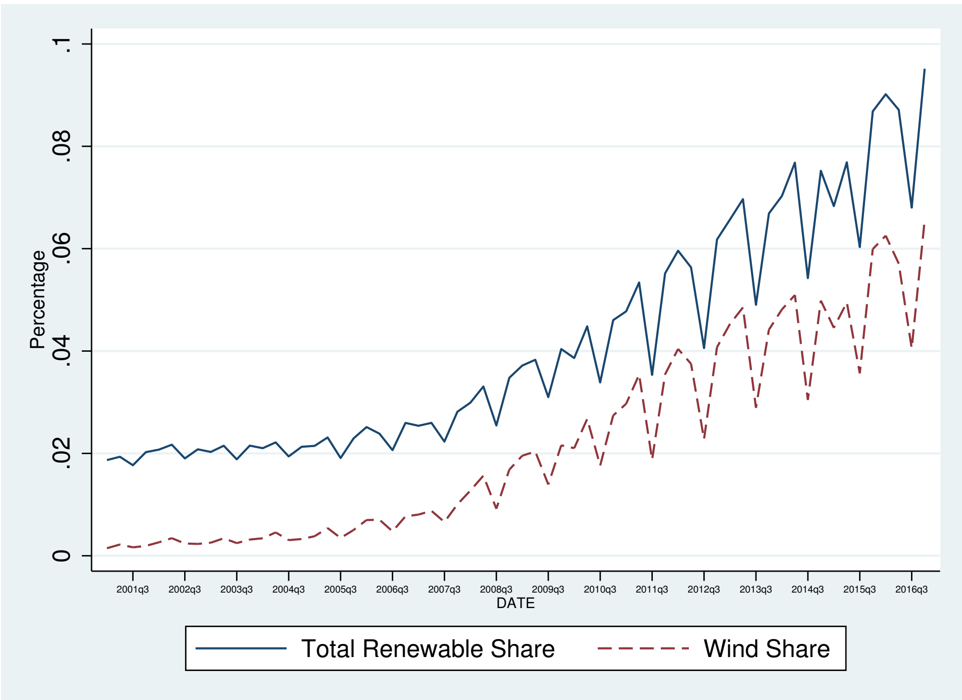
1. Introduction

Renewable energy generation has been increasing as a share of total energy generation in recent years. Figure 1 shows that after 2007, the electricity generated from renewable sources, as a share of the total electricity generation, has been steadily increasing. Additionally, it is also clear from Figure 1 that wind makes up a large percentage of renewable energy generation. In January 2018, The Energy Information Administration (EIA) reported that half the installed capacity for electricity generation in 2017 came from renewable energy (Energy Information Administration 2018a) and also projected that wind will surpass hydroelectric as the largest source of renewable electricity within the next two years (Energy Information Administration 2018b). More than half the states have some type of Renewables Portfolio Standard and this study investigates the impact of these policies on the increase in the share of renewable energy generation. Furthermore, large proportions of electricity are being supplied by renewables in states with RPS policies (Barbose 2017).

Figure 1: Data obtained from the Energy Information Administration Electricity Browser. Shares of total electricity generated from total renewables for the United States. The dashed line illustrates the large contribution of wind to the renewable energy generation.



Renewables Portfolio Standards (RPS) is a policy that requires a certain percentage of a state's total electricity generation be obtained from a renewable energy source such as solar, wind, or geothermal (Carley and Miller 2012). RPS regulations vary from state to state but generally set an initial percentage of electricity to be generated from renewable energy sources, and then increases that percentage gradually over time (Yin and Powers 2010). RPS policies are popular instruments, adopted more often than alternatives such as carbon taxes or greenhouse gas allowances (Carley and Miller 2012).

RPS policies have become a commonly adopted tool for states to address climate change. There are several studies concerned with the effectiveness of renewables mandates. Langniss and Wiser (2003) find that an RPS policy in Texas spurred renewable energy development and encouraged competition among producers. Menz and Vachon (2006) use ordinary least squares to estimate the effect of state RPS policies on renewable energy capacity for 39 states from 1998 to 2002. They find that an RPS policy has a statistically significant effect on wind capacity. Carley (2009) uses a fixed-effects vector decomposition model to investigate RPS implementation for 1998 to 2006. Results indicate that enacting an RPS policy is not a significant predictor of the share of renewable energy generation. However, for each additional year that a state has an RPS policy in place, the amount of renewable energy generation increases. Yin and Powers (2010) use a panel data set for 1993 to 2006 and introduce a stringency measure to capture the effect of design features of RPS policies. They find that when controlling for differences in RPS policies there is a significantly positive effect of an RPS on renewable energy generation. Upton and Snyder (2017) analyze a panel data set of 49 U.S. states from 1990 to 2013 and find that states with an RPS policy did not experience a statistically significant increase in renewable energy generation relative to non-RPS states.

Sarzynski *et al.* (2012) examine the effects of RPS policies as well as state financial incentives on deployment of solar technologies. They find that RPS policies are significant in increasing the deployment of solar. More recently, Barbose *et al.* (2016) focus on new renewable electricity resources to estimate the impacts and benefits of RPS policies in 2013. They find a reduction in both greenhouse gases and water consumption as a result of RPS policy implementation. Maguire and Munasib (2016) find varying impacts of RPS policies across states.

Several studies on wind capacity do not find a positive impact from implementing RPS policies. Delmas and Montes-Sancho (2011) find that RPS adoption led to a decline in renewable energy capacity. Shirmali and Kniefel (2011) use a panel data set containing all 50 states spanning from 1991 to 2007 and a state fixed-effects model to estimate the effects of RPS policies on renewable energy sources, including wind, biomass, geothermal, and solar photovoltaic. They find that voluntary RPS policies are ineffective in increasing non-hydroelectric renewable energy capacity. Hitaj (2013) uses a county-level panel analyses from 1998 to 2007 and does not find a significant effect of RPS adoption on wind capacity. Maguire (2016) investigates the influence of RPS policies on wind capacity from 1994 to 2012 and does not find statistically significant impacts on wind capacity.

Others have studied whether renewable energy potential is a determinant of RPS policy adoption. Lyon and Yin (2010) find a statistically significant effect of wind and solar potential on RPS adoption. Upton and Snyder (2015) find a positive impact on the probability of RPS adoption for both wind and solar potential. Yi and Feiock (2012) use the number of sunny days as well as the state average wind speed as proxies for solar and wind potential, respectively, and find weak evidence of their effect on RPS policy implementation.

Thirty-eight states have enacted policies to encourage or require some of their electricity generated to come from renewable sources.[1] RPS policies have varying requirements and objectives among the states, but the main objectives are to diversify electricity generation and reduce greenhouse gas emissions.[2] Some policies require a state to reach a specific level of renewable energy generation by a future date. New Mexico requires investor-owned utilities to provide 100% of electricity generated from carbon-free sources by 2045, whereas corporate utilities have until 2050. Intermittent goals are 50% by 2030

[1] Those states are: AZ, CA, CO, CT, DE, HI, IL, IN, IA, KS, MA, ME, MD, MI, MN, MO, MT, NV, NH, NJ, NM, NY, NC, ND, OH, OK, OR, PA, RI, SC, SD, TX, UT, VT, VA, WA, WV, WI .

[2] See Wiser *et al.* (2008) for a comprehensive review of Renewables Portfolio Standards.

and 80% by 2040 (Energy Information Administration 2019a). Some states encourage voluntary compliance. Oklahoma set a voluntary goal of 15% by 2015 (National Conference of State Legislatures 2017). In all cases, states that have an RPS policy are attempting to increase the amount of electricity generated from renewable sources.

There has been a movement in some states to change their laws surrounding RPS policies during the sample period. In 2015, three states made changes to their policies. West Virginia repealed their standard. Kansas switched from required compliance to voluntary, and moving in the opposite direction, Vermont switched from voluntary to required compliance.

The object of this study is to investigate the effect of implementing a renewable energy policy at the state level and adds to the literature in several ways. First, this study uses a recent sample period that captures an increase in the share of total renewable energy generation after 2007. I extended and add to the work of Carley (2009) by including the 10 years after 2006, using a quarterly frequency, and including both mandatory and voluntary RPS variables. By analyzing more recent years, the effect of declining costs of solar and wind capacity is captured. Second, similar to Shrimali and Kniefel (2011) state level quarterly panel data are used allowing for the control of state level fixed-effects and estimation of quarterly seasonal effects. In this study, the costs of installed wind projects, not present in Shrimali and Kniefel (2011), are included. Additionally, by including dummy variables for each year, the effects of amended policies and changing tax credits are captured. Third, RPS policies are not homogeneous. Policies that require compliance, as well as voluntary policies, are examined to capture the differing effects of the respective policies on renewable energy generation. Finally, the effects of RPS policies on the shares of total renewable energy, wind, solar, and geothermal energy generation are examined.

The remainder of this paper is organized as follows: section 2 describes the econometric framework and data used; section 3 presents a discussion of the results; section 4 concludes.

2. Methodology

This study is investigating the effects of RPS policies on energy renewable generation in each U.S. state from 2001 to 2016. The resulting panel data is analyzed using a standard fixed effects model.[3] Benefits of using a state panel data set to examine RPS policy effects include expanding the number of observations in the analysis and controlling for states' unobserved fixed-effects that influence energy policy.

The fixed-effects model is as follows:

$$y_{it} = \beta \mathbf{x}_{it} + \delta Year_t + a_i + \mu_{it}, \tag{1}$$

where y_{it} is the share of renewable energy generation for state i at time t, $\mathbf{x}_{it}$ is the vector of explanatory variables including the RPS binary variables, $Year_t$ is a vector of year dummy variables, a_i represents the unobserved state fixed-effects, and μ_{it} is the idiosyncratic error term.

[3] A Hausman test was performed and supports the use of the fixed effects estimation.

2.1 Data

Spanning the first quarter of 2001 to the fourth quarter 2016, data are collected from various public sources to analyze the effects of a Renewables Portfolio Standard policy on renewable energy generation. Renewable energy generation is the focus rather than capacity because of the intermittent nature of wind and solar. All 50 states are represented for 64 quarters, totaling 3,150 observations.[4] Table 1 contains descriptive statistics for the variables.

Table 1: *TotalRenewShare*, *WindShare*, *SolarShare*, and *GeothermalShare* are in percentage of total electricity generated; *RPS_Man* is the binary indicator identifying the quarters during which a state has a mandatory renewable energy policy in place; *RPS_Vol* is similarly defined for a voluntary RPS policy; *NatGasPrice* is the price of natural gas in each state; *WindCost* is the cost of installing wind projects in capacity weighted averages in 2016 dollars per kilowatt hour for the United States; *PerCapGDP* is the state GDP in chained 2009 thousands of dollars; *PopGr* is the quarterly growth rate of the states' population in percentages; *CostElec* is the average cost of electricity in cents per kilowatt hour; *PerCapElecGen* is the total amount of electricity generated divided by the states' population in megawatt hours per person.

Descriptive Statistics

	Mean	St. dev	Min	Max
TotalRenewShare	4.95	6.69	0	54.04
WindShare	2.53	5.29	0	44.53
SolarShare	0.135	0.665	0	11.00
GeothermalShare	0.299	1.24	0	11.62
RPS_Man	0.47	0.499	0	1
RPS_Vol	0.08	0.272	0	1
NatGasPrice	10.19	4.20	2.94	48.79
WindCost	1,820	331	1,336	2,382
PerCapGDP	46.21	8.70	28.82	73.48
PopGr	0.204	0.1834	-1.786	1.094
CostElec	9.295	3.649	3.937	35.267
PerCapElecGen	8.45	6.62	1.25	48.09

Net energy generation in total megawatt hours by month and type for each state is obtained from the EIA (Energy Information Administration 2017a). The total amount of renewable energy is the sum of electricity generated from geothermal, wind, solar, wood and wood products, and other biomass. Monthly totals are summed to create quarterly observations. The shares of total energy generation for total renewable energy are calculated by taking 100 times the ratio of renewable electricity generated to total electricity generated. Shares for wind, solar, and geothermal are similarly defined. To control for substitution effects of fossil fuel sources, the natural logarithm of the cost of natural gas is included.[5] There are two variables of interest. The first, *RPS_Man*, is a binary variable denoting a mandatory RPS policy. If a state enacts a mandatory policy, *RPS_Man* is set equal to one in the quarter during which the policy is enacted and remains one for each successive quarter if the policy remains unchanged. The second, *RPS_Vol* is similarly defined for a voluntary policy. Information on the timing of RPS implementation

[4] There are 3,200 total observations, however, one observation per state is lost when calculating the population growth rate.

[5] Data on the cost of coal was not available for each state during the sample period, thus the price of coal was not included.

for each state is obtained from the National Conference of State Legislatures (National Conference of State Legislatures 2017).

Two measures of state socioeconomic status are included in the model: population growth rate and per capita state GDP. Annual population for each state is obtained from the Census Bureau (U.S. Census Bureau 2017a,b). Quarterly observations are obtained by cubic spline interpolation.[6] The population growth rate is calculated by taking 100 times the log difference of the quarterly population and controls for the effects of population change on the overall demand for electricity in each state. States with higher population growth are more likely to build more power generating plants, however, it is not clear if this predicts more or less renewable energy generation. States that have more resources will have more flexibility to increase the share of renewable energy generation. Annual per capita state GDP in thousands of chained 2009 dollars, obtained from BEA and interpolated to quarterly, is included to control for states' individual wealth (U.S. Bureau of Economics Analysis 2017).

Two state electricity variables included are the average cost of electricity in each state and the per capita electricity generation. The average retail quarterly cost of electricity in cents per kilowatt-hour is obtained from the EIA (Energy Information Administration 2017b). Prices of electricity could influence the adoption of renewable energy sources, although it is difficult to predict whether the effect is positive or negative. If electric prices are low it may not be economically feasible for utilities to invest in relatively expensive renewable capacity. However, if utilities are able to pass along the costs to consumers low electric prices may make it possible for utilities to increase renewable capacity. The per capita electricity generation is calculated using the quarterly total megawatt-hours of electricity generated in each state and the quarterly population and is the megawatt hours per person. This variable captures the demand aspects of each state, and again, it is difficult to predict the impact of this variable on renewable generation. States where summers are hotter and consumers rely on air conditioning might be less willing to invest in renewable energy that can be intermittent. On the other hand, those states might be located in areas with a high number of sunny days and might be more willing to invest in solar energy.

Electricity generated from wind is a large share of the total renewable energy generation as is illustrated in Figure 1. Annual installed cost of wind projects is obtained from the EIA Wind Technologies Market Report (Wiser *et al.* 2016). Wind project costs are included as a control and are capacity weighted averages in 2016 dollars per kilowatt-hour for the United States. By controlling for wind costs I attempt to isolate the effect of the RPS policies on the renewable energy generation. Quarterly observations for wind project costs are interpolated from annual data.

3. Results and Discussion

The two RPS variables capture some of the heterogeneity in states' renewable energy policies. It is assumed that RPS policies are not randomly assigned and important differences across states, including political party dominance, expenditures on resource extraction, and renewable energy potential, contribute to whether a state adopts an RPS policy (Matisoff 2008; Huang *et al.* 2007). Ignoring this heterogeneity would bias the

[6]Because of the serial correlation introduced by the interpolation of several variables from annually to quarterly, Driscoll-Kraay standard errors are reported (Driscoll and Kraay 1998).

estimates and in this study I control for these state differences by using a fixed-effects panel data model. Additionally, by including year dummy variables the effect of changing incentives over time that are difficult to measure are captured.

The results of estimating equation (1) are presented in Table 2. The model was estimated with total renewables, wind, solar, and geothermal shares of total electricity generation as the dependent variables. Also included are quarterly dummy variables to capture seasonality and dummy variables for each year in the sample. The discussion will focus on the models estimated with quarterly and year dummy variables.

Table 2: Results for the state level fixed-effects model. Driscoll-Kraay standard errors are in parentheses. ** denotes significance at the 5% level; * denotes significance at the 10% level.

Quarterly Results

	TotalRenew_sh			**Wind_sh**			**STPV_sh**			**Geo_sh**		
RPS_MAN	1.8350**	1.8177**	1.0775**	1.2562**	1.2347**	0.7807**	0.1422**	0.1451**	0.0072	-0.0444*	-0.0462*	-0.1190**
	-0.2746	-0.2741	-0.2688	-0.2415	-0.239	-0.2372	-0.0418	-0.0417	-0.0405	-0.026	-0.026	-0.0259
RPS_VOL	2.8170**	2.7528**	1.9419**	3.1536**	3.0288**	2.4043**	-0.1376**	-0.1294**	-0.2385**	0.1081**	0.1051**	0.0528
	-0.3753	-0.3749	-0.3628	-0.3301	-0.3269	-0.3201	-0.0571	-0.0571	-0.0546	-0.0355	-0.0356	-0.0349
PerCapGDP	0.5602**	0.5478**	0.4421**	0.5525**	0.5314**	0.4771**	0.0077*	0.0095**	-0.0145**	-0.0120**	-0.0129**	-0.0249**
	-0.0283	-0.0284	-0.029	-0.0249	-0.0248	-0.0256	-0.0043	-0.0043	-0.0044	-0.0027	-0.0027	-0.0028
PopGr	-2.9407**	-2.8741**	-0.9969*	-1.9763**	-1.8695**	-0.5171	-0.4704**	-0.4803**	-0.2034**	-0.5537**	-0.5486**	-0.4133**
	-0.6067	-0.6059	-0.5928	-0.5336	-0.5283	-0.523	-0.0924	-0.0923	-0.0892	-0.0575	-0.0575	-0.0571
lPercapElec	-4.9751**	-4.1764**	-3.4918**	-0.1231	1.4210**	1.9762**	-0.5776**	-0.6803**	-0.5762**	-0.2915**	-0.2539**	-0.2191**
	-0.4549	-0.5016	-0.4847	-0.4001	-0.4374	-0.4277	-0.0692	-0.0764	-0.073	-0.0431	-0.0476	-0.0467
lCostElec	6.6247**	7.1913**	-1.4645*	5.4150**	6.4381**	0.5956	0.6854**	0.6079**	-0.8432**	-0.0152	0.0203	-0.6873**
	-0.5578	-0.5759	-0.769	-0.4906	-0.5021	-0.6785	-0.0849	-0.0877	-0.1157	-0.0528	-0.0546	-0.074
lWindCost	-1.9215**	-2.2091**	1.8563	-0.9912**	-1.5029**	1.0531	-0.5558**	-0.5159**	0.0663	0.1154**	0.0957**	0.2263
	-0.4596	-0.4651	-2.2958	-0.4042	-0.4056	-2.0257	-0.07	-0.0708	-0.3456	-0.0435	-0.0441	-0.221
lNatGasPrice	-5.2662**	-5.1383**	-2.2064**	-4.9237**	-4.7217**	-1.9327**	-0.2331**	-0.2524**	0.0168	0.0123	0.0231	0.1045**
	-0.327	-0.3288	-0.4557	-0.2876	-0.2867	-0.4021	-0.0498	-0.0501	-0.0686	-0.031	-0.0312	-0.0439
Qtr2		-0.0925	0.0578		0.0701	0.1125		0.0282	0.0723**		-0.0350*	-0.0106
		-0.1885	-0.183		-0.1644	-0.1615		-0.0287	-0.0275		-0.0179	-0.0176
Qtr3		-0.6566**	-0.2941		-1.1741**	-1.0348**		0.0915**	0.1820**		-0.0511**	0.0002
		-0.2032	-0.2017		-0.1771	-0.1779		-0.0309	-0.0304		-0.0193	-0.0194
Qtr4		0.0752	0.2502		0.1325	0.2192		-0.0087	0.0327		-0.0138	0.0079
		-0.1877	-0.182		-0.1637	-0.1605		-0.0286	-0.0274		-0.0178	-0.0175
constant	0.2359	0.0481	-15.9763	-16.3925**	-17.0405**	-28.7970**	4.1522**	4.1566**	2.8324	0.6931**	0.7302**	1.3374
	-3.2966	-3.3048	-16.585	-2.8994	-2.8815	-14.6336	-0.5018	-0.5033	-2.4963	-0.3123	-0.3134	-1.5967
N	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150	3150
Year Dummies	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes

Both mandatory and voluntary RPS policies have statistically significant positive effects on the share of electricity generated from total renewables and wind. Enacting a mandatory RPS policy resulted in about a 1.08 percentage point increase in the share of electricity generated for all renewable sources, whereas implementing a voluntary RPS policy increased total renewables share by about 1.9 percentage points. These results contrast with Shrimali and Kniefel (2011) who find voluntary policies to be insignificant, and also Carley (2009) who does not include a voluntary RPS measure but does not find RPS policies to be significant predictors of the share of renewable energy generation. To put those figures into perspective, over the sample period the average share of total renewable energy for states with a mandatory policy is about 6.5%. States with a voluntary policy have an average of about 10%. The states with neither policy type have an average share of about 2.4%. Thus, while the increases are statistically significant, there is still room for the share of renewable energy generation to grow.

Wind share increased by about 0.78 percentage points with a mandatory policy, but the effect of a voluntary policy was about three times larger at 2.4 percentage points. Wind is probably the main driver of the difference in the mandatory and voluntary estimates for total renewable share. Hitaj (2013) also finds that state and federal policies are important to wind power development. States with voluntary policies have a larger average share of renewables and the difference in the mandatory and voluntary estimates is capturing some of that effect. Changes in wind capacity additions can be partially explained by tax credits such as the Production Tax Credit and including year dummy variables captures the effects of the PTC changing over the years (Energy Information Administration (2019b).[7] It is also possible that wind is favored over solar as the choice for renewable energy generation in many states.

Solar generation is positively effected by a mandatory policy, albeit insignificantly, but voluntary policies have a statistically significant negative effect. This conflicts with Sarzynski *et al.* (2012) who find RPS positively related to increasing solar deployment. This could be because the cost of wind is cheaper relative to solar and those states with voluntary policies choose wind over solar (Energy Information Administration 2016). Regardless, the magnitudes of the effects on solar generation are relatively small, less than one percentage point.

The differences in the results for wind and solar could be explained by the increase in wind capacity as a result of tax credits in place since 1992 and recently extended (Energy Information Administration 2018c). Further, wind generation increased in share over the sample period and recently surpassed hydroelectric electricity generation due to wind capacity additions in the fourth quarter of 2019 (Energy Information Administration 2020. Both wind and solar growth have been driven by state and federal policies, and differences in these policies may provide a partial explanation for the differences seen (Energy Information Administration 2019c).

The effect of mandatory policies on geothermal is negative whereas the voluntary policy has a positive but statistically insignificant effect. Shrimali and Kniefel (2011) also found similar effects. These results are not surprising considering the popularity of wind and solar, as well as the fact that geothermal averages 0.29% as a share of total electricity generation over the sample period. In the cases of solar and geothermal, large percentages of the share of each are zero. In the case of solar, 2,350 out of 3,200 are zero and for geothermal, the number is 2,874.

Per capita GDP is significant and positive for the shares of total renewable energy and wind. A one thousand dollar increase in per capita GDP is associated with about a 0.44 percentage point increase in total renewable share and a 0.47 percentage point increase in wind share. It is significantly negative for solar and geothermal, with a one thousand dollar increase resulting in about 0.014 and 0.025 percentage point decrease, respectively. These estimates are contrary to Shrimali and Kniefel (2011) who found no effect of per capita GDP. With the share of total renewable energy positively related to per capita GDP there is evidence that state resources are positively related to the share of renewable energy.

Population growth is negative and significant for all shares except wind, with total renewable significant at the 10% level. This is in general agreement with the findings of Carley (2009). Increasing population growth one percentage point reduces total share of renewable energy generation by about one percentage point. The natural log of per capita electricity generation has a significantly positive effect on wind shares with a one megawatt hour increase resulting in a 0.019 percentage point increase in wind share. The other shares are negatively related to the natural log of the per capita electricity generation with the largest negative being for total renewable share, a one megawatt hour increase decreases total renewable share by about 0.035 percentage points.

[7] Thanks to the anonymous referee for this point.

The natural log of wind cost is statistically insignificant across all dependent variables. There are significant and negative estimates when seasonal and time effects are not included, but the signs change and the estimates become insignificant after controlling for quarterly and yearly effects. A possible explanation for the insignificant relationship between wind cost and wind share is that utilities are adding wind generation in response to mandatory policies and are relatively insensitive to cost. Another possibility is that subsidies for wind installation lower the cost to the developer.

Seasonal effects are mixed. Total renewable share does not have significant seasonal effects. For wind, the second and fourth quarter are insignificantly different from the first quarter, but the third quarter is statistically lower than the first. This is somewhat consistent with the fact that wind is subject to seasonal variations and is generally largest in the spring and fall (Energy Information Administration 2020). Solar share significantly increases in the second and third quarter relative to the first. This is intuitive since those quarters correspond to spring and summer. Unsurprisingly, geothermal share does not have seasonal effects.

Since some of the variables included in this study are not available at the quarterly frequency, quarterly values are interpolated, which does not account for seasonality. As a robustness check, equation (1) is estimated using annual data and the results are presented in Table 3. Compared to the quarterly estimates, the coefficients on the policy variables when the dependent variable is the share of total renewable energy are similar in magnitude and statistically significant, albeit with larger standard errors. For wind, the mandatory RPS variable is significant at 10% only but the voluntary variable is similar in magnitude to the estimates in Table 2 and significant at the 5% level. For many states, solar or geothermal comprises a small part of their electricity generation and thus, those states presumably find other ways to increase their renewable energy generation.

The coefficient on wind cost is larger in magnitude and statistically significant for all the dependent variables when considering the annual frequency. For the annual model, a 1% increase in wind cost is associated with an increase in total renewable share by 0.41 percentage points. Some other variables are affected. For instance, the natural log of the price of natural gas has the expected sign in the quarterly regression and yet, it is significant and positive for solar share in the annual regression. Population growth, significant for quarterly data, is insignificant when using annual data, except for geothermal. The interpolation reduces the precision of the estimates, and in some cases variables change signs and become insignificant, however, the variables of interest remain statistically significant and similar in magnitude.

A state looking to increase renewable electricity generation should consider a renewables portfolio standard, but whether a mandatory or voluntary policy is implemented matters. Obviously, different states have different capabilities for renewable energy generation. For example, Wyoming is a state without an RPS mandate and ranks high in solar energy according to the National Renewable Energy Laboratory (National Renewable Energy Laboratory 2018). A state without an RPS mandate that also has high potential for wind energy is Nebraska (National Renewable Energy Laboratory 2017). Results show that shares of renewable energy increase after implementing an RPS policy. However, voluntary policies appear to be more effective in promoting wind generation whereas voluntary policies have a negative effect on solar generation. States with higher wind potential could potentially benefit more from a voluntary policy than from a mandatory one. Thus, for the states that do not have any type of renewable energy requirements associated with electricity generation and have a desire to increase the share of energy

Table 3: Results for the state level fixed-effects model using annual data. ** denotes significance at the 5% level; * denotes significance at the 10% level. Results including year dummies are available from the author upon request.

Annual Results

	TotalRenew_sh	Wind_sh	STPV_sh	Geo_sh
RPS_MAN	1.0910**	0.7915*	-0.0131	-0.1020**
	(0.5172)	(0.4536)	(0.0834)	(0.0423)
RPS_VOL	1.5934**	1.9766**	-0.1752	0.0401
	(0.6818)	(0.598)	(0.110)	(0.0557)
PerCapGDP	0.4311**	0.4574**	-0.0119	-0.0217**
	(0.0553)	(0.0485)	(0.0089)	(0.0045)
PopGr	-0.2865	-0.1262	-0.0686	-0.1046**
	(0.2944)	(0.2582)	(0.0475)	(0.0241)
lPercapElec	-3.3725**	3.6131**	-0.8000**	-0.1474
	(1.2161)	(1.0665)	(0.1961)	(0.0994)
lCostElec	-2.0924	1.128	-1.1986**	-0.2695*
	(1.8325)	(1.6072)	(0.2955)	(0.1498)
lWindCost	41.2047**	23.3869**	8.8548**	2.5438**
	(7.3818)	(6.4739)	(1.1904)	(0.6035)
lNatGasPrice	-0.65	-1.5845	0.7137**	0.0652
	(1.3847)	(1.2144)	(0.2233)	(0.1132)
constant	-296.7642**	-199.3474**	-59.8038**	-16.1797**
	(50.5684)	(44.3489)	(8.1547)	(4.1345)
N	800	800	800	800
Year Dummies	Yes	Yes	Yes	Yes

provided by renewable sources, these results suggest that an RPS policy would help achieve that goal.

An important question is whether states that implement RPS policies are systematically different from states that do not. Huang *et al.* (2007) and Matisoff (2008) find that political characteristics, among other factors, are important determinants of RPS adoption. Matisoff (2008) also finds that renewable energy potential is important, implying that states with more renewable energy potential are more likely to adopt an RPS policy. However, neither study addressed whether these factors influenced the choice of voluntary versus mandatory policy adoption.

It is reasonable to assume that states adopting voluntary RPS policies differ in some systematic ways from those that adopt mandatory policies. This study investigates the within-state variation of states that implement a mandatory policy and those that implement a voluntary one. However, this approach does not address the differences across the respective states. Not controlling for the systematic differences across states could help explain the result that voluntary policies have a larger effect than mandatory ones. It may be that states with voluntary policies have a population that is more amenable to renewable energy generation and the policy makers pursue other renewable energy related goals in response. It could also be the case that after controlling for the differences across the states with mandatory policies and those with voluntary ones the impacts of RPS policies are much different, possibly even insignificant.

4. Conclusions

The goal of this study is to examine the relationship between the share of total electricity generation from renewable energy and RPS policy implementation from 2001 to 2016. Results suggest that the share of total renewable energy generation increased by about 1.08 percentage points after states implemented a mandatory RPS policy. For states that implemented a voluntary policy, total renewable share increased by about 1.9 percentage points. The shares of wind also increased in response to RPS policies with wind increasing three times more in response to voluntary policies than mandatory ones, and thus is most likely driving up the share of total renewable energy as a result of a voluntary policy. There is evidence that state per capita GDP is positively related to total renewable energy generation. Quarterly seasonal effects are mixed with wind energy generation larger in the third quarter relative to the first and solar experiencing increased generation in the second and third quarters.

One focus for future research is with heterogeneity of the RPS standards. Using a naive measure for RPS policies is straightforward, however, as Yin and Powers (2010) point out, ignoring the heterogeneity of the RPS policies potentially has a significant effect on the effects of an RPS. Future work will attempt to disentangle the various policies for renewable energy generation for each state. Additional variables that should be considered for inclusion are the cost of renewable and non-renewable electricity plants, different state level incentives such as energy rebate programs, and the level of interest from the renewable energy industry in each state. Controlling for the systematic differences across states that are relevant to the choice of different approaches to renewable energy generation is also a focus for future work.

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