The Effects of Renewable Portfolio Standards on Carbon Intensity in the U.S.

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Abstract

U.S. state carbon intensities are highly heterogeneous, and there have been few studies aimed at identifying the causes of these differences among states. Determining the factors, which enable certain states to develop their economies on a less carbon intensive trajectory, can give us insight into how those state characteristics or policies can be replicated to achieve lower carbon intensities in other economies. Our study finds that Renewable Portfolio Standards (RPS) have already had a negative and significant impact on carbon intensities through their influence on state electricity prices. Additionally, we show that the adoption of RPS reduced overall U.S. carbon emissions by 4% by 2010.

Keywords: Carbon intensity, Renewable Portfolio Standards, climate policy

Highlights:

- State attributes like temperature and primary industry affect carbon intensity (CI)
- Price increases are the main mechanisms through which RPS have decreased CI
- National carbon emissions were 4% lower in 2010 as a result of RPS implementation

1. Introduction

Since the industrial revolution, the development of the world economy has been fueled by carbon based energy. The growing threat of climate change, however, necessitates that society reduce its dependence on carbon-based fuels for economic development. Carbon intensity measures an economy's reliance on carbon-based energy and depends on the types of energy used, overall efficiency, and economic output (Casler and Rose 1998). As incomes grow, carbon emissions will not fall unless society is able to reduce carbon intensity. It is critical to identify the drivers of lower carbon intensity in order to continue growing our economy sustainably.

Over the past 30 years, carbon intensity in the U.S. has declined by about 50% according to the USDOE Energy Information Administration (2013). There are many potential drivers of low carbon intensity, including improved energy efficiency, shifting economic activity into sectors with lower energy intensity, and shifting the energy sector towards low carbon power, including nuclear, hydropower, and other renewables (Greening et al., 1998). Improved efficiency and changes in the composition of the economy are critically important, but given that so many states in recent years have implemented some form of renewable portfolio standard (RPS), it is useful to assess whether these policies also are having an influence on carbon intensity. Although these standards have been implemented for a wide variety of reasons, including diversification of the energy portfolio and a reduction of dependence on fossil fuels, because they push the energy sector to adopt low carbon sources of energy, RPS should also reduce carbon emissions.

Few studies to date have actually assessed the impact of state RPS on carbon emissions, but the one that has, Prasad and Munch (2012), did not find that the RPS standard had an impact on carbon emissions. This result is somewhat surprising, but it may be a function of the many confounding ways in which RPS can actually influence total carbon emissions. By requiring a given proportion of low carbon alternative energy (e.g., solar and wind), RPS standards should directly reduce carbon emissions. Because these energy sources cost more, retail electrity prices should rise, and this will likely cause a reduction in energy consumption and consequently carbon emissions (Tidball et al. 2010). It is also conceivable that state level output could decline for a time as a result of RPS if energy prices rise enough. On the other hand, RPS could increase emissions by changing the mix of state level outputs, for example by changing the proportion of output in manufacturing versus finance or real estate. Separate industries have carbon emission profiles of their own, and thus may contribute more or less to carbon emissions. It is not clear beforehand how shifts in sectoral activity will affect carbon intensity or carbon emissions.

The literature has addressed a number of these issues. Yin and Powers (2010) determined that the incremental share of renewables required by state RPS was positively correlated with the percent of state generating capacity that is non-hydro renewable. The incremental variable is a function of the nominal renewables requirement (the percent dictated by the RPS law), the state electricity load covered, and the existing renewable energy capacity and sales in the state. Shrimali and Kniefel (2011) assessed the effects of RPS on the proportion of energy generated from renewables. When the authors excluded Maine from their regression, the coefficient on RPS sales requirement variable is positive and significant. During the study period much of Maine's existing renewable fleet was eligible under the RPS policy, which reduced the incentive to invest in new renewable capacity between 1998 and 2002, and the state added 1,500 MW of natural gas capacity to its existing 3,000 MW capacity. Moreover, even without the omission of Maine minor energy contributors, like solar and geothermal energy, were positively and significantly influenced by RPS requirements.

However, Shrimali et al. (2012) reported that even a more thorough incremental share index (ISI) that accounted for the proportion of the utility industry covered by the RPS and the total retail electricity sales along with the nominal electricity requirement was negatively correlated with actual renewable energy capacity growth at a state level. The negative sign on ISI was robust to the exclusion of Maine although it was no long significant. Carley (2009) similarly reported that the presence of an RPS did not have a significant effect on the share of renewable energy-based electricity but determined that states with RPS do have a greater total renewable energy capacity compared to non-RPS states. These findings were corroborated in the study by Delmas (2011), which also determined that states with greater portions of renewable energy generation are more likely to implement RPS.

Shrimali and Kniefel (2011) also assess the indirect price effect on renewables deployment, finding a positive and significant relationship between electricity price and renewable energy ratio. A higher electricity price allows for renewable energy sources to become more cost-competitive. Shrimali et al. (2012) identified a negative relationship between lagged electricity price and a state's renewable energy ratio. The authors argue that if electricity prices are already high, then generators would avoid renewable investment, which would further increase prices. Delmas (2011) also estimated a negative relationship between electricity price and renewable energy ratio among those states that have RPS, but higher electricity prices were positively correlated with the presence of RPS. Overall, the relationship between electricity price and state renewable energy capacity or renewable energy ratio is unclear (Yin and Powers 2010).

The existing literature focuses almost exclusively on considering the effect of RPS policies on renewable energy investments, shares of electricity production, or total carbon dioxide emissions. No studies to our knowledge have examined whether RPS policies affect state level carbon intensity. This is surprising given the important role that controlling carbon intensity will have in reducing long run carbon emissions in the face of economic growth. Furthermore, three of the studies addressing the effectiveness of RPS only include data until or before 2007, and between 2007 and 2010, twelve additional states began implementing RPS or provided second year of data (for those states that had nominal goals beginning in 2007) (DSIRE). Our analysis assesses the effect of RPS standards on carbon intensity, measured as tons of carbon dioxide emissions per dollar of Gross State Product, between 1997 and 2010.

We hypothesize that RPS policies will have both direct and indirect effects on carbon intensity. The direct effects will be driven by the renewable energy policy itself, and its influence on energy output. If the policy shifts energy production towards low-carbon renewables like solar and wind, and output remains the same, then carbon intensity should fall. The indirect effects, however, could be just as important. One potential indirect effect is that the RPS policy could raise prices for energy. It is not obvious what the effect of energy prices on carbon intensity will be, given that higher energy prices could affect energy consumption as well as economic output. Another indirect effect of the RPS on carbon intensity occurs through changes in economic activity. It is possible, although unlikely (Davidsdottir and Fisher, 2011), that RPS standards could actually reduce state level outputs. To properly account for the effect of the RPS on carbon intensity, however, we maintain that it is important to also control for the effects of energy prices and economic activity. In addition to accounting for these direct and indirect effects, we control for other important policy design variables that influence the effectiveness of RPS standards. These include the scope of the RPS, the level of the penalty involved, and the potential to purchase renewable energy credits (REC) from outside the state. Using the resulting models, we predict the effect of RPS on US carbon emissions, finding that RPS implementation across the states have reduced carbon emissions over the study period.

This paper is composed as follows. The next section outlines our model and data more fully. We also discuss literature that addresses additional components of our model. The third section presents the results, and the fourth section includes a policy analysis. The final section is our conclusion.

2. Model and data

This paper models the carbon intensity of a state's economy as a function of a range of variables, including the role of energy intensive industries (Schipper et al. 2001; Murtishaw et al. 2001;Bhattacharyya and Ussanarassamee 2004), variations in climate (Davis et al. 2010; Burnett and Bergstrom 2010), and population density (Morikawa 2012; Lariviere and Lafrance 1999). In addition, the effect of specific elements of state RPS policies (Carley 2011; Dobesova et al. 2005; Chen et al. 2009), such as the average load covered and the ability to use offsets or renewable energy credits, on carbon intensity during the period 1997-2010 are included.

According to the U.S. Environmental Protection Agency (EPA) greenhouse gas (GHG) inventory, direct and indirect (through electricity consumption) GHG emissions from industry accounted for 30% of total U.S. emissions and transportation accounted for 27%. Among U.S. industries, one study suggests that the most carbon intensive industry is manufacturing followed by mining and construction (Schipper et al. 2001). Within the manufacturing sector refineries are the most carbon intense (Murtishaw et al. 2001). Although agriculture is a significant contributor to GHGs, 7% of total U.S. emissions, state emissions calculations do not include emissions from agriculture (EPA 2010), and we do not include agricultural emissions in our study. Although there is limited literature discussing the energy intensities of industries such as information, finance, health care, and education, it is generally believed that these industries are lucrative and have comparatively less carbon emissions than the manufacturing sector (Ang 1999; Davidsdotter and Fisher 2011).

Variations in climate may also have a significant impact on energy and carbon intensity (Davidsdotter and Fisher 2011). Warmer winters and cooler summers result in lower energy-use for climate control in buildings. Nationally, heating degree-days – a measure of indoor heating demand – is positively correlated with natural gas consumption. Both cooling and heating degree-days (HDD) are positively correlated with electricity demand, with cooling degree-days (CDD) having a larger effect (Davis et al. 2002; Burnett and Bergstrom 2010). According to Davidsdotter and Fisher (2011), increased HDDs and CDDs have a significant effect on economic carbon efficiency, suggesting intuitively that more energy is utilized to achieve the same level of production in less moderate temperature conditions.

A seminal study by Newman and Kenworthy (1989) determined that urban density was negatively correlated with gasoline consumption based on an analysis of 32 large cities across the globe. Residential energy use also declines when homes are more compact and closer in proximity – a characteristic of urban areas (Ewing and Rong 2008). This pattern extends to the commercial sector as well. Morikawa et al. (2012) found that the energy efficiency of service establishments is higher in more densely populated cities, which is largely explained by more efficient use of floor space. Furthermore, metropolitan areas and counties bordering metropolitan areas tend to be more productive than rural areas (Rupasingha et al 2001). Although there is limited information specifically on the correlation between population density and carbon intensity, the trends outlined above suggest that more densely populated states are less carbon intensive than states with a low population density.

In addition to differences in energy use, a state's carbon intensity will be influenced by energy source. According to Greening et al. (1998), carbon intensities in the manufacturing sectors of Nordic countries decreased significantly during the 1971-1991 period. A rise in oil prices in the 1970s led to a shift in the fuel mix from oil to electricity produced from hydropower and nuclear energy. Similarly, differences in the initial energy portfolios among states as well as changes in energy portfolios during the study period are expected to have an impact on carbon intensity.

A few U.S. states began to adopt RPS in 1994 (DSIRE 2013a). These regulations created mandatory annual goals for the contribution of renewable energy to a state's energy portfolio (DSIRE 2013a). Cost-benefit evaluations of state RPS find that, if implemented according to law, RPS should reduce carbon emissions from energy production to a greater extent than transition to natural gas (Chen et al. 2009). Alternatives to non-carbon-based fuels, however, are more expensive than natural gas and coal, so the economic impact of the transition to renewable energies is uncertain. The transition could increase electricity prices and cause leakage of energy intensive industries to less regulated states (Fischer 2010 and Wei et al. 2009).

Several studies have documented the effects of changes in electricity price on state renewable energy share. Three studies reported that higher electricity prices lead to a decreased contribution of renewable energy to state energy portfolios (Carley 2009; Delmas et al. 2011; Yin and Powers 2011). The model by Shrimali and Kneifel (2011), however, estimated that higher electricity prices have a positive and significant effect on renewable energy deployment. A negative correlation has been explained as a response by policymakers to cap the increase on electricity prices, while a positive correlation can be explained as an increase in cost-competitiveness of renewables. Davidsdotter and Fisher (2011) suggest that higher electricity prices lead to an overall reduction in carbon intensity. The relationship between electricity prices and renewable portfolio standards has not been fully resolved, and existing literature on the subject has also not yet examined the subsequent impact on carbon intensity.

Data on carbon emissions were retrieved from the EPA Greenhouse Gas Inventory, which reports emissions by state from the commercial, industrial, and residential, transportation, and electric power sectors. State-level agricultural and land-use emissions data are not available. Data on state temperature were collected from the National Oceanic and Atmospheric Administration (NOAA). NOAA's dataset provides monthly means for each state between 1895 and present day. The model contains the average January and July temperatures each year. The model also includes regional dummy variables to address any spatial or regional fixed effects.

Population density was calculated using each state's total population and land area retrieved from the U.S. Census Bureau (U.S. Census). Data on each state's gross state product (GSP) and industrial composition were collected from the Bureau of Economic Analysis (BEA). Residential electricity prices were retrieved from the State Energy Data System of the Energy Information

Administration. The prices are lagged by one year. Information regarding state renewable portfolio standards was accessed through the Database of State Incentives for Renewables and Efficiency (DSIRE), a collaborative project of the U.S. Department of Energy, the Interstate Renewable Energy Council, and the North Carolina Solar Center. Only RPS that were adopted during or before the 1997-2010 time period are being taken into account.

Table 1 summarizes the variables. In order to assess regional fixed effects, the states have been divided into regions. The western region – Washington, Oregon, and California – is the base region for the analysis. The wholesale trade, real estate, companies and enterprise management, administrative and waste management, educational services, arts and recreation, accommodation and food services, other, and government industries have been excluded from the model. Table 2 presents descriptive statistics for the variables. As of 2010, 31 of 50 states and the District of Columbia had an RPS. The model excludes data from Hawaii and Alaska.

The dataset represents a balanced panel with observations over 48 states for a 14 year period. Two panel data models are estimated. Model 1 includes only the direct effect variables that indicate whether a state has passed an RPS (passedRPS) and the stringency of the RPS (perc_renewables, avloadcov, and REC). Model 2 adds the indirect effect variables to the model – the residential electricity price (respricelag) and the price term interacted with passedRPS.

3. Results

The results in Table 3 indicate that population density, industry, region, temperature, and time all affect carbon intensity. States with higher population density have lower carbon intensities. The parameter estimate suggests that a 1% increase in population density leads to a 6-7% reduction in carbon intensity. The share of GDP from mining, transportation, and healthcare are positively correlated with carbon intensity, while the share of GDP from information and finance are negatively correlated with carbon intensity. The South, Midwest, and Mountain regions are more carbon intensive than Western states even after accounting for population density, industry share, and temperature. The Northeast and Southwest do not differ significantly from Western states after accounting for electricity price. The temperature variables, Jan and Jul, are significant in both models, with higher January temperatures decreasing carbon intensity and higher July temperatures increasing carbon intensity.

The remaining variables focus on state energy policies. The results for the variable “PassedRPS” suggests that states that have passed RPS are less carbon intensive than states that have never passed RPS. Our results indicate that states that have passed RPS are around 30% less carbon intensive than states that have never adopted a standard. The results on perc_renewables or the nominal energy goals are negative in both models. In Model 1, perc_renewables incorporates the full effects of the RPS given that electricity prices are ignored. Based on model 1, a 1.0% increase in perc_renewables leads to a 0.6% decrease in carbon intensity. The parameter estimate on perc_renewables is also negative in Model 2 when electricity prices are added, although it becomes non-significant. The parameter estimate on lagged residential electricity price is negative and highly significant in Model 2, suggesting that higher energy prices reduce carbon intensity. The interaction term between lagged energy prices and passage of the RPS is positive, indicating that the effect of higher energy prices on carbon intensity is smaller (or closer to 0) in states that have passed RPS. This is interesting, because it suggests that higher energy prices will make an economy less carbon intensive, but the effect of prices is smaller in states that have passed RPS. An increase in the average load covered by the RPS has a highly significant and positive relationship with carbon intensity. States that attempt to cover a larger share of emissions, not surprisingly, will have a larger impact on carbon intensity. The parameter on RECs allowed from other states is not significant. This is surprising as we would have expected the allowance of renewable energy credits to reduce the effectiveness of the RPS policies, but it turns out that they do not have a significant impact in any event.

4. Discussion

4.1 Structural and environmental factors

Schipper et al. (2001) suggests that the construction industry is the second most carbon intense industry after manufacturing and mining. Our results, however suggest that an increase in the construction sector will not significantly change carbon intensity, in either model 1 or 2. An increase in the proportion of mining does increase carbon intensity, as expected, and manufacturing has a positive and significant impact on carbon intensity in model 1 (although not in model 2). The result for the manufacturing sector potentially reflects a shift in carbon intensive industries to other countries, as well as diversification. Indeed an assessment of U.S. industrial energy and carbon intensities between 1973 and 1994 reported that carbon intensities in the mining sectors increased during the 1990s, whereas carbon intensity from U.S. manufacturing declined substantially (Murtishaw et al. 2001). This trend, of course, reflects the movement of many of the most carbon intensive manufacturing industries to other countries (Davis and Caldeira 2010). In contrast, mining cannot be exported (Davis and Caldeira 2010). The relationship between the healthcare industry and carbon intensity is also surprising, but likely relates to the relative carbon intensities between healthcare and the sectors it displaces.

We find that, holding all other correlates constant, more densely populated states are less carbon intensive, corroborating the previous literature (Newman and Kenworthy 1989; Morikawa et al. 2012; Davidsdotter and Fisher 2011). The effects of changes in temperature follow past literature as well, with higher summer temperatures increasing carbon intensity and higher winter temperatures reducing carbon intensity (Davis et al. 2002 and Burnett and Bergstrom 2010). The January temperature has a small effect, with a 1 degree F change in temperature reducing carbon intensity by less than 0.1%. The July temperature has a larger effect, with a 1 degree F change in temperature increasing carbon intensity by 2%. This makes sense given the relatively higher carbon intensity of cooling versus heating.

4.2 RPS effect

Implementation of RPS has complicated effects on carbon intensity. Our model calculates that states that passed RPS have lower carbon intensities overall, regardless of when the standard was implemented. This result is logical – more energy intensive states are not as likely to pass legislation that will likely increase energy prices – and it is supported by previous literature (Carley 2009; Delmas 2011). The nominal renewable goals have a statistically significant and negative effect on carbon intensity in Model 1, but the effect is no longer significant once residential electricity prices are added in Model 2. The change in the magnitude and significance of the perc_renewables parameter estimate suggests that the nominal renewable energy goals are related to higher electricity prices, which is an expected result. Furthermore, the Model 2 result, makes sense in the current policy context because most states that have developed RPS probably designed them to have a small effect initially, and most of these RPS have not been in existence for a long period of time. The Model 2 result is also in agreement with the literature on renewable energy goals, which suggests that the nominal RPS goals are not positively correlated with overall state renewable energy development (Shrimali et al. 2012; Shrimali and Kneifel 2011; Yin and Powers 2010).

Models 1 and 2 also suggest that the nominal renewable energy goals have an important indirect effect on carbon intensity through electricity prices. A $0.01 per KWH increase in electricity prices reducing carbon intensity by almost 1%. Renewable energy is also more expensive to produce than coal or natural gas-derived electricity, such that mandating an increase in renewable energy use is likely to lead to an increase in the price of electricity (Burtraw 2005). Similar to the study by Shrimali and Kniefel (2011), which show that electricity price increases lead to greater renewable energy deployment, our results indicate that an increase in electricity price leads as well to a decrease in carbon intensity. Davidstottir and Fisher (2011) also identified a negative relationship between energy price and carbon intensity. The primary effect of the RPS appears to be through the change in electricity prices.

This result is not implausible, given the potential price changes discussed in the literature. Although a review of cost-benefit analyses on RPS found that residential electric bills would increase only $0.46 per month on average in the peak RPS target year (Wiser et al. 2007), Palmer and Burtraw (2005) estimated that a national RPS implementation with a goal of producing 15% of energy from renewable resources would lead to a 2.1% increase in electricity prices.

Models 1 and 2 indicate that the use of renewable energy credits (RECs) do not have an effect on carbon intensity. This corroborates the findings in Shrimali et al. (2011) who determined that RECs do not affect the share of renewables. Carley (2011) explains that RECs have the potential to improve the cost effectiveness of RPS by utilizing less expensive sources of renewables, However, because the additional renewable energy production does not necessarily occur in state, there need not be carbon emissions reductions associated with the additional renewable energy generation.

4.3 RPS and US carbon emissions

Model 2 can be used to estimate the effect of state level RPS on national carbon emissions over the past decade. Our predicted carbon intensity by state is the baseline with policy scenario. Our without policy scenario (the counterfactual) is developed by assuming no implementation of RPS standards. Since our model above illustrates the important effect of price changes that result from RPS standards, we also need to remove the effect of electricity price changes caused by the RPS standards from our estimates. To account for the effect of RPS standards on electricity prices, we first have to develop a prediction of the effect of the RPS on electricity prices. We model this by regressing state level electricity prices on perc_renewables, the industrial terms, and a time trend. The regression results for this model are shown in the Appendix.

With this model of the effect of RPS on electricity prices, we adjust our electricity prices for the counterfactual scenario. Thus, the without policy counterfactual is constructed by setting the RPS variables to 0 and changing electricity prices by the amount predicted by the model in the Appendix. The differences in total U.S. carbon dioxide emissions between the scenario in which RPS and their respective price effects are in place and the counterfactual are shown in Table 4. This estimate is a national aggregate estimate of the effects. State level estimates are available upon request.

The projected emissions change in the counterfactual case is positive in every year with the percent difference in carbon dioxide emissions growing over time beginning in year 2000. Once RPS begin to take effect around the country, there is a modest 0.1% decrease in carbon dioxide emissions compared to the counterfactual when RPS are not implemented. As a greater number of RPS are implemented and as their stringency increases, the difference between the two cases also increase, leading to almost a 4% change in 2010. Given that by 2010 the RPS have only been in effect for a few years in many states, this is a fairly significant impact. The gap between the two cases is likely to continue to widen as RPS are fully implemented across the nation.

5. Conclusion

This paper examines the implications of widespread adoption of RPS among states on carbon intensity in the US economy. We estimate a model of carbon intensity from 1997 to 2010, a period over which a large number of the state level RPS mandates were passed and implemented by state legislatures. Many other studies have examined the influence of state RPS implementation on various attributes, including renewable energy adoption and carbon emissions, but no studies have yet looked at the implications for carbon intensity. We argue that the way most state RPS are designed, their implementation should reduce carbon intensity nationwide. Over the long run, for continued economic growth, the only way to reduce overall carbon emissions is to also reduce carbon intensity. Thus, it is critical to examine the relationship between RPS implementation and carbon intensity.

We estimate two panel data models. Model 1 includes a number of covariates related to state-specific factors, and the percentage of renewables required in the RPS in each year. Given that one of the main effects of RPS will be to increase electricity prices, and this could further reduce carbon intensity, Model 2 adds lagged electricity prices and several additional variables related to policy implementation.

As suggested by Greening et al al. (1998), we find that structural differences among state economies have a substantial impact on carbon intensity. States with greater proportions of the economy dependent on mining and healthcare are more carbon intensive than states with a large information industry. State attributes, such as high summer temperatures and population densities also inherently raise and lower carbon intensities, respectively. Also incorporated into our models are regional dummies and a time trend. After taking all of these state economic and geographic characteristics into account, our models found consistently lower carbon intensity among states that have adopted an RPS.

Our approach accounts for whether states have adopted an RPS at all and then the timing and stringency of their regulations. We find that adoption of RPS appears to have been done mainly by states that already were at the lower end of carbon intensity spectrum within the US. The size and stringency of the RPS has an important impact beyond this, however. In model 1, the impact occurs directly, and we find that each 1% increase in percentage of renewable energy required will reduce carbon intensity by 0.6%. Model 2 then incorporates the role of prices. When electricity prices are included in the model, they are highly significant but the direct role of the RPS is diminished. Based on the literature, higher prices are an expected result of RPS, but these results suggest that the main mechanism by which RPS have an impact on carbon intensity is through their effect on prices. .

We estimate that the overall effect of state-level RPS policies has been to reduce U.S. carbon emissions by up to 4% by 2010. This is sizable impact, given that not all states have adopted RPS and those that have are in their initial years of implementation. One reason why earlier studies have not found a link between RPS and overall carbon emissions is that they have ignored the role of energy prices. We find that the most important impact of the RPS actually occurs by raising energy prices. Higher energy prices will clearly have welfare consequences, but we have not measured those as part of this study.

Thus far, econometric literature has suggested that RPS have been ineffective at increasing the proportion of energy produced from renewable sources and in reducing carbon emissions. Caveats have been offered to that conclusion, because many of the RPS have very modest renewable goals in their early years and are expected to increase the share of renewables in the years to come. We assert, however, that RPS have already substantially reduced state carbon intensities in those states that have adopted RPS. Furthermore, the patchwork of RPS around the nation has served as a fairly effective substitute in the absence of federal climate policy, decreasing carbon emissions by approximately 4% nationwide so far.

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Table 1. Description of variables

Variable	Description
lCint	Log(state carbon emissions/$millions GSP) – dependent variable
lnpop	Log(State population/state land area (sq. mi.))
perc_renewables	Annual renewable energy goals
passedRPS	0/1 dummy; =1 if state has implemented an RPS by 2010
percmining	Percent contribution to GSP by mining
perccons	Percent contribution to GSP by construction
percman	Percent contribution to GSP by manufacturing
perctw	Percent contribution to GSP by transportation and warehousing
percinf	Percent contribution to GSP by information
percfi	Percent contribution to GSP by finance and insurance
percst	Percent contribution to GSP by science and technology
perchealt	Percent contribution to GSP by health
northeast	0/1 dummy; =1 if CT, DC, DE, MD, ME, MA, NH, NJ, NY, RI, VT
midwest	0/1 dummy; =1 if IA, IL, IN, IA, KS, KY, MI, MN, ND, NE, OH, PA, SD, WI
south	0/1 dummy; =1 if AL, AR, FL, GA, LA, MO, MS, NC, SC, TN, VA, WV
southwest	0/1 dummy; =1 if AZ, NM, OK, TX
mountain	0/1 dummy; =1 if CO, ID, MT, NV, UT, WY
Jan	Average state temperature in January each year
Jul	Average state temperature in July each year
respricelag	The average annual residential electricity price
passxpricelag	Interaction term between passedRPS and respricelag
year	Time trend variable indicating (1997-2010)
avloadcov	The percent of total electricity production covered by RPS
REC	0/1 dummy; =1 if state allows REC purchase

Table 2. Summary of variables

Variable	Mean	Std Dev	Minimum	Maximum
lCint	-0.564	0.608	-1.871	1.462
popdens	189.189	253.698	4.939	1186.41
passedRPS	0.562	0.496	0.000	1.000
perc_renewables	0.014	0.050	0.000	0.330
percmining	0.019	0.042	0.000	0.347
perccons	0.047	0.011	0.025	0.108
percman	0.134	0.054	0.035	0.300
perctw	0.032	0.011	0.011	0.079
percinf	0.037	0.016	0.012	0.127
percfi	0.078	0.050	0.020	0.387
percst	0.058	0.020	0.022	0.135
perchealt	0.070	0.015	0.034	0.118
Northeast	0.229	0.421	0.000	1.000
South	0.229	0.421	0.000	1.000
Midwest	0.229	0.421	0.000	1.000
Southwest	0.083	0.277	0.000	1.000
Mountain	0.125	0.331	0.000	1.000
Jan	31.329	11.475	1.600	61.300
Jul	74.174	5.243	63.000	86.500
y98-y10	0.071	0.258	0.000	1.000
respricelag	9.045	2.614	4.950	20.330
avloadcov	45.730	41.466	0.000	100.000
REC	0.354	0.479	0.000	1.000

Table 3. OLS estimates of carbon intensity models

	Model 1		Model 2	
Variable	Parameter	Standard Error	Parameter	Standard Error
Intercept	120.198***	6.966	94.476***	7.294
lnpop	-0.064***	0.020	-0.064***	0.020
PassedRPS	-0.291***	0.060	-0.620***	0.114
Perc_renewables	-0.569**	0.245	-0.073	0.282
Percmining	7.393***	0.449	7.191***	0.428
Perccons	0.094	1.900	-1.633	1.900
Percman	0.910**	0.405	0.581	0.391
Perctw	5.593***	1.506	2.384	1.482
Percinf	-2.653***	1.021	-2.588***	0.984
Percfi	-0.934**	0.407	-0.908**	0.387
Percst	-0.929	1.157	-1.610	1.106
Perchealt	13.245***	1.520	11.768***	1.461
Northeast	-0.269***	0.063	-0.066	0.066
South	0.193***	0.050	0.217***	0.048
Midwest	0.158***	0.055	0.187***	0.053
Southwest	0.029	0.064	0.058	0.062
Mountain	0.110	0.067	0.119*	0.066
Jan	-0.005**	0.002	-0.004*	0.002
Jul	0.018***	0.004	0.020***	0.004
Year	-0.061***	0.004	-0.048***	0.004
Avloadcov	0.003***	0.001	0.003***	0.001
REC	0.028	0.035	0.018	0.034
Respricelag			-0.089***	0.011
Passxpricelag			0.042***	0.012

*** indicates 1% significance
** indicates 5% significance
* indicates 10% significance

Table 4. Predicted U.S. carbon dioxide (CO_2) emissions under baseline case (RPS policies adopted) and a counterfactual that assumes no policies were adopted

	Emissions with existing RPS (million metric tons CO2)	Counterfactual case (million metric tons CO2)	Difference (%)
1997	5823.97	5823.97	0.00
1998	5642.4	5642.4	0.00
1999	5635.87	5635.87	0.00
2000	5492.07	5497.53	0.10
2001	5558.11	5563.81	0.10
2002	5477.21	5482.9	0.10
2003	5594.64	5639.36	0.79
2004	5520.34	5624.55	1.85
2005	5814.22	5933.61	2.01
2006	5904.44	6043.63	2.30
2007	5712.92	5866.47	2.62
2008	6029.95	6198.79	2.72
2009	5189.13	5369.16	3.35
2010	5480.62	5704.12	3.92

Appendix. Model results for predicting residential electricity prices as a function of state dummies, RPS variables, and a time trend

	Estimate	Approx Std Err	t-value	Pr > |t|
Intercept	-210.51	36.6739	-5.74	<.0001
percmining	4.56	2.3779	1.92	0.0559
percons	-32.61	9.6085	-3.39	0.0007
percman	-1.85	2.0623	-0.9	0.3697
perctw	-70.56	7.7706	-9.08	<.0001
percinf	-7.45	5.7036	-1.31	0.1918
percfi	6.39	2.063	3.1	0.002
percst	33.03	4.736	6.97	<.0001
perchealt	24.72	7.1138	3.47	0.0005
year	0.11	0.0184	5.95	<.0001
perc_renewables	17.70	1.3987	12.66	<.0001
Adj R-Sq	0.631			