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U.S. Energy Subsidies: Do They Reduce Electricity Generated CO_2 Emissions?

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I. Introduction

Federal subsidies for the extraction and production of energy resources are prevalent in the United States. Yet they remain controversial because many of the subsidies are directed at non-renewable sources. Fossil fuel subsidies are more difficult to justify using economic theory. The argument that subsidies help to internalize air pollution externalities applies only to renewable energy. The infant industry argument that led to the initiation of subsidies in the oil and natural gas industries more than a century ago is a distant memory and the national energy security argument is not well grounded in economic theory. Due to the dominance of world energy prices particularly in the oil industry, the United States is not in a position to insulate itself completely from the influence of world events on energy prices.

The subsidies remain, however, and since the 1970s the breadth of energy subsidization has expanded to include renewable energy sources. The problem of emissions externalities is an oft-cited reason for these additional subsidies. One potential solution, though politically infeasible, would be to end non-renewable energy subsidies. However, this simplified solution ignores the substantial role that energy plays in our economy and relies on competitive market assumptions to justify a lack of government intervention in energy markets. A more realistic policy prescription would be grounded in a thorough understanding of the current role of fossil fuel and renewable energy subsidies in influencing the amount of emissions generated. My analysis focuses specifically on the electricity market and examines the influence of subsidies for non-renewable and renewable energy sources on CO_2 emissions generated from the production of electricity in the United States.

The existing literature on energy production includes several descriptive works that explain the history and level of energy tax incentives and direct government expenditures for energy subsidies. (Lazzari 2008; Hymel 2006; Metcalf 2007) Specifically, Hymel (2006) and Lazzari (2008) provide detailed descriptions of the shifting energy subsidy landscape, highlighting the movement towards renewable energy subsidies in the 1970s. This shift coincided with a subsequent reduction in some of the historic support for non-renewable energy in the 1980s; however, these fuels remain heavily subsidized today. In addition, with some notable exceptions, such as the recent elimination of ethanol subsidies, renewable energy also continues to be subsidized.

There is a large body of literature examining the relative role of various policy instruments, including subsidies, in promoting renewable energy development (Palmer and Burtraw 2005; Kalkhul, Edenhofer, and Lessman 2013; Fischer and Newell 2008). This optimal policy literature focuses on determining the role of renewable energy subsidies under various theoretical policy scenarios, including the imposition of a carbon tax. Specifically, Kalkuhl, Edenhofer, and Lessman (2013) find that due to its distortionary effect on energy prices, subsidies are a costly solution relative to a direct tax on carbon over the long term. However, carbon taxes have thus far proven to be politically infeasible in the United States, while renewable energy subsidies continue to be implemented. Notably, the Federal Production Tax Credit, which reduces the cost of wind projects by approximately one-third, was extended at the end of 2012. This paper examines whether the subsidy policies in the United States have been effective at reducing emissions over the last twenty years, but does not consider whether they were in fact the optimal solution for emissions reductions.

To analyze the effects of government support for energy development, the analysis also examines the role of U.S. funded research and development (R&D) on energy. There is a large literature that examines the role of the federal government in promoting R&D generally and whether federal R&D serves to complement or discourage private R&D (Bye and Jacobsen 2011; David, Hall, and Toole 2000; Almus and Czarnitzki 2003). For my analysis, I examine the role of U.S. government R&D while controlling for overall industry spending on R&D, but I do not address the complementarity issues between R&D sources directly. Instead, my goal is to determine whether energy R&D has led to CO_2 emissions reductions in the electricity market.

In addition to the previous literature, several papers have focused on examining optimal ethanol or bio-fuel subsidies or the emissions impacts of bio-fuel implementation (Hutchinson, Kennedy, and Martinez 2010; Lin and Jiang 2011; Vedenov and Wetzstein 2008; Marland and Turhollow 1991; Schneider and McCarl 2003). Hutchinson, Kennedy, and Martinez (2010) provide a theoretical framework for analyzing the impact of subsidizing a low-carbon (renewable) energy source. Using a two-energy (high-carbon/low-carbon) model, with subsidization of a low-carbon fuel, they calculate a theoretical threshold above which subsidization of a low-carbon fuel with positive levels of emissions will lead to increased overall emissions.[1] This is due to the dual effect of the subsidy, which pushes production to low-carbon energy, but also lowers the equilibrium price of energy in the market. Since consumers are indifferent between energy types, this overall lowering of the price leads to increased energy consumption. The determining factor for the emissions impacts is the share of the market that is comprised of high-carbon (non-renewable) energy. If the share of high-carbon energy under the subsidy regime is higher than under the non-subsidy regime, aggregate emissions rise monotonically with the subsidy. If the share is lower than the non-subsidy regime, then emissions will initially fall, but will subsequently rise.

[1] This would be equivalent to subsidizing wind, for example. Wind generated electricity is zero emission at the time of generation, but does not have zero lifetime emissions due to emissions generated during the construction and maintenance of the wind farm.

This model has important implications for subsidy policy in the United States, where both non-renewable and renewable resources are subsidized and non-renewable resources comprise a large part of the fuel used in electricity generation. If renewable energy subsidization leads to a reduction in the share of non-renewable fuels, the model predicts an initial drop in emissions. If the share of non-renewable energy is not reduced, the model indicates that renewable energy subsidies alone may increase emissions. Further, given that emissions levels are positive for all non-renewable energy sources, subsidization of these sources is clearly expected to lead to increased emissions. The model provides a theoretical framework that demonstrates that both renewable and non-renewable energy subsidies may lead to increased emissions. The authors calibrate the model using an ethanol subsidy in the United States and find that ethanol subsidies are likely to lead to additional CO_2 emissions. Rather than focusing on ethanol subsidies, this paper delves into the debate over energy subsidies with a particular focus on an empirical analysis of the effects of renewable and non-renewable subsidies on the emissions outcomes for CO_2 in the electricity market.[2] I expect non-renewable energy subsidies to increase emissions, but the effect of renewable energy subsidies is unclear.

II. Background

The electricity market is heavily influenced by energy subsidies in the United States. Electricity generation is dominated by coal burning power plants, but also to a smaller extent by the use of natural gas, hydroelectric power, and the use of renewables such as wind and solar. In 2011, according to the Energy Information Association (EIA), coal was used for 42% of electricity generation, natural gas 25%, nuclear 19%, and renewables 13%. The majority of renewable-generated electricity was from hydroelectric power 63%, while wind was a distant

[2] The renewable energy sources that I used to construct a measure of renewable electricity generation include wind, solar, geothermal, and biomass. The fossil fuel sources include petroleum, natural gas, and coal.

second at 23% and solar contributed less than 1%. (Electric Power Monthly March 2012) The particular fuel mix varies by the resources available in each state. For example, hydroelectric power is concentrated in the Northwest, while West Virginia and Wyoming predominantly use coal-generated electricity. The electricity sector contributes approximately 40 percent of total CO_2 emissions in the United States.

This paper focuses on an analysis three types of energy subsidies; direct spending, tax expenditures, and federal research and development (R&D).[3] Energy subsidies in the United States trace back to 1916 with the introduction of tax deductions directed at oil and gas producers. These tax expenditures were directed at increasing oil and gas development.   By the 1970s, energy policy began to shift away from increasing oil and gas development to conserving energy resources and encouraging the development of renewable energy. In particular, the Energy Tax Act of 1978 led to a reduction in tax incentives for oil and gas development, and the implementation of taxes directed at promoting conservation such as the federal "gas guzzler" tax directed at cars with low gas mileage. In addition, several new subsidies directed at improving energy efficiency and promoting alternative fuels were introduced. Since the 1970s, U.S. energy policy has focused on subsidizing both renewable and nonrenewable energy sources. The 1980s were marked by a push towards unregulated energy markets, which led to the repeal of some but not all of the subsidies for both renewable and fossil fuels. The 1990s marked a return to a tax policy that is focused on energy conservation and the development of renewable energy sources(Lazzari 2008, pp. 2-8). The American Recovery and Reinvestment Act (ARRA), which significantly increased energy subsidies in 2009, marked the late 2000s.

[3] R&D is a specific type of direct government expenditure, but due to its potentially significant role, I analyze it separately.

III. **Data**

The empirical analysis focuses on the effects of subsidies on CO_2 emissions generated from electricity production. Specifically, the dependent variables are the state-year percentage of CO_2 emissions from fossil fuels and the percentage of CO_2 emissions from coal for the years 1990 through 2010.[4] The dependent variable is measured in two ways in order to allow for a focus on coal, the dominant fuel used in electricity generation, while examining the potentially disparate influence of subsidies on fossil fuels generally.

To examine the role of direct government spending, I analyze an annual measure of the U.S. Department of Energy (DOE) Annual Budget Outlays on Energy Programs (DOE Outlays).[5] The budget data is constructed from information provided by the U.S. Office of Management and Budget annually by agency and function.[6] Figure 1 contains a depiction of the overall DOE Outlays and DOE Outlays on Energy Programs from 1990 through 2010.[7] The figure shows some negative correlation between DOE Outlays and CO_2 emissions particularly in the late 2000s. Given the turbulent economic conditions over that period, in this paper I examine whether subsidies were causing the emissions reductions. In order to analyze the influence of R&D, I use annual information on Energy R&D provided by the National Science Foundation (NSF 2010). [8] To control for overall changes in R&D and to address the influence of the private sector on energy development, I also control for total annual Industry R&D spending (NSF 2013). In addition to direct spending on energy, I also analyze the role of tax expenditures for

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[4] All electricity data including emissions and net generation data were collected from the EIA.
[5] The subsidy measures are constructed for the fiscal year, while the emissions measures are constructed for the following calendar year. This leads to a slight lag built into the analysis, which benefits the identification.
[6] The budget outlays are summed across discretionary, mandatory and net interest budget categories.
[7] All subsidy measures are in real (2005) dollars.
[8] The energy R&D measure is a measure of all budget authority. For 2009, budget authority appropriated through the American Recovery and Reinvestment Act is excluded. For 2009 and 2010, the data reported is preliminary data.

energy. I constructed two annual tax expenditures measures, tax expenditures on fossil fuels and renewable energy.[9] (See Figure 2)

The additional controls used in the analysis include annual state total net generation (MWH) of electricity. Clearly emissions are expected to rise as generation increases due to the dominate role of fossil fuels, particularly coal, in electricity generation. Controlling for generation controls for factors that influence the volume of production in the energy market, in particular changes in demand for electricity generally. Lastly, I include an annual measure of U.S. real GDP to control for the influence of the overall economic climate.

IV. **Empirical Analysis**

The empirical analysis focuses on a state-year panel from 1990 through 2010. The state fixed-effects (FE) regression specification is

$$Y_{it} = \propto + \beta_1 DOE_t + \beta_2\, Fed\ Energy\ R\&D_t + \ \beta_3 Tax\ Exp_t + \beta_4 Q_{e_{it}} + \beta_5 R\&D_{ind_t} + \beta_6 GDP_t + State\ indicators_i + \ \varepsilon_{it} \qquad (1)$$

Specifically, the dependent variables are the state-year percentage of CO_2 emissions from fossil fuels and the percentage of CO_2 emissions from coal for the years 1990 through 2010.[10,11] The independent variables of interest include the total annual DOE Outlays on Energy Programs, DOE, Federal R&D spending on Energy, $Fed\ Energy\ R\&D$, and Tax expenditures for energy, $Tax\ Exp$. The tax expenditures measures include fossil fuels tax expenditures or

[9] Tax expenditure data was collected from the Analytical Perspectives, published in the years 1992-2011 by the U.S. OMB. In order to focus on tax expenditures most likely to influence the electricity market, both categories of tax expenditure data exclude those directed towards transportation related energy programs. Fossil fuel tax expenditures include those directed towards oil, natural gas, coal (excluding funding specifically for clean coal), and if it required by the data, other non-renewable sources. Renewable energy tax expenditures include those directed at renewable energy programs, such as the Federal Production Tax Credit, but excludes tax expenditures directed at improving energy efficiency. The inclusion of energy efficiency programs in the renewable energy tax expenditures measure did not affect the results presented here.

[10] The sample excludes the District of Columbia.

[11] Using a percentage of emissions rather than the level of fossil fuel or coal emissions implicitly controls for changes in the overall amount of emissions. The construction of the dependent variable as a percentage was critical for proper identification of the effects from the potentially endogenous subsidy variables.

renewable tax expenditures[12]. In addition to these subsidy measures, market factors are controlled for using the total net generation of electricity, Q_e, by state and year. An important control given that increases in electricity generation are expected to lead to overall increases in emissions because the mix of fuels used is largely non-renewable. Two variables are included to control for changes in the economic climate, U.S. GDP, GDP, and total industry expenditures on R&D, $R\&D_{ind}$.

The analysis was initially completed using a state FE regression and subsequently completed using an instrumental variables (IV) specification to address potential endogeneity issues between the subsidy measures and the emissions measures. With data describing a panel of states, I can estimate this equation using state FE to remove all time invariant state effects.[13] However, for estimates of equation (1) to result in unbiased estimates, the error must be uncorrelated with the amount of energy subsidies. A potential for correlation with the error exists due to unmeasured economic or political factors that could have been driving both emissions and subsidy levels, such as unmeasured changes in environmental preferences among voters. To address this possibility, I estimate an IV specification with lagged U.S. government debt variables as instruments for the subsidy measures.[14] Government debt is expected to influence government subsidies directly, but to have only an indirect effect on emissions through the government subsidies.

To verify the validity of the instruments, I ran tests to determine if the instruments were properly excluded from the first stage, weak, underidentified, or overidentified. The test results indicate that the instruments are properly excluded from the first stage, yield statistically

[12] Total tax expenditures were also analyzed and the findings are consistent with those presented for fossil fuels.
[13] Because the variables of interest are annual rather than state-year measures, I also conducted a test for autocorrelation of the error term and found no first order autocorrelation.
[14] The specification includes four lagged measures of government debt, debt lagged from two to ten years. The specific lagged debt measures varied with the dependent variable and are documented in the table notes.

significant F-statistics in the first stage, and pass the identification tests. [15] Finally, the Hausman test results indicate that the IV results were not statistically significantly different from the OLS results.[16] The findings in Tables 2 and 3 provide results for the second stage of the IV specification and the corresponding state FE specification. The coefficients in the IV results are of similar magnitude to the FE specification and the statistical significance of the results is consistent.

Given the lack of endogeneity in the variables of interest, I completed further analysis of the variables using a state FE specification with the addition of interaction terms. (Tables 4a and 4b) Specifically, I analyze whether a state's wind potential affects the efficacy of the subsidy measures. [17] Because wind is the dominant renewable energy used in electricity generation, government subsidy programs may disparately affect states with large wind energy potential. It is feasible that having a significant amount of wind energy may enhance the effect of the subsidies, but it is also possible that wind resource rich states may have less need for government subsidies to promote CO_2 emissions reductions and the subsides may have less influence.

I also examined the potentially disparate influence of subsidies in coal dependent states versus states that have other fuels as their dominant source of electricity generation. Specifically, I analyzed the interaction of each subsidy measure with states based on their quartile of average coal consumption for electricity generation over the sample period. Coal-

[15] If the lagged budget measures are included in the regression specification, equation (1), they are not jointly statistically significant. According to the Anderson-Rubin Wald test and the Stock-Wright LM S statistic, I cannot reject the NULL hypothesis that the joint significance of the endogenous regressors in the main equation is zero and the orthogonality conditions are valid. In addition, the instruments do have a strong statistically significant relationship with the subsidy measures based on the Angrist-Pischke multivariate F tests of excluded instruments.

[16] The exception in regards to the Hausman test results was in the case of the three-year moving average for coal emissions. Table 5 includes second stage IV results for the three-year moving average analyses; no state FE regressions are included for the three-year moving average specifications.

[17] Wind potential calculations indicate the amount of wind that a state or region is theoretically capable of producing under a specific set of assumptions, excluding transmission limitations. The installed capacity calculations are based on an assumption of 5 MW/km^2 of installed capacity.

reliant states may be less responsive to federal subsidies that promote renewable fuels for electricity generation and therefore subsidies may have diminished influence.

V. Results

The analysis of the impact of energy subsidies on the percentage of fossil fuels CO_2 emissions indicate that increases in DOE Outlays on Energy Programs lead to decreases in emissions. Table 2 column 1 indicates that a one billion dollar increase in DOE Outlays results in a reduction in fossil fuels CO_2 emissions of 0.09 percent, a small effect. [18] For robustness, I analyzed the effect of the three-year moving average of DOE Outlays on fossil fuel emissions. The findings in column 1 of Table 5 indicate that there is not a statistically significant relationship over the three-year time horizon. While there is a significant contemporaneous influence of DOE Outlays on fossil fuel emissions, the longer moving average period unexpectedly reduces rather than increases the effect. This may be due to the

For coal emissions, the findings in Table 2, column 3 indicate that a one billion dollar increase in DOE Outlays leads to a reduction in CO_2 emissions of approximately 0.4 percent on average. The three-year moving average results presented in Table 5, column 2 supports these findings, the magnitude of the coefficient increases to approximately 0.9 percent.[19] In both cases, an increase in DOE Outlays leads to a reduction in CO_2 emissions from coal. Given that coal is the dominant fuel used in electricity generation, even a small reduction in the percentage of CO_2 emissions may have a relatively significant influence in the electricity market. In addition, given the contemporaneous nature of the influence and its robustness over the three-

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[18] I also analyzed a restricted data set, from 1990-2007, to examine the possibility that the results were being identified solely from the effects of ARRA. The results were consistent with those presented here in Table 3, columns 1 and 2 for DOE Outlays, the coefficients on the Tax Expenditures variables were not statistically significant.

[19] The findings in Table 3, columns 1 and 2, are not robust to the restricted 1990-2007 data set, indicating the ARRA may have been the dominate factor in the identification of the effects of the subsidy measures on coal CO_2 emissions.

year time horizon, it may be that DOE Outlays on Energy Programs are leading to economically significant reductions in emissions over longer time horizons. While DOE Outlays are not categorized according to fuel type due to data limitations, overall spending has been shifting towards additional renewable subsidies so the finding is not unexpected.

For tax expenditures, increases in both fossil fuel tax expenditures and renewable energy tax expenditures led to increases in fossil fuels CO_2 emissions, but did not have a statistically significant influence on coal emissions. The findings indicate that a $1 billion dollar increase in fossil fuel tax expenditures leads to an approximately 0.2 percent increase in emissions.[20] A one billion dollar increase equates to between a one and two standard deviation increase in fossil fuel tax expenditures. While the magnitude of the coefficient is once again small, given the contemporaneous nature it may be economically significant. However, the three-year moving average of both tax expenditures proved to be statistically insignificant. (See Table 5.) The findings also indicate that the effect of renewable tax expenditures is positive; a one billion dollar increase in renewable tax expenditures leads to a 0.6 percent increase in emissions. This result is not unexpected based on the theoretical predictions. If the share of non-renewables does not decline, then the price effects of the renewables subsidies are expected to lead to increased emissions. Although, given that, a one billion dollar increase would equate to approximately a four standard deviation increase in renewable tax expenditures and due to the small magnitude of the coefficient, this result is not economically significant. Overall, tax expenditures did not robustly have a statistically significant influence on contemporaneous CO_2 emissions.

Changes in the Federal Energy R&D budget authority did not have a statistically

[20] This finding was not robust to an alternative specification, covering the period through 2007.

significant influence on CO_2 emissions.[21] This finding was robust across specifications and dependent variables. Due to the contemporaneous nature of the analysis, the findings regarding R&D, which is expected to have measurable influence over a longer time horizon, are not surprising.

V.1 Wind Potential (Table 4A)

In order to examine the influence of energy subsidies further, I analyze the potentially disparate role of subsidies across states for two state level characteristics, wind potential, and coal consumption. For the wind potential analysis, I constructed five categories of states based on their 1991 wind potential; top 5 wind potential, from 5-10, from 11-20, bottom 20.[22] As compared with states in the bottom 20 in wind potential, the influence of DOE Outlays on CO_2 emissions is mitigated in wind energy rich states, particularly for those states that are in the top 10 in terms of wind potential.[23] The finding is robust across dependent variables. This may indicate that DOE Outlays on Energy programs have a stronger effect at reducing CO_2 emissions in states with more marginal wind resources. Because DOE Outlays are not categorized based on fuel type, it is not possible to argue that DOE expenditures on renewable energy are mitigated in these wind resource rich states. Interestingly, unlike DOE Outlays, fossil fuel tax expenditures do not have a statistically significantly different influence across states based on wind resource categories.[24]

[21] The coefficient on Energy R&D in the 3-year moving average specification was significant in the coal emissions specification, but it was significant only at the 10 percent level.
[22] Commercial scale wind potential varies dramatically by state; the bottom 20 states do not have sufficient wind resources to produce commercial scale wind and were therefore grouped together.
[23] The finding is consistent if wind is alternatively categorized into top 20 and bottom 20 wind potential states.
[24] The results for renewable tax expenditures are consistent with those presented in Tables 4a, 4b for fossil fuel tax expenditures.

V.2 Coal Consumption (Table 4B)

There are also differences in the effect of DOE Outlays on fossil fuel CO_2 emissions, but not for coal CO2 emissions. Particularly for those states in the top two quartiles of coal consumption, increases in the DOE Outlays lead to decreases in the effectiveness of the subsidy measures on reducing CO_2 emissions. This indicates that the influence of R&D varies significantly between states based on their dependence on coal as a fuel for electricity generation.[25] States that are more coal dependent are less likely to reduce emissions due to DOE spending than other states. This set of interactions is also interesting because the findings indicate that the CO_2 emissions reductions are being generated from a source other than from a reduction in coal consumption, which is controlled for in the regression. The coefficients on the DOE Outlays interactions indicates that DOE Outlays may lead to the adoption of coal emissions reducing technology or alternative types of coal relatively more often in states that are less coal reliant.

VI. Discussion

The findings in this paper indicate that a policy focused on increasing federal spending on energy programs at the DOE will lead to reductions in CO_2 emissions from fossil fuels generally and coal specifically, though the magnitude of the contemporaneous effect is small. The findings indicate that tax expenditures are not having a robustly significant effect across the annual and the three-year moving average analyses. The findings of this paper provide support for existing criticism of energy subsidies on the grounds that the costs exceed the benefits (Hymel 2006), but this paper focuses only on contemporaneous reductions in emissions. Given that technology

[25] I also analyzed a restricted data set, excluding states such as Vermont, Rhode Island, and Idaho, which do not have electricity generation from coal over this period. The findings were consistent with those presented in Table 4b.

improvements are expected to produce gains over a longer time horizon, this is an important limitation of this analysis and is left for future work. It is interesting to note that the effects of federal subsidies are having disparate effects on emissions across states. In particular, states with significant wind or coal endowments are not affected by the subsidies as strongly as other states. Future discussions of federal energy subsidies should take into account the potentially disparate effects across states and subsidy type. Lastly, in addition to this paper, future empirical work that quantifies the benefits of specific subsidies over longer time horizons will also benefit the development of effective energy subsidy policies.

Figures

Figure 1

Figure 2

Table 1: Summary Statistics

	Count	Mean	Median	Standard Deviation	Minimum	Maximum
Percentage of CO_2 Emissions from Fossil Fuels	1050	0.999	0.999	0.02	0.86	1.00
Percentage of CO_2 Emissions from Coal	1050	0.72	0.89	0.30	0.00	0.999
DOE Outlays (Energy Programs)[a]	1050	7.64	6.97	1.58	6.37	13.65
Fossil Fuel Tax Expenditures[a]	1050	1.49	1.30	0.76	0.43	3.7
Renewable Tax Expenditures[a]	1050	0.22	0.11	0.24	0.00	0.85
U.S. Government R&D for Energy[a]	1050	1.95	1.90	0.71	0.95	3.10
Total Net Electricity Generation (MWH)	1050	73302	51146.9	66093.3	1107.3	411695
Industry R&D[a]	1050	167.60	180.64	57.24	83.21	258.69
U.S. GDP[a]	1050	10655.5	11038.6	1808.16	7917.9	13159.28

Note: All of the summary statistics cover the period 1990-2010.
a: Billions of Real (2005) Dollars

Results

Table 2: Instrumental Variables (Stage 2)

Dependent Variable: **Percentage of CO_2 Emissions[a] from**	**Fossil Fuels[b]**		**Coal**	
DOE Outlays - Energy Programs (Billions $)	**-0.000869****	**-0.00140*****	**-0.00374***	**-0.00293**
	(-2.279)	(-2.613)	(-1.801)	(-0.855)
U.S. Federal Energy R&D[c] (Billions $)	-0.000841	-0.00120	0.00573	0.00524
	(-0.838)	(-1.213)	(0.993)	(0.956)
Fossil Fuels Tax Expenditures (Billions $)	**0.00249****		-0.00418	
	(2.338)		(-0.661)	
Renewable Tax Expenditures (Billions $)		**0.00617****		-0.00745
		(2.248)		(-0.455)
Total Net Generation (MWH)	3.41×10^{-08}	3.04×10^{-08}	-4.60×10^{-07}	-4.55×10^{-07}
	(0.672)	(0.598)	(-1.002)	(-0.992)
Industry R&D[d] (Billions $)	-5.68×10^{-05}	-6.94×10^{-05}	-0.000218	-0.000223
	(-1.365)	(-1.451)	(-1.037)	(-0.970)
Real U.S. GDP (Billions $)	6.01×10^{-07}	5.40×10^{-07}	2.68×10^{-06}	2.85×10^{-06}
	(0.419)	(0.369)	(0.304)	(0.322)
Observations	1050	1050	1050	1050
Number of States	50	50	50	50
R-squared	0.011	0.012	0.102	0.106

Note: robust t-statistics in parentheses, *** p<0.01, ** p<0.05, *p<0.1. Errors are clustered at the state level. First stage instruments include debt lagged three, five, six, and eight years for the Fossil Fuels columns and debt lagged three, five, seven, and nine years for the Coal columns.
a: Electricity generated CO_2 emissions.
b: Fossil fuels for electricity generation included coal, petroleum, and natural gas.
c: Federal research and development budget authority for energy.
d: U.S. research and development expenditures, by source of funds.
* All subsidy measures are in of Real (2005) Dollars.

Table 3: Fixed Effects

Dependent Variable: **Percentage of CO_2 Emissions[a] from**	**Fossil Fuels[b]**		**Coal**	
DOE Outlays - Energy Programs (Billions $)	**-0.000481****	**-0.000746****	**-0.00385****	**-0.00341*****
	(-2.030)	(-2.186)	(-2.492)	(-2.892)
U.S. Federal Energy R&D[c] (Billions $)	-0.000659	-0.000477	0.00326	0.00338
	(-0.733)	(-0.631)	(0.926)	(1.021)
Fossil Fuels Tax Expenditures (Billions $)	**0.000863****		0.00355	
	(2.223)		(0.801)	
Renewable Tax Expenditures (Billions $)		**0.00297****		0.0115
		(2.069)		(1.005)
Total Net Generation (MWH)	3.04×10^{-08}	3.02×10^{-08}	-4.47×10^{-07}	-4.51×10^{-07}
	(0.592)	(0.585)	(-0.952)	(-0.961)
Industry R&D[d] (Billions $)	-3.65×10^{-05}	-5.98×10^{-05}*	-0.000371**	-0.000376**
	(-1.311)	(-1.727)	(-2.094)	(-2.136)
Real U.S. GDP (Billions $)	3.65×10^{-07}	8.87×10^{-07}	5.01×10^{-06}	4.89×10^{-06}
	(0.334)	(0.793)	(0.763)	(0.746)
Constant	0.994***	0.994***	0.783***	0.785***
	(121.3)	(135.6)	(16.94)	(16.47)
Observations	1050	1050	1050	1050
Number of States	50	50	50	50
R-squared	0.017	0.018	0.107	0.107

Note: robust t-statistics in parentheses, *** p<0.01, ** p<0.05, *p<0.1. Errors are clustered at the state level.
a: Electricity generated CO_2 emissions.
b: Fossil fuels for electricity generation included coal, petroleum, and natural gas.
c: Federal research and development budget authority for energy.
d: U.S. research and development expenditures, by source of funds.

Table 4a: State Fixed Effects - Wind Potential Interactions

Dependent Variable:	Percentage of CO_2 Emissions[a] from Fossil Fuels[b]	Percentage of CO_2 Emissions[a] from Coal
DOE Outlays - Energy Programs (Billions $)	**-0.000510****	**-0.00667*****
	(-2.063)	(-2.690)
x Wind Potential Top 5	**0.000529****	**0.00486***
	(2.257)	(1.763)
x Wind Potential (6-10)	**0.000529****	**0.00616****
	(2.259)	(2.211)
x Wind Potential (11-20)	-0.000488	0.00445
	(-0.692)	(1.386)
U.S. Federal Energy R&D[c] (Billions $)	0.000317	0.00624
	(0.343)	(1.489)
x Wind Potential Top 5	-0.00134	-0.0134
	(-1.525)	(-1.498)
x Wind Potential (6-10)	-0.00112	**-0.0164***
	(-1.047)	(-1.959)
x Wind Potential (11-20)	-0.00357	0.000291
	(-1.180)	(0.0291)
Fossil Fuels Tax Expenditures[d] (Billions $)	**0.00108***	0.00256
	(1.973)	(0.337)
x Wind Potential Top 5	-0.000283	0.0197
	(-0.393)	(1.670)
x Wind Potential (6-10)	-0.000711	0.00424
	(-0.694)	(0.319)
x Wind Potential (11-20)	-0.000427	-6.03×10^{-05}
	(-0.206)	(-0.00449)
Observations	1008	1008
Number of States	48	48
R-squared	0.05	0.14

Note: robust t-statistics in parentheses, *** p<0.01, ** p<0.05, *p<0.1. Errors are clustered at the state level. Alaska and Hawaii are excluded due to a lack of 1991 wind potential estimates. The regressions above included additional control variables Total Net Generation, U.S. Real GDP, and Industry R&D.

a: Electricity generated CO_2 emissions.

b: Fossil fuels for electricity generation included coal, petroleum, and natural gas.

c: Federal research and development obligations, budget authority, and budget authority for basic research.

Table 4b: State Fixed Effects - Coal Consumption Interactions

Dependent Variable:	**Percentage of CO_2 Emissions[a] from Fossil Fuels[b]**	**Percentage of CO_2 Emissions[a] from Coal**
DOE Outlays - Energy Programs		
(Billions $)	**-0.00133***	-0.00187
	(-1.903)	(-0.394)
x Top Coal Quartile States	**0.00121***	0.000301
	(1.842)	(0.0601)
x Second Coal Quartile States	**0.00140****	0.00257
	(2.133)	(0.497)
x Third Coal Quartile States	0.000771	-0.00686
	(1.140)	(-1.213)
U.S. Federal Energy R&D[c] (Billions $)	-0.00194	0.00248
	(-0.626)	(0.197)
x Top Coal Quartile States	0.00182	0.00574
	(0.589)	(0.356)
x Second Coal Quartile States	0.00130	0.00586
	(0.406)	(0.381)
x Third Coal Quartile States	0.00205	-0.00262
	(0.631)	(-0.145)
Fossil Fuels Tax Expenditures		
(Billions $)	0.00178	0.00801
	(1.258)	(0.477)
x Top Coal Quartile States	-0.000930	0.00369
	(-0.537)	(0.194)
x Second Coal Quartile States	-0.00131	-0.0131
	(-0.686)	(-0.664)
x Third Coal Quartile States	-0.00111	0.00632
	(-0.537)	(0.285)
Coal Consumed[d]		
(Billion Btu)	6.88×10^{-09}	**4.81×10^{-07}*** **
	(1.273)	(3.500)
Observations	1050	1050
Number of States	50	50
R-squared	0.032	0.202

Note: robust t-statistics in parentheses, *** p<0.01, ** p<0.05, *p<0.1. Errors are clustered at the state level. The regressions above included additional control variables Total Net Generation, U.S. Real GDP, and Industry R&D.
a: Electricity generated CO_2 emissions.
b: Fossil fuels for electricity generation included coal, petroleum, and natural gas.
c: Federal research and development obligations, budget authority, and budget authority for basic research.
d: Coal consumed in the electric power sector.

Table 5: Three-Year Moving Average - Instrumental Variables (Stage 2)

Dependent Variable: **Percentage of CO_2 Emissions[a] from**	**Fossil Fuels[b]**		**Coal**	
DOE Outlays - Energy Programs (Billions $)	-0.000329	0.000137	**-0.00885****	-0.00482
	(-0.635)	(0.178)	(-2.234)	(-1.039)
U.S. Federal Energy R&D[c] (Billions $)	0.000212	-0.000127	**0.0185***	**0.0138***
	(0.164)	(-0.0956)	(1.925)	(1.809)
Fossil Fuels Tax Expenditures (Billions $)	-0.000694		-0.0124	
	(-1.174)		(-1.185)	
Renewable Tax Expenditures (Billions $)		-0.00253		-0.0301
		(-1.096)		(-1.396)
Total Net Generation (MWH)	1.50×10^{-08}	1.47×10^{-08}	-5.68×10^{-07}	-5.61×10^{-07}
	(0.349)	(0.344)	(-1.115)	(-1.107)
Industry R&D[d] (Billions $)	-4.61×10^{-05}	-2.80×10^{-05}	-0.000277	-8.31×10^{-05}
	(-1.308)	(-0.871)	(-1.282)	(-0.271)
Real U.S. GDP (Billions $)	1.41×10^{-06}	9.96×10^{-07}	8.85×10^{-06}	3.44×10^{-06}
	(0.913)	(0.689)	(1.052)	(0.414)
Observations	950	950	950	950
Number of States	50	50	50	50
R-squared	0.014	0.012	0.105	0.109

Note: robust t-statistics in parentheses, *** p<0.01, ** p<0.05, *p<0.1. Errors are clustered at the state level. First stage instruments include debt lagged five, seven, eight and ten years for column 1 and debt lagged five, six, seven, and nine years for column 2.

* All subsidy measures are in real (2005) dollars.

a: Electricity generated CO_2 emissions.

b: Fossil fuels for electricity generation included coal, petroleum, and natural gas.

c: Federal research and development budget authority for energy.

d: U.S. research and development expenditures, by source of funds.

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