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Abstract

In this paper, we study how local politics affect state level implementation of a critical federal environmental policy, the Clean Air Act, in the electricity generation sector. The analysis focuses on the installation of capital intensive air pollution abatement technology in highly regulated "nonattainment" areas, which violate federal air quality standards. The primary research design uses a regression discontinuity in the vote share for Republican governors and event study analyses of close elections. In nonattainment areas, Republican gubernatorial control differentially decreases new air pollution abatement capital spending by 90% and the probability of installing the most effective nitrogen oxide abatement technology by nine percentage points, relative to attainment areas and the counterfactual of Democratic gubernatorial control. The health benefits from reduced nitrogen oxide emissions in nonattainment areas likely exceed the additional costs of new air pollution abatement technology at electric utilities. However, the estimated benefit-cost ratios are smaller than those from many other air pollution abatement policies and net benefits may be negative for technology that will operate for fewer than five years.

Keywords
Abatement technology, Close elections, Clean Air Act, Electric utilities,

1. Introduction

Since its creation, the federal Clean Air Act (CAA) and its amendments have regulated air pollution in the US. Over the past 50 years, the CAA and its amendments have been largely successful and have provided sizable benefits to human health and the environment (Epa, 2009, Walker, 2013, Currie and Walker, 2019). However, previous literature finds heterogeneity in air emissions, ambient air quality, and CAA benefits throughout the US (Hsiang et al., 2019, Clay and Muller, 2021). The CAA delegates much of its implementation and enforcement authority to individual states and some CAA provisions leave room for regulatory discretion. It is therefore plausible that one source of heterogeneous environmental outcomes in the US is the partisan ideology of state level political leaders. Indeed, there is evidence that state level political leadership contributes to the variation across time and space in ambient air quality (Beland and Boucher 2015), environmental enforcement (Innes and Mitra 2015), water pollution abatement (Doyle et al. 2016), and climate change beliefs (Meyer 2019).[1]

The purpose of this paper is to examine the differential implementation of the CAA across political regimes, in a setting where there is room for regulator discretion. We investigate the installation of air pollution abatement technology as an underlying mechanism for the heterogeneity in ambient air quality across the US. Specifically, we estimate the effect of the political leadership of each state, via the political affiliation of its governor and its state legislative majority, on the expenditures and types of air pollution abatement technology at coal and natural gas fired electric utilities in the US.[2].[3]

Gubernatorial and state legislative partisan affiliation likely correlate with unobserved state level characteristics that also affect the adoption of air pollution abatement technology, e.g., citizen attitudes about environmental protection. Consequently, a naive regression of air pollution abatement technology adoption on political control suffers from omitted variable bias and likely does not estimate the causal effect of interest. For our gubernatorial analysis, we therefore use a regression discontinuity (RD) design where we condition on the margin of victory and look for a discontinuous change in the outcome for a close Republican election win versus a close Democratic election win. Our approach follows the seminal work of Lee, 2001, Lee, 2008, which several studies apply to the gubernatorial context (e.g., Leigh, 2008, Beland, 2015, Beland and Boucher, 2015, Doyle et al., 2016, Meyer, 2019). Intuitively, outcomes in states governed by Democratic winners of close gubernatorial elections serve as counterfactuals for outcomes in states governed by Republican winners of close gubernatorial elections. We estimate the average causal effect of a close Republican gubernatorial win relative to what is expected with a close Democratic gubernatorial win. Then, in our analysis of the partisan control of the state legislature, we follow the multidimensional RD design of Feigenbaum et al. (2017), which several studies apply in other contexts (e.g., Caughey et al., 2017, Bergquist, 2019). Here, we estimate the average causal effect of electing a narrow Republican majority to the lower house (state house of representatives).

We make several contributions with this work. First, we identify how the partisan affiliations of political leaders affect the installation of air pollution abatement technology at regulated facilities. Several studies estimate the effects of gubernatorial political affiliation on economic and social outcomes (e.g., Lee, 2001, Lee, 2008, Beland, 2015). However, prior work focuses on state level budgeting and policy decisions, while ours examines an outcome that federal statute delegates to local authorities, while leaving room for regulator discretion. We therefore provide evidence of the differential implementation of federal policy at the local level. Second, we contribute to the literature on regulatory discretion (e.g., Duflo et al., 2018, Kang and Silveira, 2021). We examine how political leaders' partisan affiliations differentially impact abatement technology adoption when regulators have discretion over acceptable technologies versus when rules mandate a single technology. Third, our study provides a mechanism for the heterogeneity of air emissions and ambient air quality in the US (Hsiang et al., 2019, Clay and Muller, 2021). In related work, Beland and Boucher (2015) identify differences in ambient air quality between states controlled by Democratic governors and states controlled by Republican governors. Our study sheds light on how this differential ambient air quality occurs. Relatedly, we contribute to the larger literature evaluating the CAA, including its benefits and costs, which Currie and Walker (2019) thoroughly review. Lastly, previous work suggests that the CAA implementation process is inefficient (NRC 2004).[4] We empirically examine this claim and provide evidence of inefficiencies in the process, suggesting that a more flexible system could deliver more air pollution abatement for the same costs to society.

To develop our contributions, we implement the close election RD design in several settings. First, we estimate the effect of a Republican governor on the adoption of air pollution abatement technology by examining facility level expenditures on new capital equipment; we find statistically insignificant effects for electric utilities in areas that meet federal standards, or "attainment" areas. Alternatively, we find that in states controlled by a Republican governor, electric utilities in areas that do not meet federal standards, or "nonattainment" areas, expend 90% less on new air pollution abatement technology, compared to electric utilities in attainment areas and the counterfactual of Democratic gubernatorial control.

Second, we estimate the effect of a Republican governor on the adoption of specific air pollution abatement technology at the boiler level. Like with expenditures, we find that the effects of a Republican governor on the adoption of the most effective nitrogen oxide (NOx) abatement technologies are present only in nonattainment areas. The likelihood of the adoption of Selective Catalytic Reduction (SCR) or Selective Non-Catalytic Reduction (SNCR) equipment at boilers in our sample, compared to the adoption of Low NOx Burners (LNB) or Over Fire Air (OFA) [or other technologies], is statistically insignificant in attainment areas. For nonattainment areas in states controlled by a Republican governor, however, electric utilities are nine percentage points less likely to install SCR/SNCR than electric utilities in states controlled by a Democratic governor. This result is unsurprising given the nature of the CAA. The US Environmental Protection Agency (EPA) mandates technological prescriptions only in areas that fail to meet federal standards and cost minimizing firm managers are unlikely to install capital intensive abatement technologies when not required by law.

Third, we implement the multidimensional RD design on the same outcomes to estimate the impact of electing a narrow Republican majority to the state house of representatives. We find that a Republican majority decreases the extent of new air pollution abatement capital expenditures and the probability of adopting the most effective NOx abatement technology in nonattainment areas. However, the estimated effects are substantially smaller in magnitude than those of the gubernatorial analysis. The point estimates on the differential effects of a close Republican legislative majority for electric utilities in nonattainment areas are roughly 50% smaller than those from the gubernatorial analysis. Moreover, the effects are less precisely estimated for the state legislative analysis. Overall, our empirical results suggest that gubernatorial control is more important than state legislative control in determining how electric utilities make air pollution abatement decisions. Governors have the most direct control over the implementation of the CAA, but control of the state house of representatives can also influence outcomes through more indirect channels.

Finally, we show that the estimated effects are economically meaningful and provide policy recommendations. We examine the benefits and costs of the NOx abatement technologies that electric utilities adopt because of regulatory requirements. We find that the additional benefits associated with reduced mortality from localized emission reductions generally exceed the additional costs of installing the most effective NOx abatement technology, when compared to the installation of less effective technologies. However, depending on the lifespan of the abatement technology and the policy discount rate, estimated benefit-cost ratios are often lower than many other air pollution abatement policies. In cases of the technology having a lifespan of less than five years, additional annualized abatement costs likely exceed additional annualized benefits. Further, we assess the effectiveness of the abatement technology requirements at improving ambient air quality in nonattainment areas and find little to no evidence that abatement technology adoption at electric utilities has a significant impact at improving ambient air quality or helping areas exit nonattainment. Collectively, our results suggest that political leaders should carefully consider the goals of the CAA implementation process and their desired time horizon when mandating abatement technology as part of regulatory requirements.

2. Background

This section describes the regulatory framework surrounding ambient air quality and air pollution abatement strategies at electric utilities. We first discuss the specifics of the CAA's air quality standards, which include statutory mandates and their implications for both electric utilities and state environmental protection agencies. We then examine the technology available for electric utilities to decrease emissions of specific air pollutants.

2.1. Regulatory Environment

As part of the CAA, the National Ambient Air Quality Standards (NAAQS) aim to improve air quality in the US by limiting the ambient air concentrations of harmful pollutants. To this end, the CAA establishes two forms of ambient air quality standards: (1) primary standards, which protect the health of vulnerable populations and (2) secondary standards, which protect the public welfare (EPA 2016). EPA designates nonattainment areas where the ambient concentration of at least one criteria air pollutant exceeds either standard. Once this designation occurs, several regulatory requirements go into effect. Most importantly, states must construct nonattainment state implementation plans (SIP) that prescribe how they will bring ambient air quality into attainment with the relevant NAAQS. Within each SIP, states outline a variety of abatement strategies to reduce emissions from local sources, thereby reducing the ambient concentration of the pollutant and improving local air quality.[5] Although states have flexibility in their overall abatement choices, each SIP must include a technological component. Federal statute requires that all stationary emission sources in nonattainment areas install air pollution abatement technology that is reasonable in both cost and effectiveness, referred to as "reasonably available control technology" (RACT). Major stationary emission sources (those that emit more than 100 tons of a criteria air pollutant or its precursors each year) are subject to further requirements, such as the use of cleaner fuel. Other regulatory requirements of nonattainment designation include the inventorying and additional monitoring of emissions at major stationary sources (Walker 2013), the forecasting of changes in future ambient air quality, and the construction of maintenance plans to ensure that areas exiting nonattainment will not re-enter nonattainment after meeting the appropriate NAAQS. Finally, there exist additional incentives for states to exit nonattainment, although these incentives do not mandate specific abatement strategies. For example, EPA can impose additional emission requirements and recommend the withholding of federal funding (Gibson 2019).

The process through which states design and develop SIPs is ongoing and involves many interested parties. State environmental protection agencies, local air districts, and public comments all provide input on SIP content.[6] In addition, EPA, as part of administering the NAAQS, sometimes works with state environmental protection agencies to construct initial SIP templates (EPA 2019a). States can also preemptively construct draft SIPs for relevant areas before they enter nonattainment (Gibson 2019). Importantly, SIPs are not federally enforceable until approved by the appropriate EPA regional office.[7] Although EPA outlines the process for SIP development and approval, states must construct their own plan for approval.[8] For states unable or unwilling to submit a SIP, EPA develops a Federal Implementation Plan.[9] EPA and states view SIPs as "living documents" that require continuous updating (EPA 2013a). SIP revisions therefore occur frequently, with the number of submittals varying by state.[10] EPA enforces deadlines (between 18 and 36 months) to submit a SIP after nonattainment designation (EPA 2020).[11] Once adopted, the governor or their designee oversees submission of each SIP element to EPA (EPA 2019b).

Inherent within this process is the ability of the partisan affiliations of a state's political leaders to influence SIP content, including RACT designation. Ultimately, governors wield the most direct control over SIP content, as they can submit SIP revisions and commitments directly to EPA. In practice, governors work with interested parties to craft the SIP and then provide its final approval and submission (and any revisions) to EPA. Collectively, governors have the greatest degree of influence over the contents of each SIP through their final approval, political appointees, and collaboration with EPA. The influence of the state legislature on the SIP process is more indirect. In general, state legislatures are most likely to affect administrative policy through oversight mechanisms and by exerting influence on the budget, potentially modifying the resources available to an agency (Bergquist 2019).[12] State legislatures directly influence the SIP process through public comment and their approval of governor appointments to regulatory agencies (e.g., state air agencies).

2.2. Air Pollution Abatement Technology

For nonattainment areas, EPA approved SIPs do not require the broad adoption of the most effective air pollution abatement technology or even the adoption of all cost effective technology. Depending on the pollutant that areas must abate, a catalog of options exists. The technological objective of any SIP is to outline how the adopted abatement technology improves the ambient air quality of the criteria pollutant in question. Therefore, states must identify the effectiveness of the abatement technology necessary to satisfy EPA requirements and reach attainment, while also considering the costs imposed on stationary emission sources. Most importantly, SIP guidelines require that all stationary emission sources that lack adequate abatement technology adopt some form of RACT. Here, we focus on sulfur dioxide (SO2) and NOx emissions and abatement technology because these are criteria air pollutants, electric utilities are their leading emitters in the US (EPA 2017), and these are the pollutants that we examine in our empirical analysis.

For SO2 emissions, there are few abatement options available that EPA considers RACT. The primary form of technological abatement for SO2 emissions is flue gas desulfurization (FGD). There exist different FGD configurations depending on fuel content and other boiler characteristics, but RACT requirements for SO2 emissions nearly always contain an FGD component. All FGDs have high rates of effectiveness. Semi-dry FGD technology effectively removes 92% of SO2 emissions, while wet FGD uses a lime spray dryer and effectively removes 96% of SO2 emissions (EPA 2013b). For SO2 emissions, there does not exist a less effective abatement technology that EPA still considers RACT. The RACT determinations of nonattainment SIPs for SO2 emissions rely only on facility characteristics, thus removing any discretion on the part of the regulator.

Alternatively, NOx abatement technologies and their effectiveness vary by boiler. As a result, there exists heterogeneity throughout the US in the types of technologies that EPA designates as NOx RACT. LNB and OFA systems, which are the most common form of NOx abatement technology, can be considered RACT under the NAAQS. However, these technologies are considerably cheaper and have a lower NOx removal rate (25–60%) than SCR/SNCR systems [75–90%] (Xiong et al. 2016), which many nonattainment SIPs require that electric utilities adopt as RACT.[13] LNB and OFA are therefore less effective abatement technologies that still fulfill the requirements of the CAA.[14] NOx RACT determination also depends on the facility. EPA considers the operations at electric utilities when comparing the use of different NOx abatement technologies. Collectively, the variety of NOx abatement technologies available and eligible for EPA to consider RACT introduces discretion into the determination for state environmental protection agencies that does not exist for SO2 abatement.

Finally, the chronology of air pollution abatement technology installation is important due to gubernatorial oversight of SIPs. Electric utilities field test commonly used NOx abatement technologies and they are completely operational usually within one year (Institute of Clean Air Companies 2006).[15] Additionally, the typical receipt of purchase order for NOx abatement technology occurs within eight weeks of a requested quote. Expeditious planning and installation make the alteration of any SIP mandated abatement equipment unlikely.

3. Data

In this section, we provide a brief overview of our primary data sources and the construction of our analysis sample. We provide further details and sample summary statistics in Online Appendix A.

3.1. Sources and Sample Construction

We collect data from several sources. First, three Energy Information Administration (EIA) forms contain information on the air pollution abatement technology installed at electric utilities in the US. The relevant EIA forms are the EIA 767, 860, and 923. Online Appendix A.1. describes these EIA forms in greater detail. Next, we gather data on gubernatorial elections and their victory margins from David Leip's Atlas of US presidential elections (2020).[16] Likewise, we obtain data on state legislative elections from Klarner (2018), which covers the universe of state legislative elections from 1967 to 2016. We follow the literature (e.g., Caughey et al., 2017, Bergquist, 2019) and focus on the impact of electing a Republican majority to the lower house because state senate elections are typically staggered, with many senate seats not up for election in each cycle. Consistent with prior studies, we focus on general elections in single member, partisan districts. Therefore, we omit nonpartisan Nebraska and elections from state-years with multimember districts.[17] Finally, we gather data on county level nonattainment status from the EPA Green Book (2020).

We construct four primary analysis samples; there are two samples each for gubernatorial and state legislative elections. Our first gubernatorial sample contains information on new air pollution abatement capital expenditures, which EIA measures at the facility level. We convert all expenditures to real 2015$ and then create a panel of facility-years from 2001 to 2017, which are the years that the current version of the EIA 860 is available.[18].[19] We consider as our sample only a balanced panel of facilities, i.e., those that operate during each of the contiguous years from 2001 to 2017 and did not switch fuels.[20]

We combine our panel of facility-years with gubernatorial election data from all 50 states. We include only elections won by a Democrat or Republican (we exclude Independent victories). Because governors serve four-year terms, we match the results of each election (typically in November of the year preceding the governor's appointment) with any new air pollution abatement capital expenditures at each facility for the following four years.[21] During our sample period, there are 206 gubernatorial elections won by a Democrat (97 victories) or a Republican (109 victories).[22] The new air pollution abatement capital expenditures measure includes spending on technology for the abatement of all pollutants. We therefore identify facilities in nonattainment areas for any of the six criteria air pollutants regulated by the NAAQS.[23]

We construct a second gubernatorial analysis sample like that described above, with two differences. First, the second gubernatorial analysis sample contains information on the type of SO2 and NOx abatement technology installed at each electric utility (rather than capital expenditures), which EIA measures at the boiler level. This second gubernatorial analysis sample is therefore a balanced panel of boiler-years, rather than facility-years. Second, because we are interested only in SO2 and NOx emission control for this boiler-level analysis, we focus on the nonattainment designations that require the installation of RACT for each pollutant. For SO2 emissions, these designations are SO2 and particulate matter (PM) nonattainment. For NOx emissions, these designations are ozone, nitrogen dioxide (NO2), and PM nonattainment.

Finally, we construct two state legislative samples analogously to the gubernatorial samples. We first match the balanced panel of 2001–2017 facility level observations to the state legislative elections. The second state legislative sample matches the balanced panel of boiler-years to the state legislative elections. All but two states have two-year terms in the lower house, so we match election results to air pollution abatement data for the following two years.[24]

Table 1 presents summary statistics for each analysis sample. The descriptive statistics of the gubernatorial sample resemble those of the state legislative sample in both Panel A (facility level) and Panel B (boiler level).[25]

Table 1. Sample summary statistics.

Empty Cell	Gubernatorial analysis		State legislative analysis	
Variable	**Mean**	**SD**	**Mean**	**SD**
Panel A. Facility level sample				
New air pollution abatement capital expenditures (000 s) [2015$]	9,530	29,374	9,930	29,997
Boilers	2.30	1.45	2.36	1.54
Nonattainment (any pollutant)	0.271	0.444	0.269	0.444
Average boiler age (years)	35.90	11.99	35.91	11.75
Unemployment rate	6.41	2.51	6.42	2.41
Population (10,000 s)	46.86	139.25	43.59	126.73
Republican governor	0.588	0.492	---	---
Republican majority (lower state house)	---	---	0.604	0.489
Panel B. Boiler level sample				
SCR/SNCR technology	0.306	0.461	0.300	0.458
FGD technology	0.372	0.483	0.376	0.484
Coal fired boiler	0.731	0.443	0.741	0.438
Nonattainment (NOx affected pollutants)	0.281	0.450	0.278	0.448
Nonattainment (SO2 affected pollutants)	0.197	0.398	0.194	0.395
Age (years)	37.51	13.07	37.60	12.99
Unemployment rate	6.47	2.42	6.50	2.35
Population (10,000 s)	53.27	161.4	47.30	144.72
Republican governor	0.586	0.493	---	---
Republican majority (lower state house)	---	---	0.614	0.487

Notes: Summary statistics are at the facility-year (Panel A) and boiler-year (Panel B) level and for the observations of the final analysis samples (from all margins of victory). In Panel B, SCR/SNCR technology and FGD technology represent the presence of the most effective abatement technology for NOx and SO2 emissions, respectively, at each boiler in each year. Nonattainment for NOx affected pollutants represents electric utility boilers located in PM, ozone, and NO2 nonattainment areas. And nonattainment for SO2 affected pollutants represents electric utility boilers located in PM and SO2 nonattainment areas.

4. Econometric Framework and Results for Gubernatorial Partisan Affiliation

In this section, we describe our empirical framework to estimate the impact of the governor's political party on air pollution abatement at electric utilities. We use an RD design to identify the effects of the governor's partisan affiliation on our outcomes of interest. This strategy uses outcomes of close elections as a quasi-experiment. Lee, 2001, Lee, 2008 pioneered the "close election RD design", which papers such as Lee et al. (2004), Petterson-Lidbom (2008), and Ferreira and Gyorko (2009) apply. Leigh, 2008, Beland, 2015, Beland and Boucher, 2015, Beland and Oloomi, 2017, Beland and Unel, 2018, and Meyer (2019) use the RD design specifically in the context of gubernatorial elections.

We first describe the RD design and our estimating equations in subsection 4.1. We then graphically show the validity of the RD design for our outcomes of interest and provide RD design validity tests in subsection 4.2. and results in subsection 4.3.

4.1. RD Design and Estimation Strategy for Gubernatorial Partisan Affiliation

For our analysis, we use local linear regressions estimated on samples of close elections between Democratic and Republican candidates.[26] We define the vote margin in state *s* in year *t* as VM_{st}, where positive values indicate the election of a Republican governor and negative values indicate the election of a Democratic governor; margins close to zero in absolute value indicate a close election. The RD threshold therefore occurs at VM_{st}. Our baseline RD estimator with linear controls is:

(1)

$$Y_{ijst} = \beta * RG_{st} + \varphi * VM_{st} + \lambda * RG_{st} * VM_{st} + \gamma \boldsymbol{X_{ijst}} + \psi_t + \zeta_s + \varepsilon_{ijst}$$

where Y_{ijst} is the outcome of interest, VM_{st} is the vote margin, RG_{st} is an indicator for a Republican governor holding office, ψ_t are year fixed effects, and ζ_s are state fixed effects. $\boldsymbol{X_{ijst}}$ includes baseline covariates for plant (boiler) i in county j of state s during year t.

The RD treatment effect is the difference between the expected outcome given a Republican gubernatorial win and the expected outcome given a Democratic gubernatorial win at the RD threshold (vm_0).
Equation (1) estimates this treatment effect with the parameter β. There are no observations exactly at (vm_0), so local linear RD instead uses observations close to the RD threshold for estimation. We choose a bandwidth according to the optimal bandwidth calculations of Calonico et al. (2019), hereafter "CCFT". The optimal bandwidth of CCFT minimizes the mean squared error of the local linear estimator and improves upon the optimal bandwidth calculations of Imbens and Kalyanaraman, 2012, Calonico et al., 2014a. Important for our context, the optimal bandwidth of CCFT allows for the clustering of standard errors at a group level. Treatment assignment in our application is at the state level, whereas we observe outcomes at the facility or boiler level. Thus, for the optimal bandwidth calculations, we cluster standard errors at the state level.[27]

While equation (1) identifies the effect of gubernatorial partisan affiliation on air pollution abatement technology type and expenditures at electric utilities overall, we expect differential effects for facilities located in attainment versus nonattainment areas (see section 2 for further context). To investigate this hypothesis, we alter equation (1) by fully interacting an indicator for CAA nonattainment designation with the RD variables and the state fixed effects. The baseline RD specification to test for differential effects is:

(2)

$$\begin{aligned} Y_{ijst} = \beta_1 RG_{st} + \beta_2 NA_{jst} + \beta_3 RG_{st} * NA_{jst} + \beta_4 VM_{st} + \beta_5 VM_{st} * NA_{jst} + \beta_6 * RG_{st} \\ * VM_{st} + \beta_7 * RG_{st} * VM_{st} * NA_{jst} + \gamma \boldsymbol{X_{ijst}} + \psi_t + \zeta_s * NA_{jst} + \varepsilon_{ijst} \end{aligned}$$

where the notation is identical to equation (1) and NA_{jst} is an indicator for electric utility location within a nonattainment area. Here, β_1 and β_3 are the parameters of interest. β_1 represents the impact of a Republican governor on the air pollution abatement outcome of an electric utility located in an attainment area and β_3 represents the differential effect of a Republican governor on the air pollution abatement outcome of an electric utility located in a nonattainment area, relative to an electric utility in an attainment area. Again, we use the CCFT optimal bandwidth calculation and cluster standard errors at the state level.[28]

For our analysis, the outcomes of interest are new air pollution abatement capital expenditures and the choice of SO2 and NOx abatement technology. We observe our measure of new air pollution abatement capital expenditures at the facility, rather than the boiler, level, and we observe all capital expenditures grouped together. Facilities can invest in multiple technologies in any year. Therefore, we conduct this analysis at the facility-year level, where we consider nonattainment status for any of the criteria pollutants.

In contrast, the observation of air pollution abatement technology type depends largely on whether the electric utility had the technology in the previous year, because these air pollution abatement technologies have a long useful life and electric utilities typically do not remove them once they have been installed (Scaqmd, 2018, Epa, 2019c). We are interested in identifying how the partisan affiliation of a governor affects concurrent air pollution abatement technology adoption. Simply using an indicator for the observation of an installed technology is insufficient because such an indicator incorporates all past air pollution abatement investment decisions along with current decisions. Therefore, we condition on whether the boiler has the air pollution abatement technology installed in the year prior. Our quasi-experiment is therefore conceptualized as, "conditional on the previous year's air pollution abatement technology, is there a discontinuous change in the probability of observing the air pollution abatement technology when a Republican wins a close gubernatorial election relative to when a Democrat wins?".

4.2. Graphical Evidence and RD Validity Tests for Gubernatorial Partisan Affiliation

To visually display the magnitudes of potential discontinuities in our outcomes, we plot binned residuals from a regression of each outcome on the conditioning variables in equation (1). For example, we regress inverse hyperbolic sine (arcsinh) transformed real new air pollution abatement capital expenditures on year and state fixed effects, the number of boilers, and indicators for coal fuel and nonattainment status. We then create bins of small ranges of vote margins. Within each vote margin bin, we average the residuals from the regression and fit a line of best fit on each side of the threshold delineating close Democratic versus close Republican gubernatorial elections. In these graphs, bins to the left of zero indicate close Democratic victories and bins to the right of zero indicate close Republican victories. Fig. 1 shows the RD plots for new air pollution abatement capital expenditures and Fig. 2 shows the RD plots for NOx abatement technology. For both outcomes, we show binned residuals for the overall sample (Panel A), facilities in attainment areas (Panel B), and facilities in nonattainment areas (Panel C). In each case, we use windows that approximately correspond to the optimal bandwidths described in subsection 4.1. We divide residuals into five equally spaced bins on each side of the election threshold.

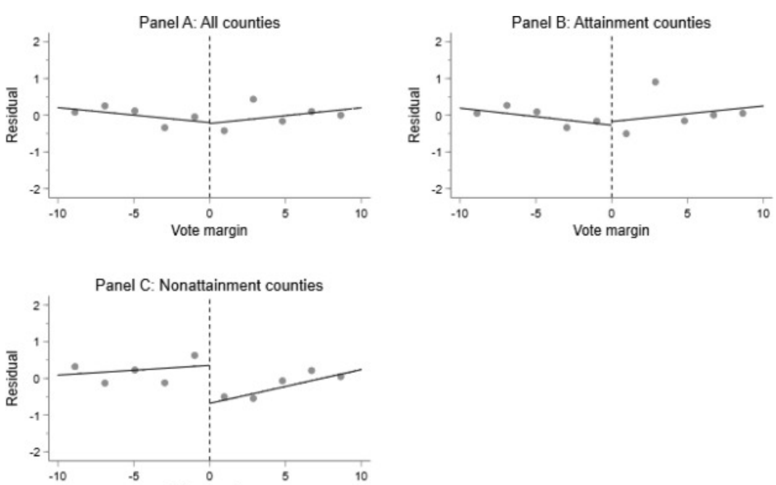

Fig. 1. **RD plots for new air pollution abatement capital expenditures, gubernatorial partisan affiliation***, Notes*: These graphs show RD plots for the residuals from regressions of arcsinh transformed real new air pollution abatement capital expenditures on year fixed effects, state fixed effects, number of boilers, and indicators for coal fuel and nonattainment status (panel A). Plotted points represent averages of the residuals within equal width bins. We show best fit lines on each side of the RD threshold. Bins to the left of zero indicate close

Democratic victories and bins to the right of zero indicate close Republican victories. Panel A includes all electric utilities, Panel B includes electric utilities in attainment areas, and Panel C includes electric utilities in nonattainment areas.

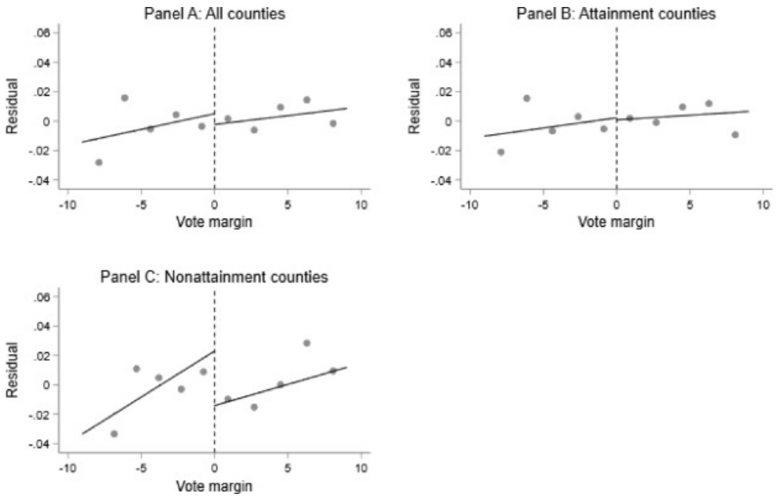

Fig. 2. **RD plots for SCR/SNCR technology, gubernatorial partisan affiliation,** *Notes*: These graphs show RD plots for the residuals from regressions of linear probability models where an indicator for installed SCR/SNCR technology is regressed on year fixed effects, state fixed effects, the one-year lagged value of the dependent variable, and indicators for coal fuel and nonattainment status (panel A). Plotted points represent averages of the residuals within equal width bins. We show best fit lines on each side of the RD threshold. Bins to the left of zero indicate close Democratic victories and bins to the right of zero indicate close Republican victories. Panel A includes all boilers, Panel B includes boilers in attainment areas, and Panel C includes boilers in nonattainment areas.

Fig. 1 shows that crossing from a close Democratic victory to a close Republican victory results in a discontinuous drop in new air pollution abatement capital expenditures only in Panel C. Likewise, Panel C of Fig. 2 shows a drop in the probability of the presence of the most effective NOx abatement technology when crossing the RD threshold from a close Democratic gubernatorial victory to a close Republican gubernatorial victory for boilers in nonattainment areas; there is no substantial change in the other panels.

Consistent with Beland (2015), our RD specifications condition on state and year fixed effects. The literature sometimes refers to this specification as the fixed effects RD estimator (e.g., Pettersson-Lidbom 2012). Our identification depends on within-unit variation (Grembi et al. 2016) because any time-invariant differences across states are subsumed into the state fixed effects. In this design, one potential threat to identification could be differential counterfactual trends in outcomes among states where Democrats and Republicans win a close election. To address this concern, we estimate event-time varying RD treatment effects (Grembi et al. 2016). In a way analogous to difference-in-differences event studies, we define the “event” as a close Republican win (the year of the election). Fig. 3 presents event studies for new air pollution abatement capital expenditures and SCR/SNCR technology. These figures show no evidence of differential pre-trends among electric utilities in states where Republicans win a close election, as compared to electric utilities in states where Democrats win.

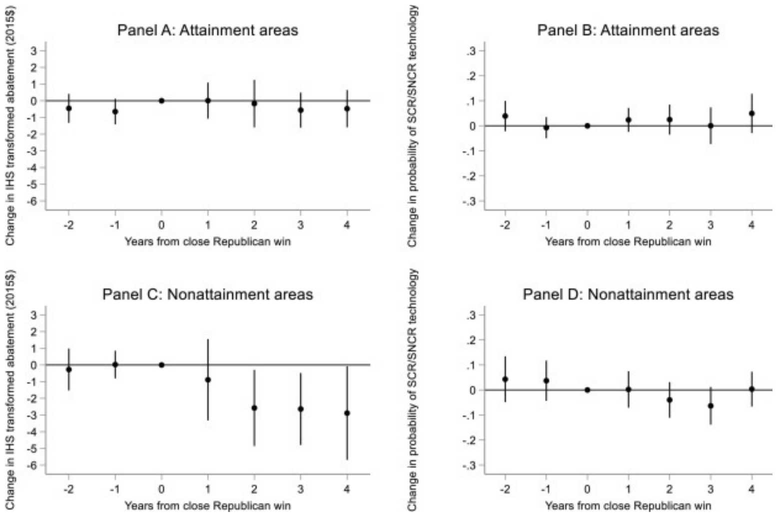

Fig. 3. RD event studies for new air pollution abatement capital expenditures and probability of SCR/SNCR technology, gubernatorial elections. *Notes*: This figure presents point estimates from the estimation of an RD event study of a close Republican gubernatorial win on new air pollution abatement capital expenditures (Panels A and C) and a dummy indicating the presence of the most effective NOx abatement technology (SCR/SNCR) [Panels B and D]. Standard errors are clustered at the state level and produce 95% confidence intervals, which are included. Panels A and B present event studies for electric utilities located in attainment areas. Panels C and D present event studies for electric utilities located in nonattainment areas. All estimations include state and year fixed effects and the appropriate controls from the full specifications of equations (1), (2).

Next, we conduct two classes of RD validity tests: placebo tests and density tests. In the online appendix, we present and discuss placebo tests for the baseline covariates of boiler age, county unemployment, and county population. In addition to our baseline covariates, we test for discontinuities in several other variables in the online appendix. These include new air pollution abatement capital expenditures in the four years prior to the governor taking power (facility level), NOx abatement technology installation in the four years prior to the governor taking power (boiler level), the year of the election, partisan control of the lower state house, partisan control of the state senate,[29] and partisan composition of the federal delegation. As detailed in Online Appendix C.2., we do not find any significant discontinuities in any of these placebo outcomes. We also present RD density tests in Online Appendix C.2.; we fail to reject the null hypothesis of no manipulation in the density of vote margin for the overall sample, attainment areas, and nonattainment areas. In summary, these placebo and density tests add confidence in the identifying assumption of smooth potential outcomes through the RD threshold, both overall and for the differential effect in nonattainment areas.

4.3. Results for Gubernatorial Partisan Affiliation

In this subsection, we discuss our empirical results for the gubernatorial analysis. We first examine as the outcome new air pollution abatement capital expenditures. Second, we provide estimation results for the adoption of the most effective NOx abatement technology as the outcome. Finally, we present results for our placebo test.

4.3.1. New Air Pollution Abatement Capital Expenditures

We begin by estimating equation (1) using arcsinh transformed real new air pollution abatement capital expenditures as the dependent variable. This transformation resembles the natural log transformation but retains zero values for the dependent variable. Interpretations on our coefficients of interest therefore approximate the percentage change in real new air pollution abatement capital expenditures, at the facility level (Bellemare and Wichman 2020). Column 1 of Table 2 shows that there is no statistically significant effect of the governor's party affiliation on this dependent variable; the point estimate on the coefficient is relatively small in magnitude as well. Column 2 adds several additional controls: plant age, county population, and county unemployment rate. The point estimate on the coefficient remains relatively small in magnitude and statistically insignificant.

Table 2. Baseline RD results, new air pollution abatement capital expenditures, gubernatorial partisan affiliation.

Variable	(1)	(2)	(3)	(4)
Republican governor	0.00689	−0.0133	0.281	0.273
	(0.613)	(0.617)	(0.686)	(0.677)
Republican governor × NA			−2.292**	−2.387**
			(0.903)	(0.916)
NA	0.530	0.513		
	(0.452)	(0.464)		
State FE	X	X	X	X
Year FE	X	X	X	X
Additional controls		X		X
Mean of dep. var.	4.702	4.702	4.702	4.702
Bandwidth	9.697	9.697	9.697	9.697
Clusters	43	42	43	42
Observations	2,020	2,015	2,019	2,014

Notes: Columns 1 and 2 [3 and 4] represent separate RD specifications of equation (1) [(2)], where the dependent variable is arcsinh transformed real new air pollution abatement capital expenditures. The number of boilers and percent of boilers burning coal are included as controls in each column. Additional controls include plant age and county population. Robust standard errors in parentheses are clustered at the state level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Next, we test for differential effects of gubernatorial partisan affiliation on new air pollution abatement capital expenditures based on the nonattainment status of the area in which each facility is located. We estimate equation (2), again using arcsinh transformed real new air pollution abatement capital expenditures as the dependent variable. As shown in columns 3 and 4 of Table 2, there is no statistically significant effect from a Republican win on expenditures in attainment areas. However, relative to a close Democratic win, a close Republican win leads to a statistically significant 90% differential decrease in air pollution abatement expenditures in nonattainment areas. There are several likely reasons for this large effect. First, approximately half of all observations come from facilities with zero capital expenditures. Second, when there is a capital expenditure, it can be very large. The 75th percentile level of new air pollution abatement capital expenditures is over $2 million and the 95th percentile level is over $60 million. Additionally, our sample consists of large and heavily polluting electric utilities, where air pollution abatement capital is expensive (Scaqmd, 2018, Epa, 2019d); a relatively small increase in the probability of purchasing air pollution abatement capital can lead to large expected changes in total expenditures.

In Online Appendix C.6., we present a supplementary analysis where the outcome is an indicator for any positive capital expenditures; these results qualitatively support the above findings. Also in the online appendix, we investigate whether the governor's political party affects the probability of electric utility retirement. For this analysis, we use the full panel of coal and natural gas burning plants (rather than the balanced panel). We then create an indicator for boiler retirement (proportion of retired boilers at a plant for facility level analysis) and re-estimate RD specifications (1), (2) for this outcome. As shown in Online Appendix Table A43, we do not find any evidence that a governor's partisan affiliation affects the overall probability of electric utility retirement, nor do we find evidence that the governor differentially affects the probability of retirement for electric utilities located in nonattainment areas.[30]

4.3.2. Air Pollution Abatement Technology Installation by Type

Next, we investigate the adoption of specific air pollution abatement technology types. Here, we focus on the adoption of NOx abatement technology because EPA considers multiple technologies as RACT for this pollutant. The most effective technologies, SCR/SNCR, remove substantially more NOx from steam discharges compared to other technologies (Xiong et al. 2016). We therefore estimate equations (1), (2), using an indicator for SCR/SNCR as the dependent variable, to examine how political regimes affect the installation of the most effective NOx abatement technology. Because all electric utilities must install some form of abatement technology while in nonattainment (RACT), the omitted category for this outcome is other NOx abatement technology, most likely LNB/OFA. The coefficient on our treatment measure represents the differential in SCR/SNCR adoption over LNB/OFA (or other technology) adoption. We proceed here analogously to the previous subsection, but we now condition on previous SCR/SNCR presence at each boiler and our analysis is at the boiler-year level. Table 3 shows baseline results for the overall sample (columns 1 and 2) and RD results where we test for differential effects based on the nonattainment status of each boiler's location (columns 3 and 4). As before, columns 1 and 2 show that there is no effect of a Republican governor on the overall probability of SCR/SNCR installation. However, columns 3 and 4 show that, relative to the counterfactual of a close Democratic win, a close Republican win differentially decreases the probability of SCR/SNCR installation in nonattainment areas, instead of less effective RACT, by roughly nine percentage points. These results are robust to the inclusion of additional covariates in columns 2 and 4 of Table 3.[31]

Table 3. Baseline RD results, SCR/SNCR technology, gubernatorial partisan affiliation.

Variable	(1)	(2)	(3)	(4)
Republican governor	−0.00480	−0.00392	0.0142	0.0147
	(0.0217)	(0.0217)	(0.0252)	(0.0254)
Republican governor × NA			−0.0938**	−0.0909**
			(0.0406)	(0.0407)
NA	−0.00498	−0.00167		
	(0.0144)	(0.0141)		
State FE	X	X	X	X
Year FE	X	X	X	X
Additional controls		X		X
Mean of dep. var.	0.366	0.366	0.366	0.366
Bandwidth	9.191	9.191	9.191	9.191
Clusters	42	42	42	42
Observations	4,097	4,089	4,096	4,088

Notes: Columns 1 and 2 [3 and 4] represent separate RD specifications of equation (1) [(2)], where the dependent variable is an indicator for SCR/SNCR technology. Indicators for the one-year lag of SCR/SNCR technology and coal fuel are included as controls in each column. Additional controls include boiler age and county population. Robust standard errors in parentheses are clustered at the state level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

4.3.3. Air Pollution Abatement Technology Placebo Test: FGD

Above, we show that Republican policymakers apply less stringent air pollution abatement technology requirements to electric utilities in nonattainment areas when they have discretion to do so. However, there are some pollutants for which regulators have no such discretion. The only technological solution to abate SO2 that EPA considers as RACT is FGD.[32] As a result, we should not see any differential impacts of the governor's political party on the probability of FGD adoption based on the nonattainment status of an electric utility's location. Applying this reasoning, we conduct a falsification test where FGD installation is the placebo outcome. We limit the sample to coal burning boilers and estimate equations (1), (2) using procedures analogous to the NOx abatement technology type outcome.

Columns 1 and 2 of Table 4 show that there is no effect of a Republican governor on the probability of observing FGD technology at a coal burning boiler. We do not find any significant differential effect in columns 3 and 4 either; electric utility boilers are not statistically any more or less likely to install FGD in nonattainment areas relative to attainment areas under a Republican governor as compared to a Democratic governor. These results are consistent with political leaders having limited discretion to substitute cheaper technology for SO2 abatement.

Table 4. Baseline RD results, FGD placebo, gubernatorial partisan affiliation.

Variable	(1)	(2)	(3)	(4)
Republican governor	−0.00163	−0.000222	−0.0150	−0.0124
	(0.0252)	(0.0262)	(0.0234)	(0.0244)
Republican governor × NA			0.0442	0.0462
			(0.0475)	(0.0492)
NA	0.0122	0.0190		
	(0.0166)	(0.0163)		
State FE	X	X	X	X
Year FE	X	X	X	X
Additional controls		X		X
Mean of dep. var.	0.514	0.514	0.514	0.514
Bandwidth	8.073	8.073	8.073	8.073
Clusters	36	36	36	36
Observations	3,267	3,259	3,267	3,259

Notes: Columns 1 and 2 [3 and 4] represent separate RD specifications of equation (1) [(2)], where the dependent variable is an indicator for FGD technology. Indicators for the one-year lag of FGD technology are included as controls in each column. Additional controls include boiler age and county population. Robust standard errors in parentheses are clustered at the state level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5. Econometric Framework and Results for State Legislative Majority Partisan Affiliation

In this section, we examine the more indirect channel of political influence on air pollution abatement technology adoption under the CAA—the state legislature.

5.1. Multidimensional RD Design and Estimation Strategy for State Legislative Majority Partisan Affiliation

In the context of a state legislature, the outcomes of many elections determine which party achieves majority status. For our analysis, we follow the multidimensional RD design of Feigenbaum et al. (2017). In the multidimensional RD design, one creates a distance measure to represent the closeness of a set of district level election results to the results that would deliver majority status to one of the political parties.

Feigenbaum et al. (2017) demonstrate the two-step process for developing the RD forcing variable. In the first step, the researcher determines how many seats the minority party would have needed to win to attain majority status, which we denote *K*. In the second step, the researcher obtains the Euclidean distance (the forcing variable) by summing the squares of the loss margins for the *K* closest elections. We multiply this distance by −1 when Democrats win the majority because we define our RD treatment as a close Republican majority. We then re-estimate equations (1), (2), replacing “Republican governor” with “Republican majority” and “vote margin” with “Euclidean distance”. The RD threshold occurs at a Euclidean distance of zero and we again select our bandwidth of elections using the CCFT optimal bandwidth calculation. We apply the same RD techniques as described in subsection 4.1. (e.g., uniform kernel, cluster standard errors at the state level, use the same conditioning variables for optimal bandwidth calculations).[33]

5.2. Graphical Evidence and RD Validity Tests for State Legislative Majority Partisan Affiliation

Fig. 4, Fig. 5 provide multidimensional RD plots analogous to Fig. 1, Fig. 2. Fig. 4 shows RD plots for the effects of state legislative control on new air pollution abatement capital expenditures and Fig. 5 shows the RD plots for the effects of state legislative control on the adoption of the most effective NOx abatement technology. There is no visible discontinuity in Panel A or when restricting to facilities in attainment areas in Panel B, but there is a noticeable decrease in the level of abatement spending in Panel C when restricting to facilities in nonattainment areas. However, the magnitude of the decrease in Panel C is smaller than its counterpart in Fig. 1. Panel A of Fig. 5 shows a noticeable discontinuity in the likelihood of installing the most effective NOx abatement technology at the threshold for the pooled sample. When comparing Panels B and C, it is evident that the discontinuity in the overall sample is driven by boilers in nonattainment areas (Panel C).

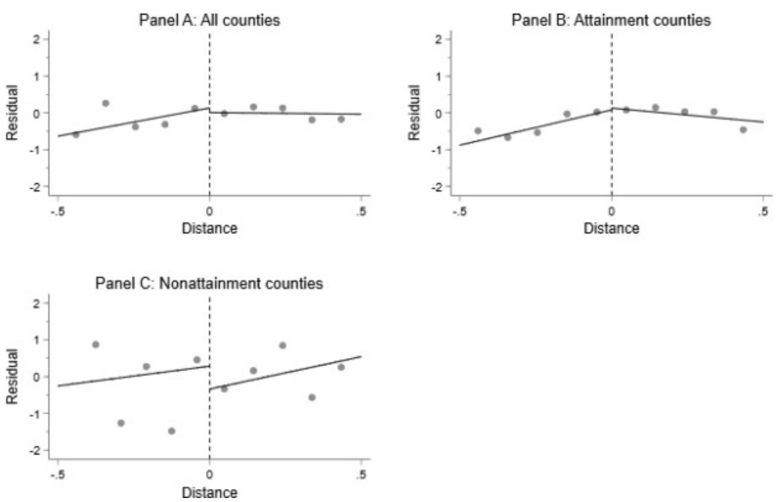

Fig. 4. Multidimensional RD plots for new air pollution abatement capital expenditures, state legislative majority partisan affiliation*, Notes*: These graphs show RD plots for the residuals from regressions of arcsinh transformed real new air pollution abatement capital expenditures on year fixed effects, state fixed effects, number of boilers, and indicators for coal fuel and nonattainment status (panel A). Plotted points represent averages of the residuals within equal width bins. We show best fit lines on each side of the RD threshold. Bins to the left of zero indicate close Democratic victories and bins to the right of zero indicate close Republican victories. Panel A includes all electric utilities, Panel B includes electric utilities in attainment areas, and Panel C includes electric utilities in nonattainment areas.

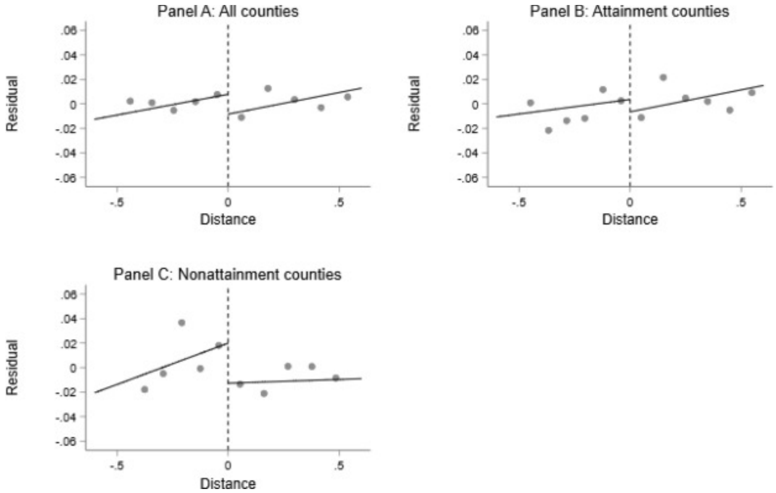

Fig. 5. **Multidimensional RD plots for SCR/SNCR technology, state legislative majority partisan affiliation.** *Notes*: These graphs show RD plots for the residuals from regressions of linear probability models where an indicator for installed SCR/SNCR technology is regressed on year fixed effects, state fixed effects, the one-year lagged value of the dependent variable, and indicators for coal fuel and nonattainment status (panel A). Plotted points represent averages of the residuals within equal width bins. We show best fit lines on each side of the RD threshold. Bins to the left of zero indicate close Democratic victories and bins to the right of zero indicate close Republican victories. Panel A includes all boilers, Panel B includes boilers in attainment areas, and Panel C includes boilers in nonattainment areas.

In Online Appendices D.1. and D.2., we present event studies in time and placebo and density tests to demonstrate validity of the multidimensional RD design. Like before, we find no evidence of significant differential pre-event trends. We also do not see a discontinuous density at the RD threshold or significant discontinuities in the placebo outcomes.

5.3. Results for State Legislative Majority Partisan Affiliation

We proceed in discussing results for the state legislative majority analysis analogously to those from our analysis of gubernatorial partisan affiliation.

5.3.1. New Air Pollution Abatement Capital Expenditures

Table 5 tabulates multidimensional RD results for the outcome of arcsinh transformed real new air pollution abatement capital expenditures. Columns 1 and 2 do not present a significant overall effect of a Republican majority in the lower house of representatives, relative to a Democratic majority. However, columns 3 and 4 show that, relative to attainment areas and the counterfactual outcome of a close Democratic majority, a close Republican majority differentially decreases new air pollution abatement capital spending by 63% in nonattainment areas. Although still sizeable, this effect is smaller in magnitude than the analogous effect for Republican gubernatorial control after a close election. In Online Appendix D.5., we also show results for the outcome of positive air pollution abatement capital expenditures. There, the results qualitatively agree with those presented in Table 5 but are not statistically significant at conventional levels. These results again suggest that majority control of the state legislature plays a somewhat smaller role in the command and control SIP development and implementation processes.

Table 5. Baseline multidimensional RD results, new air pollution abatement capital expenditures, state legislative majority partisan affiliation.

Variable	(1)	(2)	(3)	(4)
Republican majority	−0.109	−0.111	0.113	0.119

	(0.269)	(0.266)	(0.262)	(0.260)
Republican majority × NA			−0.991**	−1.031**
			(0.445)	(0.437)
NA	0.527	0.493		
	(0.499)	(0.560)		
State FE	X	X	X	X
Year FE	X	X	X	X
Additional controls		X		X
Mean of dep. var	4.505	4.505	4.505	4.505
Bandwidth	0.540	0.540	0.540	0.540
Clusters	33	33	33	33
Observations	3,271	3,271	3,271	3,271

Notes: Columns 1 and 2 [3 and 4] represent separate RD specifications of equation (1) [(2)], where the dependent variable is arcsinh transformed real new air pollution abatement capital expenditures. The number of boilers and percent of boilers burning coal are included as controls in each column. Additional controls include plant age and county population. Robust standard errors in parentheses are clustered at the state level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

5.3.2. Air Pollution Abatement Technology Installation by Type

Next, we focus on the effect of a close Republican majority in the state legislature on the adoption of the most effective NOx abatement technology (SCR/SNCR). Columns 1 and 2 of Table 6 show that a close Republican majority in the lower state house decreases the overall probability of the installation of SCR/SNCR technology by approximately two percentage points. However, it is clear from columns 3 and 4 that electric utilities located in nonattainment areas drive the effect. A close Republican majority differentially decreases the probability of SCR/SNCR installation in nonattainment areas by 4.5 percentage points. In comparison to the gubernatorial control results, the differential effect identified here is substantially smaller in magnitude and less precisely estimated. We again interpret these findings as support for the argument that the executive branch of the state government is most important for developing and implementing SIPs, but that the legislative branch can play an indirect role in the process as well.

Table 6. Baseline multidimensional RD results, SCR/SNCR technology, state legislative majority partisan affiliation.

Variable	(1)	(2)	(3)	(4)
Republican majority	−0.0222**	−0.0219**	−0.00964	−0.00963
	(0.00889)	(0.00895)	(0.00856)	(0.00881)
Republican majority × NA			−0.0464*	−0.0457*
			(0.0237)	(0.0239)
NA	0.0203	0.0232		
	(0.0159)	(0.0155)		
State FE	X	X	X	X
Year FE	X	X	X	X
Additional controls		X		X
Mean of dep. var.	0.314	0.314	0.314	0.314
Bandwidth	0.609	0.609	0.609	0.609
Clusters	33	33	33	33
Observations	7,904	7,904	7,904	7,904

Notes: Columns 1 and 2 [3 and 4] represent separate RD specifications of equation (1) [(2)], where the dependent variable is an indicator for SCR/SNCR technology. Indicators for the one-year lag of SCR/SNCR technology and coal fuel are included as controls in each column. Additional controls include boiler age and county population. Robust standard errors in parentheses are clustered at the state level. *** p < 0.01, ** p < 0.05, * p < 0.1.

5.3.3. Air Pollution Abatement Technology Placebo Test: FGD

Recall that the only technological SO2 abatement system that EPA identifies as RACT is FGD. Therefore, we should not see a significant differential effect of close Republican control in the state legislature on FGD adoption in nonattainment areas relative to attainment areas. As in subsection 4.3.3., we limit the sample to coal burning boilers and re-estimate equations (1), (2) with this new outcome. Columns 1 and 2 of Table 7 show that there is no statistically significant overall effect of a close Republican majority on FGD installation. Like before, we do not find a significant differential effect of close Republican majority control on differential FGD adoption in nonattainment areas either (columns 3 and 4 of Table 7). These null effects again add credibility to our claims that we identify the partisan effect of SIPs on air pollution abatement technology.

Table 7. Baseline multidimensional RD results, FGD placebo, state legislative majority partisan affiliation.

Variable	(1)	(2)	(3)	(4)
Republican majority	0.00207	0.00276	−0.0133	−0.0127
	(0.0160)	(0.0159)	(0.0175)	(0.0174)
Republican majority × NA			0.0665	0.0691
			(0.0502)	(0.0500)
NA	0.0261*	0.0325**		
	(0.0141)	(0.0146)		
State FE	X	X	X	X
Year FE	X	X	X	X
Additional controls		X		X
Mean of dep. var.	0.482	0.482	0.482	0.482
Bandwidth	0.858	0.858	0.858	0.858
Clusters	33	33	33	33
Observations	6,562	6,562	6,562	6,562

Notes: Columns 1 and 2 [3 and 4] represent separate RD specifications of equation (1) [(2)], where the dependent variable is an indicator for FGD technology. Indicators for the one-year lag of FGD technology are included as controls in each column. Additional controls include boiler age and county population. Robust standard errors in parentheses are clustered at the state level. *** p < 0.01, ** p < 0.05, * p < 0.1.

6. External Validity and Political Contributions as an Alternative Mechanism

The RD design has high internal validity for estimating causal effects at the RD threshold. However, we may also be interested in the effects of political leadership in states further away from the threshold. In the context of close election RDs, de la Cuesta and Imai (2016, pg. 389) note, "the external validity of the RD design is limited because the average treatment effect is identified only at the threshold." The problem is that, as one moves away from the RD threshold, any attempt to identify a causal effect of an election becomes less credible. States that Democratic candidates easily win serve as poor counterfactuals for areas that Republican candidates easily win. In Online Appendix F, we present difference-in-differences estimates from wider windows, using the methodology of Angrist and Rokkanen (2015).[34] As discussed in Online Appendix F, qualitative results hold across all outcomes when estimating the average treatment effect on wider bandwidths. Coefficient point estimates sometimes differ in magnitude, but confidence intervals overlap. We therefore do not find evidence to suspect that the average effect of state level political leadership is drastically different from the RD local average treatment effect.[35]

Next, we examine a potential alternative mechanism for our findings—political contributions. If, for example, electric utilities (and their executives) differentially contribute to Republican governors who win close elections, it is possible that those Republican administrations would be more lenient on electric utilities when constructing nonattainment SIPs. If this hypothetical occurs, then our gubernatorial results may not apply to other industries.

In Online Appendix G, we examine political contributions along several dimensions. First, we compare the partisan composition of political contributions from executives at electric utilities versus executives in other industries. We then focus on contributions specifically to gubernatorial campaigns. For gubernatorial contributions, we again test for descriptive differences in the partisan composition of contributions. Of most importance for our results of interest, we test for a discontinuous change in the contributions from electric utility directors/executives to winning gubernatorial candidates in close Republican wins versus close Democratic wins. We do not find any evidence to suggest that electric utility executives differentially contribute to political parties in general or to specific gubernatorial candidates. Electric utility directors/executives descriptively look nearly identical to their counterparts in other industries, both in partisan contribution behavior and in ideology. Likewise, we do not find any evidence that electric utility directors/executives discontinuously contribute more or less to Republican winners of close elections relative to Democratic winners of close elections. We therefore conclude that it is unlikely that Republican winners of close gubernatorial elections differentially favor or penalize electric utilities relative to other industries based on contributions to their campaigns.

7. Economic Implications

In this section, we examine the economic implications of our analysis. First, we assess the benefits and costs of different NOx abatement technologies, which are affected by different political regimes. We then assess the efficacy of new air pollution abatement capital expenditures and the adoption of the most effective NOx abatement technology at electric utilities at bringing areas back into attainment with the NAAQS and at improving overall ambient air quality. For our analysis, we restrict the sample to include only electric utilities located in nonattainment areas. Under this restriction, the regulator exogenously determines the technological adoption, rather than the firm manager endogenously determining the technology, as is the case in attainment areas.[36]

7.1. Benefits and Costs of Air Pollution Abatement Technology in Nonattainment Areas

To determine benefits, we first estimate the relationship between boiler level NOx emissions and the adoption of air pollution abatement technology at electric utility boilers. We gather boiler level NOx emission data from EPA's Air Markets Program Database and estimate the following equation:

(3)

$$f(NOx)_{ijst} = \beta Abate_{ijst-1} + \boldsymbol{X}'_{\boldsymbol{ijst}}\gamma + \psi_t + \pi_i + \varepsilon_{ijst}$$

where the notation is identical to that in equation (1), with the following differences. First, subscript i denotes the boiler. Second, NOx_{ijst} represents boiler level NOx emissions, measured in tons, which we arcsinh transform. Third, $Abate_{ijst-1}$ represents an indicator for the most effective NOx abatement technology (SCR or SNCR). Because we focus on boilers that install NOx abatement technology due to a nonattainment designation, the omitted category is other RACT, which almost exclusively is LNB or OFA. β therefore captures the differential between the most effective and other RACT adoption. We cluster standard errors at the county level.

Table 8 presents results for the estimation of equation (3). When a SIP requires an electric utility boiler in a nonattainment area to install SCR/SNCR technology, NOx emissions at that boiler decrease by nearly 39%

compared to boilers that must install other (likely LNB/OFA) technology. This differential is plausible and within the range of NOx removal efficiency that engineering estimates provide (25–60% for LNB/OFA, 75–90% for SCR/SNCR). As a result of these additional emission decreases, the requirement of the most effective NOx abatement technology produces greater benefits than the requirement of other NOx abatement technology. We use an updated version of the Air Pollution Emission Experiments and Policy integrated assessment model, AP3, to calculate an average monetized value of the additional benefits from SCR/SNCR technology (Muller and Mendelsohn, 2007, Muller and Mendelsohn, 2009, Muller et al., 2011). Like previous studies, we use a linear damage function because the emissions from a single source are distributed widely across space, so the marginal damages of emissions do not change with the level of emissions by a single source (Muller and Mendelsohn, 2007, Muller and Mendelsohn, 2009, Kerl et al., 2015; Holland et al. 2020). We focus on the mortality effects from increased annual PM2.5 concentrations since mortality accounts for 95% of total monetized health damages and most of the mortality effects are due to PM2.5 concentrations (Jaramillo and Muller, 2016, Sergi et al., 2020).[37] The AP3 model provides the marginal damages of a one-time, one-ton increase in NOx emissions and accounts for population exposure, time, space, and other emission dispersion characteristics. Here, we use our estimate from Table 8 to calculate the predicted decrease in NOx emissions at boilers in our sample that enter nonattainment and install SCR/SNCR because of nonattainment SIP requirements.[38] Then, at the boiler level, we multiply the predicted decrease in NOx emissions by the county specific AP3 marginal damage estimate. On average, we find that the additional reduction in damages, i.e., benefits, of SCR/SNCR installation over other RACT installation at these boilers is approximately $17.74 million per boiler per year (in 2015 dollars).[39]

Table 8. Effect of SCR/SNCR technology on NOx emissions.

Variable	(1)
SCR/SNCR technology	−0.490*** (0.123)
Boiler FE	X
Year FE	X
Additional controls	X
Mean of dep. var.	7.20
Observations	2,403

Notes: This table presents regression results from a separate specification of equation (3). SCR/SNCR technology represents the presence of the most effective abatement technology for NOx emissions at each boiler in each year. Additional controls include county level unemployment rate and population. Robust standard errors in parentheses are clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Next, we calculate the equivalent annual differential cost for the installation of the average SCR/SNCR system in our sample. This is the additional annualized capital cost plus the estimated additional annual operation and maintenance costs, as compared to the typical LNB/OFA system. First, for each sample boiler in a nonattainment area, we multiply the estimated per kw capital cost (Epa, 2019d, Epa, 2019e) by its reported capacity to estimate the one-time capital cost for SCR/SNCR installation.[40] Likewise, we estimate the average capital cost for LNB/OFA at $21.47/kw (2015$) (DOE 1999) and use this value to estimate the counterfactual capital cost for an LNB/OFA system. We then use standard methods to annualize the capital costs under varying assumptions of the SCR/SNCR lifespan and the discount rate (EPA 2010).[41] We next estimate the additional annual operation and maintenance costs for each boiler with SCR/SNCR technology relative to the operation and maintenance costs for LNB/OFA.[42] Finally, we add the differential annualized capital costs to the differential operation and maintenance costs to produce an estimate of the total differential annual cost of the average SCR/SNCR system in a nonattainment area.

Appendix Table A52 shows estimated annualized cost differentials for lifespans ranging from five to 30 years and discount rates ranging from 1% to 7%. Here, we focus on cost estimates assuming a 3% discount rate. Assuming a 30-year lifespan on the SCR/SNCR technology, the annualized cost differential above an LNB/OFA system is approximately $4.08 million. Compared to the estimated differential annual benefits of $17.74 million, we estimate a benefit-cost ratio of 4.35:1; each $1 spent on the SCR/SNCR technology is expected to deliver $4.35 in benefits. Assuming a 15-year lifespan, this benefit-cost ratio declines to 3.00. Finally, with a five-year lifespan, estimated benefits and costs are approximately equal (1.32:1 benefit-cost ratio). For lifespans shorter than five years, annual costs likely exceed annual benefits. State administrations should therefore carefully consider the time horizon of interest when determining RACT as part of nonattainment SIPs. For example, if a natural gas plant is expected to operate for many years into the future, forcing the most effective technology is likely to deliver positive net benefits. On the other hand, if there is a high probability that a coal fired plant would shut down or refuel within five years, then forcing the most effective technology would likely deliver negative net benefits.

Our estimated benefit-cost ratios are lower than those from many other air pollution abatement policies estimated in the literature, where benefits are often ten times the costs (e.g., Shapiro and Walker 2020; Shapiro 2022). If the policy goal is to reduce NOx emissions, we could likely do so at substantially lower cost to society through more flexible policies than by forcing SCR/SNCR installation at electric utilities. For example, Shapiro and Walker (2020) estimate the NOx Budget Program delivered marginal benefits that were 10 times higher than the mean offset price. Another leading alternative could be to target the transportation sector. Over 55% of NOx emissions stem from the transportation sector (EPA 2014) and the marginal cost of reducing NOx from power plants is twice the marginal cost of reducing NOx from cars (Fowlie et al. 2012).

7.2. Effectiveness of Air Pollution Abatement Technology at Improving Ambient Air Quality

We next examine if more air pollution abatement affects ambient air quality in nonattainment areas. This exercise is important, because the goals of each nonattainment SIP and of RACT requirements are to improve ambient air quality and to bring nonattainment areas back into attainment with the relevant NAAQS. First, we estimate the following specification:

(4)

$$Ambient_{jst} = \beta Abate_{jst-1} + \boldsymbol{X}'_{\boldsymbol{jst}}\gamma + \psi_t + \pi_j + \varepsilon_{jst}$$

where the notation is like that of equation (3). Because EPA designates nonattainment status at the county level, the analysis is now at the county-year level and includes year and county fixed effects, ψ_t and π_j, respectively. Here, the outcome, $Ambient_{jst}$, takes one of two forms for county j in state s of year t: 1) a dummy indicating the exit from nonattainment (the entire post-exit regime) or 2) the ambient concentration of each criteria air pollutant.[43] The former indicates that a nonattainment area improves its ambient air quality to a level below the appropriate standard and EPA has re-designated the area as maintenance.[44] And the latter, which we gather from EPA's Air Quality System (AQS), is the daily maximum yearly average of each criteria air pollutant's ambient concentration (Auffhammer and Kellogg 2011).[45] Our regressor of interest, $Abate_{jst-1}$, is one of two county level measures of air pollution abatement capital, lagged one year, which allows the abatement technology time to decrease emissions and improve ambient air quality.[46] First, we are interested in the effect of past air pollution abatement capital expenditures on ambient air quality. We use the same real air pollution capital expenditure data from previous sections and create a cumulative capital expenditure variable. For each year and facility, this measure sums all past real capital expenditures beginning in 1985 (the first year available from EIA). We sum across all facilities in each county-year and arcsinh transform the county level sum to produce our regressor of interest. Second, we focus on NOx abatement technology. For this specification, $Abate_{jst-1}$ represents a county level count of the number of electric utility boilers with the most effective NOx abatement technology installed and the outcome is the exit from nonattainment for those criteria air pollutants affected by NOx emissions or their ambient air concentrations. We include state-by-year fixed effects in all specifications in this subsection to control for unobserved state level trends. Finally, we cluster standard errors at the county level and use the count of facilities (for cumulative abatement expenditures) and boilers (for NOx abatement technology) as analytic weights in all regressions.

Table 9 presents results for the estimations of equation (4) where the exit from nonattainment is the outcome. At the county level, higher levels of new air pollution abatement capital expenditures at electric utilities do not significantly affect the likelihood that a county exits and stays out of nonattainment for any criteria air pollutant.[47] For the most effective NOx abatement technology at these boilers, we see similar insignificant results.

Table 9. Effect of air pollution abatement on exiting nonattainment.

Variable	(1)	(2)
Cumulative air pollution abatement capital expenditures	0.00535	
	(0.0151)	
SCR/SNCR technology		−0.00326
		(0.0106)
County FE	X	X
State-by-year FE	X	X
Additional controls	X	X
Mean of dep. var.	0.121	0.2
Observations	1,238	1,306

Notes: Each column presents regression results from a separate specification of equation (4). SCR/SNCR technology represents the presence of the most effective abatement technology for NOx emissions at each boiler in each year. Additional controls include county level unemployment rate and population. Robust standard errors in parentheses are clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Next, Table 10 presents results for the estimations of equation (4) where the ambient concentration of each criteria air pollutant is the outcome. There are no significant effects of air pollution abatement technology, either cumulative spending or the installation of the most effective NOx abatement technology, on the county level ambient concentrations of criteria air pollutants. For all specifications in Table 10, the regression coefficients are statistically insignificant and close to zero. In online appendix table A53, we do find that cumulative air pollution abatement capital spending significantly affects the outcome of the 99th percentile of the 1-hour average of SO2.[48] Overall, additional air pollution abatement technology at electric utilities does not significantly improve ambient air quality in nonattainment areas, with the exception of peak SO2 concentrations.[49]

Table 10. Effect of air pollution abatement on ambient air quality.

Empty Cell	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Variable	**CO**	**Lead**	**SO_2**	**Ozone**	**Ozone**	**NO_2**	**NO_2**	**PM(AQS)**	**PM(AOD)**	**PM(AQS)**	**PM(AOD)**
Cumulative air pollution abatement capital expenditures	0.216 (0.189)	0.00130 (0.00578)	−0.219 (0.265)	−0.000331 (0.000351)		−0.214 (0.307)		−0.0232 (0.146)	0.000362 (0.0367)		
SCR/SNCR technology					9.83e-06 (0.00018)		0.0586 (0.193)			−0.00210 (0.0787)	−0.0246 (0.0181)
County FE	X	X	X	X	X	X	X	X	X	X	X
State-by-Year FE	X	X	X	X	X	X	X	X	X	X	X
Additional controls	X	X	X	X	X	X	X	X	X	X	X
Mean of dep. var.	3.66	0.0545	3.07	0.0751	0.0754	18.53	18.65	10.83	9.19	10.83	9.24
Observations	453	288	781	1,018	962	505	464	1,001	1,512	917	1,372

Notes: Each column presents regression results from a separate specification of equation (4). SCR/SNCR technology represents the presence of the most effective abatement technology for NOx emissions at each boiler in each year. Additional controls include county level unemployment rate and population. Robust standard errors in parentheses are clustered at the county level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Our results support the assumptions of previous studies. To achieve attainment at the individual county level, nonattainment SIPs contain many components that affect different industries and emission sources, because ambient air quality is a common pool resource. For example, SIPs outline strategies to reach attainment using traditional air quality control measures, such as the federal mandate of RACT adoption at stationary emission sources, as well as other forms of air quality management, such as outdoor wood burning bans. As a result, the adoption of RACT at stationary sources is only a small component of each SIP. Our results are also consistent with the argument that nonattainment status is exogenous to the average stationary source's emissions, because each source (even large sources) contributes relatively little to the overall ambient air quality of a large geographic area (Auffhammer et al., 2011, Muller and Mendelsohn, 2009, Gibson, 2019, Raff and Walter, 2020).

Collectively, our results suggest that the requirement of SCR/SNCR as RACT at electric utility boilers, which is more likely under Democratic political leaders that won close elections, leads to localized benefits from reduced PM2.5 associated mortality that can outweigh the additional NOx abatement costs if the technology will be operational for at least five years.[50] However, these more stringent abatement technology requirements do not lead to significantly improved ambient air quality or to the re-designation of areas out of nonattainment.

8. Conclusion

In the US, the administration of federal environmental policy is often delegated to individual states. However, little is known about how political considerations at the state level affect the implementation and enforcement of environmental legislation. We address this gap in the literature by examining the heterogeneity in the adoption of federally mandated air pollution abatement technology at electric utilities within the context of the CAA. To develop our contributions, we first estimate the effects of gubernatorial political affiliation on new air pollution abatement capital expenditures and the installation of emission abatement technology at electric utilities. We implement a close election RD design where we test for discontinuous changes in these outcomes in close Republican versus close Democratic gubernatorial election victories, while allowing for a differential effect in attainment versus nonattainment areas. We focus on the adoption of the most effective technology for NOx abatement because EPA considers multiple technologies as RACT for NOx emissions, which allows for discretion on the part of local environmental protection agencies. We find that the probability of the installation of the most effective NOx abatement technology decreases by nine percentage points at electric utilities in nonattainment areas in states won by Republican governors in close elections, relative to the counterfactual of a close Democratic gubernatorial victory. We also find a 90% differential between Republic controlled states and Democratic controlled states on new air pollution abatement capital expenditures for nonattainment areas. Importantly, we find no significant effects of gubernatorial partisan affiliation on the installation of the most effective NOx abatement technology nor on new air pollution abatement capital expenditures in attainment areas because cost minimizing firm managers, rather than the state environmental protection agency, make abatement choices.

We then estimate the effects of close majority control of the lower state house of representatives on the same air pollution abatement outcomes, using a multidimensional RD design. A close Republican majority decreases new air pollution abatement capital expenditures and decreases the probability of installing the most effective NOx abatement technology in nonattainment areas. However, the effects are weaker than their gubernatorial counterparts; the point estimates are much smaller and the treatment effects are less precisely estimated than the gubernatorial results. These results are consistent with the reality that governors have the most direct control over the SIP process while the state legislative branch plays a more indirect role.

Our results are economically important for several reasons. First, we show that the preferences of political leaders generate heterogeneous air pollution abatement capital outcomes in the electricity generation sector, at least for nonattainment areas. Second, we establish that delegating the administration of the CAA to states only matters in contexts when the scope for political influence is sufficiently wide—namely for pollutants with multiple technologies that EPA considers RACT and for nonattainment areas. For pollutants with only one class of RACT technology, such as SO2, the preferences of political leaders are unlikely to drive differences in the adoption of air pollution abatement technology.

Lastly, while we show that the partisan affiliation of the state administration matters for the installation of air pollution abatement technology at electric utilities in nonattainment areas, we find that, for NOx emissions, the differential annualized benefits from installing the most effective and more expensive air pollution abatement technology typically outweigh the differential annualized costs, but benefit-cost ratios are often lower than many other air pollution abatement policies. However, we find little evidence that this technology is successful in substantially improving the ambient air quality in nonattainment areas. Thus, state administrations should carefully consider the overall goals of the SIP process and their desired time horizon when determining RACT as part of nonattainment SIPs. Finally, our collective results imply that the SIP proposal and review process should move away from the focus on compliance with rigid and procedural steps and rather take a more holistic approach that emphasizes progress toward meeting the NAAQS.

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Notes

[1] Relatedly, there is evidence that more conservative politicians are less environmentally friendly in their voting behavior. Cragg et al. (2013) find that members of the US House of Representatives and the US Senate with more conservative ideologies have a lower probability of voting to support climate change mitigation and pro-environmental legislation. Cragg et al. (2013) also note that, in 2009, the average League of Conservation Voters (LCV) score (a popular measure of how pro-environment a member of Congress is in their voting positions) was 93% for the Democratic leadership and 0% for the Republican leadership. Shipan and Lowry (2001) show that LCV scores were much closer together in the 1970s but diverged substantially to where average LCV scores among US House and Senate Democrats were 35 points higher than their Republican counterparts. Other references on this partisan divergence in support for environmental protection include Dunlap et al. (2001) and Dunlap and McCright (2008). Economic and environmental outcomes are interrelated, so we also note that several studies identify

the effects of political leaders on economic activity and the labor market by leveraging close state elections as natural experiments (Lee 2008; Leigh 2008; Beland 2015).

[2] We examine all electricity generating facilities in the US, including those in both regulated and deregulated markets. Throughout this paper, we collectively refer to these facilities using the overarching term "electric utilities".

[3] Governors have considerable power over the executive branch of state governments, including environmental protection agencies, in the US (Beland 2015). These agencies are directly responsible for the implementation and enforcement of the CAA. While the executive branch has the most direct control over implementation and enforcement of the CAA, there are reasons to expect that the legislative branch also indirectly influences its implementation and enforcement (Bergquist 2019).

[4] The National Research Council (2004) argues that the CAA implementation process focuses on compliance with bureaucratic steps rather than realized progress toward meeting federal standards. State actions with provisions that meet the abatement technology requirements may therefore not result in substantial pollution reductions in practice.

[5] EPA provides a menu of control measures for NAAQS implementation.

[6] SIP recommendations from state regulators, legislatures, local air management districts (LAMD), and public comments are only suggestions and are not legally enforceable. LAMD are often responsible for monitoring, compliance, and permitting. Some LAMD may help construct relevant SIPs, but state oversight and approval occur at the gubernatorial level. Other interested parties include agencies such as Public Utility Commissions (PUCs), which are often appointed by governors and approved by state legislatures. PUC commissioners are restricted from engaging in *ex parte* communications regarding SIPs to encourage impartiality.

[7] When EPA implements new NAAQS, states must also file infrastructure SIPs, which are less detailed than nonattainment SIPs and present the state infrastructure in place to attain the standards. For both nonattainment and infrastructure plans, the SIP development and approval process is under the authority of the governor or their appointee and can change with each administration (see 40 CFR Part 52 for state specific plans).

[8] Submitted plans can be approved, conditionally approved, or disapproved. Generally, plans are not approved due to stringency or timeliness. EPA can disapprove a SIP for being too stringent.

[9] Currently, EPA has ten FIPs, one of which it constructed for tribal lands (EPA 2018). FIPs are not permanent and are promulgated if a SIP is disapproved for being incomplete or failing to meet CAA requirements.

[10] For example, EPA approved the Missoula, MT nonattainment SIP for carbon monoxide in 1986. The SIP was subsequently updated in 1994 (twice), 1999, 2001 and 2005. Montana elected new governors who took office in 1993, 2001, and 2005. EPA can approve portions of a SIP while requiring changes to other inadequate elements.

[11] Nonattainment designation for NOx requires submission within 18 months.

[12] As discussed by Bergquist (2019) in an examination of partisan control of state government on environmental enforcement actions, "legislatures can influence agency activities by adjusting resources through the budget, using existing oversight mechanisms, or changing the rules and procedures that serve as oversight mechanisms for the legislature." For more background on general mechanisms of political influence in state government, see the discussion in Bergquist (2019).

[13] Srivastava et al. (2005) provide a more extensive list of available NOx abatement technology and include removal rates.

[14] The average lifetime of each abatement technology type is important for our identification, which we discuss further in a subsequent section. For NOx abatement, typical RACT technologies have substantial lifetimes (SCAQMD 2018; EPA 2019d).

[15] Typically, LNB/OFA take 24–32 weeks to start up, SNCR requires 51 weeks for completion (this involves start-up, optimization, and compliance testing), and larger SCRs require 52 weeks for completion (with similar steps as an SNCR system). Smaller SCR installations average less than nine months for completion (Institute of Clean Air Companies 2006).

[16] Several studies that employ the close gubernatorial RD design use Leip's atlas (e.g., Beland 2015; Meyer 2019). The atlas contains the outcome and vote margin for all presidential, gubernatorial, and senatorial elections in the US dating back to 1992.

[17] In multimember districts, each party may run as many candidates as there are seats. Therefore, the partisan margin of victory is defined differently than in single member districts.

[18] Although we gather new air pollution abatement capital expenditures data from the EIA 767 and EIA 923, we use as our sample period the years that the EIA 860 is available to remain consistent with the sample that includes the type of air pollution abatement technology installed at each boiler, described below.

[19] Our sample does not contain information for 2006 because EIA did not collect any data during that year.

[20] A balanced panel is necessary for our analysis for two reasons. First, there may be some underlying reasons for facilities to exit the panel, e.g., shutdown, switch from coal to natural gas, that also affect the air pollution abatement technology uptake at the facility; this attenuation would bias our estimates. Second, the facilities that come online after 2001 are subject to the requirements of New Source Review (NSR) [facilities that switch fuel are also subject to NSR requirements]. The NSR program requires that new facilities install very specific types of air pollution abatement technologies. Thus, there is no mechanism, i.e., discretion, through which the state political leadership affects the adoption of air pollution abatement technology at NSR facilities. Inclusion of these facilities in our analysis sample would also bias our estimates. NSR also requires major stationary emission sources (which include nearly all coal and natural gas electric utilities) that make "significant" modifications to their operations, i.e., changes that result in emission increases of more than 100 tons, to install the best available control technology or technology with the lowest achievable emission rate, depending on their location. Like new facilities, this program eliminates the mechanism through which the political leadership of each state can influence air pollution abatement technology adoption at these facilities. We therefore eliminate all facilities that are subject to the requirements of NSR at some point during our sample period. Next, because each facility can have multiple boilers, we include in our balanced panel only those facilities with all boilers in operation for the full 17 years. We do not include in our sample facilities that were in operation for the period 2001–2017 but had individual boilers come online, shut down, or switch fuel for the same reasons. It is possible that electric utilities refuel or retire because of NAAQS requirements. We assess this possibility in subsection 4.3.1. and in Online Appendix Table A43.

[21] New Hampshire and Vermont have two-year gubernatorial terms, so we only apply election results for the two years following the election for electric utilities in these states.

[22] The optimal bandwidth, as described in subsection 4.1., includes 92 close gubernatorial elections. Online Appendix Table A5 summarizes the number of Democratic and Republican gubernatorial victories within varying bandwidths and provides more information on within-state variation in gubernatorial election outcomes.

[23] Online Appendix H investigates specifications using the nonattainment status of each individual criteria pollutant, rather than pooling the measures.

[24] Alabama and Mississippi have four-year terms in the lower house, so we match election results to the following four years in those two states.

[25] Online Appendix Tables A1-A4 provide additional statistical summaries for all analysis samples.

[26] There is some disagreement in the literature regarding the usage of the term "local linear". Some authors refer to any RD design with linear controls estimated on a local sample as "local linear", whereas others reserve the term "local linear" for situations where the researcher views the RD as a nonparametric

estimation problem. The latter view allows for an arbitrary relationship between the forcing variable and the outcome near the RD threshold. As noted by Lee and Lemieux (2010), "the main difference, then, between a parametric and nonparametric approach is not in the actual estimation but rather in the discussion of the asymptotic behavior of the estimator as sample sizes tend to infinity." We use a conventional RD specification that inherently assumes that the functional form of the regression relationship is known (linear) in the estimation window. When viewing RD as a nonparametric problem, one approximates an unknown functional form near the threshold so there is a bias that arises in the estimator. In practice, this approximation means that bias-correction of the RD treatment effect should be used when viewing RD as a nonparametric problem. In contrast, our conventional parametric RD approach ignores any bias. The practical reason for our choice is that our parametric approach facilitates the straightforward hypothesis testing for differential effects based on characteristics of the electric utility (CAA nonattainment status). It also facilitates the inclusion of state fixed effects, which can reduce the residual variance. As explained in this section, we do use an optimal bandwidth procedure that minimizes the MSE of the local linear estimator.

[27] We provide power calculations for our RD design in Online Appendix C.4.

[28] We use the rdrobust package (Calonico et al. 2014b; 2017) within Stata to calculate optimal bandwidths. For each outcome, we use the uniform kernel and the "cluster" option to find the MSE-optimal bandwidth, as described in Calonico et al., 2017, Calonico et al., 2019. We condition on year fixed effects and indicators for coal fuel usage and nonattainment status for all bandwidth calculations. For the air pollution abatement technology type outcomes, we also condition on the one-year lagged value of the dependent variable. For new air pollution abatement capital expenditures, we also condition on the number of boilers at each facility. We cluster standard errors at the state level. The online appendix shows results from sensitivity analyses where we 1) use alternative bandwidths, 2) use lagged nonattainment status, 3) limit the estimation samples to states where the governor's party has been in power for one or more years, 4) aggregate to the county level and use alternative weights, 5) exclude the smallest generators from the sample, and 6) leave out one state at a time from the sample. Lagged nonattainment status is motivated by the observation that there can be a 12–18 month lag between area designation as nonattainment and the execution of the SIP. Similarly, there could be a time lag from when the governor's party takes control to when this affects the details of the SIP, motivating the analyses where we require the governor's party to be in power for one or two years. Our baseline analysis is at the facility or boiler level because we are interested in estimating the average causal effect across US electric utilities. The results of these robustness exercises are consistent with the results discussed in subsection 4.3.

[29] One potential concern could be that other state policies aside from implementation of the CAA drive differential changes in air pollution abatement technologies and expenditures. However, as shown in Online Appendix Tables A8-A11, a close Republican gubernatorial win does not discontinuously change the probability of a Republican majority in the lower state house nor in the state senate. These results hold for the overall effect and for the differential effect in nonattainment areas. Therefore, it is unlikely that any state level policy requiring legislative action or approval or appointments requiring Senate confirmation (such as PUC appointments) would drive our results.

[30] This result is unsurprising. The literature identifies the primary reason for the retirement of electric utilities, especially coal plants, as economical, rather than regulation induced (e.g., Fell and Kaffine 2018; Linn and McCormack 2019).

[31] Because we examine the largest emitters of harmful air pollutants (electric utilities), many of the boilers in our sample are regulated under other air pollution control policies, such as the NOx Budget Program (NBP) or the Acid Rain Program (ARP). It is therefore possible that the boilers in our sample adopt air pollution abatement technology to comply with the requirements of these other regulatory programs, rather than

the NAAQS. We address this possibility and its implications for our results in Online Appendix E. Also in Online Appendix E, we examine the differential effect of gubernatorial political affiliation under these tradable permit policies on the adoption of air pollution abatement technology. Here, the NBP and ARP (and other policies) serve as placebos because we do not expect differential effects for policies where state political leaders have no regulatory discretion in requiring technological abatement (instead, electric utility managers can choose on their own how to comply with these policies). Online Appendix Tables A36 and A37 present results for these estimations and provide evidence for our expectation that the differential effect that we identify under the NAAQS is unique to this setting.

[32] The burning of natural gas produces negligible SO2 emissions, but the burning of coal produces substantial SO2 emissions. Additionally, some coal fired utilities must use coal with lower sulfur content as part of nonattainment SIPs. However, the only technological abatement method that EPA considers RACT is FGD.

[33] In the online appendix, we show sensitivity analyses where we 1) use alternative bandwidths, 2) use lagged nonattainment status, 3) limit the analysis sample to states where the majority's party has been in power for at least one year, and 4) aggregate to the county level and use alternative weights. These results are like those discussed in subsection 5.3.

[34] Hainmueller et al. (2015) implement this approach in the context of close elections.

[35] As discussed by de la Cuesta and Imai (2016), any approach to infer causality away from the RD threshold sacrifices internal validity. "Generalization of RD estimates necessitates extrapolation, which in turn rests on an untestable assumption similar to the one made in standard observational studies" (de la Cuesta and Imai, 2016, pg. 393).

[36] Online Appendix C.5. assesses the percentage of emissions from the electric utility sector from boilers in our samples.

[37] NOx is a precursor pollutant to PM2.5 so the AP3 model provides marginal damage estimates for increases in NOx emissions. We use the county level marginal damage estimates for medium stacks in these calculations. As is standard in the literature, we use the EPA recommended VSL of $7.4 million (2006 dollars), which is $8.7 million in 2015 dollars. We also use the standard AP3 concentration–response functions of Krewski et al. (2009) for individuals over 30 years old and Woodruff et al. (2006) for infants under one year old. We use the 2014 AP3 input files and calibration coefficients. We obtain AP3 code and data from https://public.tepper.cmu.edu/nmuller/APModel.aspx.

[38] The average boiler level NOx reduction implied by the estimate in Table 8 is 1,200 tons (median of 710 tons).

[39] Reductions in damages range from $105,000 to approximately $100 million across all boilers. The median reduction in damages is approximately $12 million (all in 2015$).

[40] The average capital cost for SCR/SNCR technology in our sample is $125.49/kw (2015$).

[41] The relevant formula for calculating the annualized cost accrued at the end of each of n periods is AC=CC∗r∗(1+r)n(1+r)n-1, where CC is the one-time capital cost, r is the discount rate, and n is the lifespan of the technology (EPA 2010).

[42] We multiply industry and EPA estimates (per MWh) by boiler capacity and average annual operational hours (by abatement technology and fuel type), as reported on EIA form 928.

[43] We use the AQS parameter that most closely matches the relevant NAAQS during the sample period (average lead TSP, maximum 1-hour carbon monoxide, annual 4th highest daily maximum ozone, annual average NO2, annual average PM2.5). For some criteria pollutants (CO, NO2, SO2, PM2.5) there are multiple relevant parameters. In these cases, we show results for one of the parameters in Table 10 and tabulate results for the other parameters in Online Appendix Table A53.

[44] This re-designation does not occur automatically. States must petition to have the area re-designated once the air quality standard has been met. However, these requests are made swiftly, because of the

negative outcomes associated with continued nonattainment, e.g., forfeiture of federal highway funds, industry avoidance.

[45] Not every county has air quality monitors in the EPA AQS so there could be a concern about selection effects. We therefore replicate the analysis using PM2.5 from satellite imagery, which is available for every county. We use the van Donkelaar et al. (2019) and Hammer et al. (2020) V4.NA.03 ground level PM2.5 total concentrations. Hammer et al. (2020) and von Donkelaar et al. (2019) detail the methodology they use to estimate PM2.5 from Aerosol Optical Depth (AOD) satellite retrievals. We access the V4.NA.O3 data at https://sites.wustl.edu/acag/datasets/surface-pm2-5/. This dataset is gridded at the 0.01° × 0.01° resolution. We use GIS software to calculate county-year level average concentrations. Across all nonattainment county-year observations in the sample, the pairwise correlation of AQS PM2.5 and satellite estimated PM2.5 is 0.82.

[46] Some counties contain more than one electric utility. We therefore sum the outcomes to the county level.

[47] Because we do not know the type of air pollution abatement technology installed, our independent and dependent variables may be mismatched. For example, it is possible that the expenditure amount reported to EIA is for lead abatement technology even if the electric utility is in a nonattainment area for SO2. The lead abatement equipment has little impact at reducing emissions of SO2, which is necessary to exit SO2 nonattainment. And thus, our estimates are likely biased toward zero. As a result, we also estimate separate specifications where the outcome is the exit from nonattainment of individual criteria air pollutants (the five designations that appear during our sample period). For these estimations, we find similar results to those presented using an aggregated outcome measure.

[48] The effect on the 24-hr max value of SO2 is also economically meaningful. These findings on peak levels of SO2 are sensible because the electricity sector accounts for approximately 75% of US SO2 emissions (EPA 2014). In contrast, the electricity sector generates a much smaller percentage of NOx emissions (where transportation is a much more important source).

[49] For these analyses, it is possible that electric utilities in areas with worse air quality spend more on air pollution abatement, which would bias our estimates toward zero. We therefore acknowledge that here, we do not necessarily identify a causal effect.

[50] While beyond the scope of this paper, we note that a comprehensive benefit-cost analysis of political differences in air pollution abatement technology and air pollution abatement capital expenditures would need to consider outcomes in other affected industries.