

Regulatory Spillover and Climate Co-benefits: Evidence from the New Source Review Lawsuits*

H. Ron Chan[†]
University of Manchester

Yichen Christy Zhou[‡]
Clemson University

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Abstract

Carbon policies have been shown to generate benefits in reducing local pollutants, but the reverse is not well studied. This paper examines the impact of New Source Review (NSR) lawsuits for violating SO₂ and NO_x standards on CO₂ emissions. Using a discrete-time duration model, we estimate and predict the likelihood of being named in a lawsuit. We find that a one percent increase in the lawsuit probability (0.2 standard deviations) reduces CO₂ emissions by 0.5 percent, comparable to a \$10/ton carbon tax. Further decomposition analysis suggests that the shutdown of coal-fired-only power plants produces most of the carbon co-benefits.

Keywords: New Source Review, environmental lawsuits, pollution emissions, climate policies, fuel switch

JEL codes: L94, K32, Q58, H23

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[†]Department of Economics, University of Manchester, Arthur Lewis Building-3.078, Manchester, M13 9PL, United Kingdom. Contact: ron.chan@manchester.ac.uk

[‡]John E. Walker Department of Economics, Clemson University, SIRRINE HALL #223, Clemson, SC 29634, USA. Contact: yichen2@clemson.edu

1 Introduction

Economic policies and regulations may incentivize firms to re-allocate resources and re-optimize their production, creating the potential for unintended spillovers or substitution for unregulated inputs. In particular, regulating sulfur dioxide (SO₂) emissions in the power sector could increase carbon dioxide (CO₂) emissions if the plant installs more energy-intensive emission control equipment, or decrease CO₂ emissions as a result of switching to a cleaner fuel with a lower carbon content. Quantifying climate co-benefits from non-climate policies has important implications for improving cost-benefit analyses of future policies of the same kind. This paper is the first to document evidence of climate co-benefits from regulating local pollutants in the power sector.

The interaction between local and global emissions, especially the impact of climate policies on SO₂, NO_x, and their health effects, has been studied extensively.¹ Examining the climate effect of policies on local pollutants offers important insights into the effectiveness of overlapping policies. Depending on how policies affect the operating margins across different plants, policy interactions may strengthen or weaken the effect of individual policies. However, the spillover of local pollutant policies on greenhouse emissions is rarely studied, and the current literature has found a null effect. [Holland \(2012\)](#) found that meeting the Clean Air Act (CAA) standards has no effect on CO₂ emissions from California power plants since California power plants are mostly gas-fired plants, so the channel of fuel switch is minimal. [Brunel and Johnson \(2017\)](#) found that CAA attainment status has no effect on CO₂ in the manufacturing sector because the manufacturing sector does not have effective margins to reduce carbon intensity.

We investigate the effects of the New Source Review (NSR) program and how NSR lawsuits probabilities affect SO₂, NO_x, and CO₂ emissions from US power plants and their operations from 1995 to 2015. The power sector is a major source of pollution emissions. It accounted for 74 and 34 percent of total SO₂ (7.7 million tons) and CO₂ (6.8 trillion tons) emissions, respectively, in the United States in 2010 ([EPA, 2012a, 2016](#)). We focus on coal- and gas-fired power plants, the total of which account for 98, 99, and 99 percent of SO₂, NO_x, and CO₂ emissions from the power sector respectively. The NSR was included as part of the 1977 Amendments to the Clean Air Act with the goal of reducing SO₂ and NO_x emissions from the power sector. It regulates not only the construction of new power-generating facilities but also existing facilities to adopt emission control technologies.

One of the primary empirical questions is whether or not regulating SO₂ and NO_x would reduce or increase CO₂ emissions in the power sector. In our sample, coal-fired plants without

¹This list includes but is not limited to [Burtraw et al. \(2003\)](#), [Groosman et al. \(2011\)](#), [Muller \(2012\)](#), and [Parry et al. \(2015\)](#). Other works have studied cross-media substitution from air pollution regulation to water pollution ([Gibson, 2018](#)) and from renewable energy subsidies to local pollutants ([Novan, 2017](#)). A theoretical work by [Böhringer and Rosendahl \(2010\)](#) shows that renewable quotas together with carbon trading can promote investment in dirty technology compared to carbon trading alone.

gas capacity account for 61, 64, and 63 percent of SO₂, NO_x, and CO₂ emissions from the power sector respectively. The NSR may induce a fuel switch from coal to natural gas since gas produces less SO₂ and NO_x.² Since gas is also less carbon-intensive than coal, this could lead to a reduction in CO₂ emissions, holding other factors such as fuel prices and other policies constant.³ Also, NSR may induce plants to reallocate production from older units to newer units via intensive margins, since the latter is likely to be equipped with not just better SO₂ and NO_x technologies, but also better generating efficiency (as measured by operating heat rate), which tends to reduce CO₂.

In contrast with the above possibilities, emission control technologies are generally energy intensive. Therefore, installing and increasing the usage of SO₂ and NO_x control technologies may cause power plants to consume more electricity and generate more CO₂ emissions. Also, NSR may discourage power plants from building new (and usually more efficient, less CO₂ intensive) boilers since doing so may trigger a long and undesirable review process to acquire new source permits (Evans et al., 2008; Heutel, 2011; Bushnell and Wolfram, 2012) and have little effect on speeding up the closure of existing dirty plants (List et al., 2004). This type of distortion may limit the potential for CO₂ reduction and could even increase CO₂ emissions.

Our assessment hinges on forming a correct treatment group, i.e., to know when the NSR became a salient regulation of power plants and the types of plants that are likely to face a credible threat. Although the NSR was instituted in 1977, reform did not take place until 1999 when the US Department of Justice (DOJ), representing the EPA, brought lawsuits to the Supreme Court against 83 power-generating units at 24 power plants.⁴ The basis of the lawsuits depends on whether a plant has undergone a change that constitutes unlawful action. To motivate our empirical strategy, we explain the controversy around what constitutes unlawful action, how the stringency of the policy changes over time, and how it varies across plants in different regions in Section 2.1. This ambiguity implies that the EPA has a certain control and freedom on which plant to target, and that we only observe plants involved in the lawsuits but not plants vulnerable to the threat. This challenge leads us to estimate the probability of being named in an NSR lawsuit, which quantifies the risk of “getting caught” for each power plant, hereafter the *NSR lawsuit probability*.

We adopt a discrete-time duration model to estimate the plant-specific NSR lawsuit probability, in which we build upon the cross-sectional probit model of NSR lawsuits in Keohane et al. (2009). This allows us to predict the lawsuit probability and form a continuous treatment

²In 2010 the average SO₂ emission rate was 0.84 lbs/mmBtu for coal-fired generating units and 0.02 lbs/mmBtu for natural-gas-fired units. The average emission rate of NO_x was 0.27 lb/mmBtu for coal-fired generators and 0.13 lb/mmBtu for gas-fired generators according to EIA <https://www.eia.gov/todayinenergy/detail.php?id=37752>.

³The CO₂ emission rate in gas-fired units (117 lb/mmBtu in 2016) is half that of coal-fired units (210 lb/mmBtu) according to EIA https://www.eia.gov/environment/emissions/co2_vol_mass.php

⁴This enforcement action has continued and brought settlements against a total of 275 units from 85 plants between 1999 and 2015. The EPA has won all NSR lawsuits, and power plants can make an effort to obtain the best favorable settlement.

variable that is plausibly exogenous for our next set of analyses on current emissions and plant operations. This dynamic approach is important because we need to allow both NSR lawsuit probabilities to vary across plants and over time, and the probabilities to correlate flexibly over time within a plant as well. To predict lawsuit probabilities, we use historical emissions and energy production as in [Keohane et al. \(2009\)](#), then include other cross-sectional variations such as the judicial district where a plant is located. Consistently to our approach, we found the predicted likelihood of lawsuit risk to not only increase over time but also at a different rate across plants.

Using predicted NSR lawsuit probabilities from the duration model, we proceed to estimate how NSR lawsuit probabilities affect both regulated and unregulated emissions using annual data from US power plants between 1995 and 2015. To separate the scale effect on emissions, we control and instrument for gross electricity generation. To isolate confounding factors, we include extensive plant and year fixed effects. To remove the effects of economic conditions and overlapping policies, we further control natural gas price, and whether a state in a year has been regulated under the NO_x National Budget Trading Program (NBP), the Clean Air Interstate Rule (CAIR), and the Regional Greenhouse Gas Initiative (RGGI).

We found that NSR lawsuit probability has a significant and sizable effect on SO₂, NO_x, and CO₂ emissions. Our results imply that a one percent increase in the NSR lawsuit probability (about a 0.2 standard deviation) decreases SO₂ by 0.6 percent, NO_x by 1.2 percent, and CO₂ by 0.5 percent. This change is equivalent to yearly reductions in SO₂ emissions by 43.7 thousand metric tons, NO_x by 29.1 thousand metric tons, and CO₂ by almost 10 million metric tons in 2007 – all of which are sizable compared with national emission inventories ([EPA, 2016](#)). Evaluating emissions at a 42 dollar-per-metric-ton social cost of CO₂ (SCC), the climate co-benefits would be 415 million US dollars (in 2007 real dollar terms).⁵ The magnitude of CO₂ co-benefits implies that it is important to account for climate spillover into the total economic benefit of regulating pollution emissions from the power sector. Our results also suggest that NSR has been effective in terms of reducing carbon emissions. Specifically, the magnitude of co-benefits from a one percent lawsuit risk is equivalent to the benefit of a \$10/ton carbon tax, using results from [Linn et al. \(2014\)](#).

It is necessary to understand how energy policies can achieve carbon reduction from the power sector efficiently, and whether our findings of climate co-benefits can be generalized to other environmental policies for the power sector. To answer these questions, we decompose the counterfactual CO₂ co-benefits by plants with and without gas-fired generators. We find that each group of both contributes roughly half of the estimated co-benefits. Moreover, if we focus on the intensive and the extensive channels in reducing carbon emissions, we find these channels work differently for the two groups of plants. Within co-benefits from coal-fired-only

⁵We assume 3 percent discount rate for the SCC. More assumptions can be found in the EPA 2017 archive https://19january2017snapshot.epa.gov/climatechange/social-cost-carbon_.html

plants, three quarters come from the extensive margin. Specifically, 14.1 percent of co-benefits is from the operating coal-fired-only plants and 44.5 percent is from shutting them down. In contrast, the co-benefits from plants with gas-fired generating capacity is mostly due to the intensive margin. Specifically, we found that operating plants with gas-fired units contributes 29.7 percent of co-benefits, while the extensive margin contributes only 11.7 percent of co-benefits.

To investigate the factors that drive the intensive channels, we further examine how NSR lawsuits induce plants to improve both abatement technologies and thermal efficiency, holding the scale of production and other factors constant. Specifically, higher NSR probabilities have led to significantly lower SO_x, NO_x, and CO₂ emission rate (lb/mmBtu), hereafter the *technology channel*. However, a higher NSR lawsuit probability only affects a unit's thermal efficiency (heat rate, mmBtu/mWh) by a small magnitude and the estimate is insignificant, hereafter the *efficiency channel*. This result implies that most of the reduction in SO_x, NO_x, and CO₂ emissions from operating plants are the results of improving the abatement technology, rather than power generation efficiency.

This paper contributes to the following strands of literature. First, this study contributes to the literature on regulatory spillover and overlapping policies as discussed initially. In addition, studying the sources of spillover offers important insights for more effective carbon policy design: we quantify various channels that contribute effectively to CO₂ reduction, especially the extensive margin of the fuel switch.⁶ Our results provide a reassuring implication that at the current equilibrium, there would not be a leakage from regulating SO₂ and NO_x that leads to an increase in unregulated CO₂ and other greenhouse gases from strengthening the regulation of SO₂ and NO_x production in the power sector.

Second, this paper also contributes to the body of knowledge surrounding on how the NSR created vintage-differentiated regulations (VDR) distortion and how this distortion affects SO₂ and NO_x emissions. Past studies have found evidence of the delayed investment channel in new units, and the induced reduction channel in investments in new technologies in existing units, which is a typical type of distortion from VDR (List et al., 2004; Heutel, 2011; Bushnell and Wolfram, 2012). But past studies have not agreed to the sign and magnitude of environmental impacts (Evans et al., 2008; Keohane et al., 2009; Bushnell and Wolfram, 2012).⁷

Lastly, this paper is also related to the literature on enforcement and compliance (see Helland, 1998; Earnhart, 2004; Gray and Shimshack, 2011), partly because the degree of enforcement is

⁶Previous work has suggested a fuel switch can induce CO₂ reduction, e.g., (Linn et al., 2014). Broadly speaking, our work is related to the design and impact of the Clean Power Plan and related federal policies on greenhouse gas mitigation (Bushnell et al., 2017; Abito et al., 2018).

⁷The literature has stopped investigating in the NSR since the Equipment Replacement Provision (ERP) of NSR in 2003, which in practice relax the stringency of NSR. However, ERP was revoked in 2007 and NSR has been strengthened and relaxed a few times since then, so an updated study is needed. (We provide the background and changes of NSR from 1977 to 2015 in Section 2.1).

difficult to measure when there is no clear threshold of violation and policies are uncertain. In this paper, we focus on estimating the perceived stringency by estimating the probability of being named in a lawsuit. Doing so allows us to measure the effective intensity of enforcement.

The rest of the paper is organized as follows. Section 2 gives a background on the New Source Review program and briefly describes our data sources. Section 3 presents our two-step approach in estimating how the NSR affects the probability of being litigated, and how that probability affects plant operation and emissions, and Section 4 presents results on both stages of our estimation results. Afterward, we present decomposition results in Section 5 to quantify margins that explain our carbon co-benefits results. Section 6 presents additional evidence on intensive margins such as emission control technology adoptions and a within-plant fuel switch. Section 7 presents our conclusion.

2 Data and Background of NSR

2.1 The New Source Review program

Many regulations and mandates in the United States impose different standards between new and existing units. For example, the Corporate Average Fuel Economy (CAFE) standard only targets new vehicles; building codes only regulate the energy efficiency of new buildings; the EPA only mandates buildings constructed after 1978 to make a real state disclosure or safety certification for lead paint; the U.S. Food and Drug Administration (FDA) only reviews applications of new drugs without repeated review of previously approved drugs, even though the standard of approval may increase with scientific development over the time; and the 1970 Clean Air Act (CAA) only imposes mandates for existing emission sources. The distortion that arises from these differential treatments can create a regulation wedge, or a “leakage”, across different units. In the case of the power sector, the 1970 CAA would encourage firms to delay the introduction of new units, extend the lifetime of existing units that are exempt from the CAA regulations, undermine the effectiveness of the regulation, and potentially raise the net cost of the regulation.

The New Source Review (NSR) was created as part of the 1977 Clean Air Act Amendments, to regulate the modification of existing power generating units that were not subject to regulation under the 1970 CAA, and to expedite the process of replacing older and less efficient units with new units. A utility company that plans to undergo a modification to an existing unit in a given plant has an option to voluntarily apply for the New Source “Permit to Construct” which requires the plant to undergo an extensive review process. The proposed utility must provide simulated evidence that the modified unit will meet the requirement of the National

Ambient Air Quality Standards (NAAQS) in the county where the unit is located.⁸ Although NAAQS is very specific at the county level, there is no specific rule regulating the emission rate at the end of each pipe. Therefore, the review process usually requires applying plants to install the Best Available Control Technology (BACT). To avoid installing costly BACT or triggering a lengthy review process, which is also costly to the firm, the utility company can choose to delay modifications, or fail to inform the EPA of their modifications. Doing so may trigger a lawsuit alleging a utility company has violated the Clean Air Act by failing to inform the EPA of the modification or deliberately delaying new modifications to a unit that needs to be improved. In the latter case, the lawsuit usually quotes emission records from previous decades. Later in our estimation, we utilize historical variation of power plant operational characteristics to predict the NSR lawsuit risks. The likelihood of facing an NSR lawsuit, in turn, significantly affects emissions and plant operations.

The ambiguous nature of the lawsuits motivates us to estimate the probability of a lawsuit. First, the power industry was not aware of the NSR threat until November 1999, when the U.S. Department of Justice (DOJ), as an enforcement agent of the EPA, sued 8 utility companies alleging 24 power plants and 83 units violated the NSR.⁹ We interpret this as an exogenous increase in NSR lawsuit probability from 1999 onwards.

Second, it is unclear as to which plants the EPA will target. In those first set of lawsuits, the DOJ alleged major, life-extending modifications had been made to these units without the proper permitting process under the NSR. However, the definition of major modifications has been open to interpretation and has changed over time (discussed below), leaving the EPA with significant discretion as to which plants to target for litigation. For example, the EPA has the flexibility to decide what kind of change is large enough to affect the regional level NAAQS, which means there may be different enforcement levels between plants in CAA attainment vs. non-attainment counties. As another example, the interpretation of the law depends on judges at different federal courts which would affect the expected outcome of the lawsuits. Table 1 shows that emissions from district 5 are comparable to district 3, 4, and 10 but district 5 has had zero lawsuits. This variation in the leniency across regions would, in turn, affect how the EPA targets plants across jurisdictions.

Third, the ambiguous nature of enforcement has changed over time because the NSR program has experienced several periods of rule changes.¹⁰ Figure 1 shows a spike in the number of NSR lawsuits in 1999 during the Clinton Administration. During the first term of the Bush Administration, the EPA went through with a rule change of the NSR called the Equipment Replacement Provision (ERP). Starting in December 2002, ERP exempted any

⁸The utility must adopt to EPA-approved engineering models to project future emission levels. The common models used are AERMOD and CALPUFF.

⁹The utility companies sued in November 1999 were American Electric Power (AEP), Cinergy, Dynergy, FirstEnergy, Southern, TECO Energy, and Tennessee Valley Authority.

¹⁰More details on the EPA's NSR reform webpage <https://www.epa.gov/nsr/nsr-regulatory-actions#nsrreform>.

routine modification change that requires less than 20 percent of the capital cost of a given plant in one year. The high threshold effectively removed the risk that companies would be required to retrofit or to install BACT in existing units. Consistent with this rule change, Figure 1 shows that the average number of NSR lawsuits decreased by 2004. After four years, in March 2006, the D.C. Circuit Court vacated the ERP. Consistent with the removal of ERP, in Figure 1 we start to see an increasing pattern of NSR lawsuits after 2006. Since then, the Bush EPA proposed a revision of the NSR that would permit authorities to combine and aggregate emissions from plants modifications when projects across different plants but under the same utility companies were related, known as the “aggregation policy”. This rule would effectively reduce the stringency of the NSR, and the final rule was issued in Jan 2009, within the first week of the Obama administration. The new Obama EPA delayed the effective date of the “aggregation policy” to March 2010. Consistent with the rule change, Figure 1 shows that the average number of NSR lawsuits declined after 2010. To incorporate variation in NSR enforcement since 1999, we estimate a time-varying probability of being named in an NSR lawsuit for each plant using a discrete-time duration model, which we then use to estimate the reduced-form relation of lawsuit probability on emissions and plant operations.

The basis of our main hypothesis is that we think firms believe that NSR lawsuits are a credible threat in our sample period and would respond to avoid an allegation. First, the EPA has won existing allegations. Second, the negative consequences of the lawsuit must be so extreme that they would provide plants with an incentive to respond before any threat becomes salient. Most settlements require utility companies to retire, retrofit, or install BACT for specific power-generating units in the plants with alleged modifications. Utilities are required to install BACT in plants allegedly in violation within a proposed short window or face immediate retirement, as well as up to \$27,500 per-day in civil penalties. The potential penalty and forced retirement provide good incentives for utility companies to reduce emissions, especially for plants that face a higher risk of a lawsuit. In this paper, we propose and estimate a reduced-form relationship on how NSR lawsuit likelihood affects emissions and plant operation margins.

2.2 Data

To perform extensive ex-post analysis on how the NSR affects emissions and plant operations, we collected data for 1,350 coal- and gas-fired plants from about 800 utility companies between 1995 and 2015. We collected monitoring data that reported SO₂, NO_x, and CO₂ emissions using the Continuous Emission Monitoring System (CEMS) database from the EPA. We also collected power plant operation data including gross load and net power generation, heat input, fuel use, and other plant characteristics using the Form-767, 906 and 923 from the U.S. Energy Information Administration (EIA).

To further examine the extensive margin that drives the emission reduction, we collected nameplate and operating capacities of electricity generating units, and their retirement status from the EIA Form-860. To study the intensive margin, we computed emission rates (tonnes of emissions per unit of heat input) using emission data from CEMS and heat input from the EIA Form-767 and Form-923, and thermal efficiency (operating heat rate, defined as heat input needed per unit of power generation) using heat input and power generation. In Table 2, we show that there is a significant amount of variation in the key variables of interest, including emission level, emission rate, heat rate, and likelihood of being named in an NSR lawsuit.

To examine how NSR lawsuit probabilities affect emissions and plant operations, we extracted information from all 31 NSR lawsuit consent decrees covering 85 power plants and 275 power generating units, starting from the first cases in November 1999 to the last case of Duke Energy in 2015 from the EPA Coal-fired Power Plant Enforcement web page.¹¹

It is important to use the most relevant date that defines when a lawsuit becomes a salient threat, because we not only need to estimate the dynamic survival likelihoods consistently but also quantify the date to which the firm will respond by using avert actions to reduce the risk.¹² We link the above lawsuits with detailed lawsuit enforcement data using the Integrated Compliance Information System - Federal Enforcement and Compliance (ICIS - FE&C) data set from the EPA Enforcement and Compliance History Online (EPA ECHO) database. The ICIS-FE&C data set allows us to track all the milestones of the lawsuits and provide detailed enforcement characteristics. An important milestone includes the date the lawsuit was filed in federal court. Prior to the court date, first we observe the date DOJ was referred to proceed allegation as well as the date the enforcement data was entered into the database, and after that we observe the date(s) the complaint is/are filed in the court, as well as the settlement date.¹³ We chose to use the date when the data was entered into the enforcement database as the baseline measure to estimate our survival model because plants will get a notice from the court on this date and would begin to prepare for the lawsuit.¹⁴

¹¹EPA Power Enforcement Page <https://www.epa.gov/enforcement/coal-fired-power-plant-enforcement>. Readers will notice there are no lawsuits in 2015 in Figure 1 since Duke Energy first got a legal notification when the enforcement data was entered in 2000. See our explanation in the next paragraph and our Appendix Table A.1 for detail.

¹²This is not an important issue for previous studies since they aim to estimate or construct a cross-sectional NSR risk. For example, Keohane et al. (2009) estimate cross-sectional probit risk in 1999 and 2000. Bushnell and Wolfram (2012) assume the NSR risk starts in 1998 and ends in 2002 for all coal-fired plants without scrubbers.

¹³Usually the date of "enforcement data entered" is recorded right after (a day or a few days) the date when a case is referred to the DOJ. In the next few weeks, we observe the date "complained filed to court". In the next few months (and in very few case years if a lawsuit is pushed back), we observe the date when a "consent decree is made at the court". As a reference, Keohane et al. (2009) use 1999, which implicitly assumes the lawsuit date is somewhere from the "DOJ date" to the "consent decree date". Lastly, months (in very few case years) after the consent decree date, we observe a date when "the final order is lodged".

¹⁴Ideally we would like to use the DOJ referring date but the data is missing for public regulated plants. Usually, the enforcement data entry date is a few days later than the DOJ date; and the court date is a few month later.

In Appendix Table A.1, we report all NSR lawsuits from 1999 to 2015. On average, cases have settled within about six years.¹⁵ Later for robustness we use other dates to define our lawsuit timing. In addition, no utilities have had multiple lawsuits in our sample. For all lawsuit cases, the DOJ won.

To predict NSR lawsuit probabilities, we collected historical emissions and power generation data prior to the first wave of NSR reform in 1999. Although the CEMS dataset does not track emissions prior to 1995, historical net generation and heat input data were collected from 1980 to 1995 in EIA Form-767. Similar to Keohane et al. (2009), we imputed historical SO₂ emissions using information on power generation, fuel quality, and fuel use. We also collected federal judicial circuit district information to predict NSR lawsuit probabilities. Figure 2 shows the map of federal circuit districts in the U.S., and Table 1 shows the total number of lawsuits by federal judicial circuit district.

Finally, we collected information of other overlapping federal or regional environmental and energy policies that might affect power plant operations. Specifically, we collected states and years that would be affected by the Clean Air Interstate Rule (CAIR) which regulates SO₂ and NO_x after 2009, the NO_x Budget Trading Program (NBP) which was in place from 2003 to 2008, and the Regional Greenhouse Gas Initiative (RGGI) which has regulated CO₂ emissions since 2009 in some states in the New England region. We also collect county-level attainment status of the National Ambient Air Quality Standards (NAAQS) over our sample period. Table 2 displays the summary statistics of key variables used in our analyses.

3 Empirical Strategy

3.1 Estimate NSR Enforcement Likelihoods

To assess the impact of New Source Review lawsuits on plant emissions and operations, we need to identify the plants that are affected by the NSR from other plants, i.e., correct treatment and control groups. Otherwise, the NSR lawsuit will be endogenous and a comparison across affected and unaffected plants will be biased. For instance, Duke Energy had an NSR lawsuit in 2000. This case can be correlated with other reasons that Duke Energy is a heavy emitter in

¹⁵From 1999 to 2015, 37 settled utility companies were required to pay 188 million dollars civil penalty (with an average of 5 million dollars), 34 settled plants were required to spend or pay in total 26 billion dollars for compliance action (with an average of 722 million dollars), and 4 companies to spend or pay in total 26 million in supplementary projects (with an average at 6.5 million dollars). The numbers are from the lawsuit settlements. The compliance action cost includes the sum of the dollar values of injunctive relief and the physical or nonphysical costs of returning to compliance. Injunctive relief represents the actions a regulated entity is ordered to undertake to achieve and maintain compliance, such as installing a new pollution control device to reduce air pollution, or preventing emissions of a pollutant in the first place. The supplementary cost applies to the types of environmentally beneficial projects which a defendant/respondent agrees to undertake in a settlement of an enforcement action, but which the defendant/respondent is not otherwise legally required to perform.

2000, e.g., that Duke Energy has been a heavy emitter in the past. For another instance, in 2003 Santee Cooper was named in an NSR lawsuit. It is likely that Santee Cooper had a risk of being named in the lawsuit as early as 2000. Therefore, computing changes in emissions from Duke Energy from 1999 to 2000, and examining how this number is compared to how Santee Cooper changes from 1999 to 2000 will inform us the biased effect of an NSR lawsuit.

To make the comparison, previous studies have either adopted engineering assumptions or formed time-invariant control and treatment groups. Ex-ante studies such as EPA Regulatory Impact Analyses (RIAs) have simulated emission trajectories by assuming important parameters like the percentage of plants that might have complied with the 1999 NSR rule before the ERP rule change (e.g., EPA, 2012b, 2015) using the Integrated Planning Model (IPM).¹⁶ NRC (2006) improve on the IPM model by allowing plants to adjust their extensive and intensive margins and use a broader range of assumed parameters, but they still assumed that specific sets of selective plants would undergo retrofit, retire, or repower under the NSR. However, doing so makes the assessment sensitive to the chosen economic assumptions and parameters.

Previous ex-post studies have either assumed time-invariant control and treatment groups or estimated time-invariant risks of litigation using cross-sectional methods. Bushnell and Wolfram (2012) use the historical installation of SO₂ emission control status (i.e., whether a plant had a scrubber before 1999) to separate plants into a control group that is relatively safe from NSR litigation and a treatment group that is vulnerable to NSR. They then examine how plant operations and emission rates vary across groups from 1999 to 2002 and after the ERP rule change in 2003. Keohane et al. (2009) use historical emissions and power generation from the 1980s to estimate a cross-sectional likelihood of an NSR lawsuit, and then study how the estimated lawsuit risk affects emissions from 1996 to 2000.

However, to examine the effect of the NSR on changes from 1995 to 2015, we need to allow the likelihood of an NSR lawsuit to vary over time. First, the NSR has experienced several rule changes since 1999 so that the perceived stringency has changed over time. Also, the probability of being named in a lawsuit for a given plant can be correlated and persistent over time. To account for those factors, we deploy a discrete-time duration model to flexibly estimate the likelihood of NSR lawsuits using historical emissions, power generation, capacity, emission control technologies, and lawsuit leniency across 11 federal circuit courts.

Specifically, we begin by motivating a discrete-time survival model $S(t|Z_i) = S_0(t) \exp\{Z_i\delta\}$, where $S(t|Z_i)$ is the rate of plant i surviving to year t without being involved in a lawsuit,

¹⁶EPA RIAs use the Integrated Planning Model (IPM) by ICF Consulting to simulate the impact of the NSR. “IPM is a deterministic model of the electricity sector that uses linear programming techniques to find a lowest-cost approach to determine how electricity generators might meet projected demand and the amounts and types of generating-capacity investment and retirement sufficient to meet peak demand and regional reserve requirements” (from NRC (2006) Chapter 6).

and Z_i are covariates to predict survival probability. By rewriting the survival function into a complementary hazard function and applying a log-log transformation to the baseline hazard, we transform the dynamic duration model into the following complementary log-log hazard (C-log-log) model. The discrete-time hazard rate for plant i in year t is given by:

$$\rho_{it} = 1 - \exp \{ - \exp \{ Z_i \delta + \phi_t \} \} \quad (1)$$

where the hazard rate $\rho_{it} \equiv \Pr(\text{lawsuit}_{it} = 1)$ describes the conditional probability that plant i will be involved in a lawsuit in year t given that i survived in year $t - 1$. We explain the covariate Z_i next. The hazard rate of each year t is picked up by year fixed effects ϕ_t . The clock in our c-log-log model increments by year. To allow for correlation within plants, we cluster our standard error at the plant level.

Because we estimate hazard using a discrete-time duration model, the parameters in the vector δ are identified using the cross-sectional variation across plants. Specifically, the covariate Z_i includes the first and second moments in historical emissions and power generation prior to 1999 (from 1985 to 1994, which may trigger a specific allegation of violations in an NSR lawsuit), log generating capacity in 1997, scrubber installation status in 1997, and fixed effects of 11 federal judicial districts. First, we use historical emissions and power generation to identify plants that are more likely to be subject to a lawsuit. Plants named in NSR lawsuits were mostly sued for recent modifications, however, the violations cited in most consent decree dated back to the 1980s and early 1990s.¹⁷ Keohane et al. (2009) similarly use historical emission information to predict the threat of a lawsuit in 1999 and 2000. For robustness, we changed this historical period to predict NSR lawsuit probabilities and we found similar results.

Second, since all consent decrees cite violations in SO₂ and many of them cite enforcement measures to install SO₂ technologies (such as scrubbers), plants without scrubbers are more vulnerable to NSR lawsuits (Reitze, 2001; Jaber, 2004). We therefore include pre-1999 NSR reform scrubber installation to predict NSR lawsuit hazard, as in Bushnell and Wolfram (2012). Moreover, it is possible that the DOJ is more likely to focus on relatively higher-profile cases and larger plants have higher odds of being named in a lawsuit, we therefore include the log of pre-1999 NSR reform capacity in the covariate Z_i to control for the size of a plant.

Lastly, we find plants named in NSR lawsuits are not proportionately drawn from the distribution of all plants but instead cluster around the Rust Belt and are rarely seen around the pro-business federal circuit courts. Table 1 shows the number of lawsuits by federal circuit districts (All NSR lawsuits are settled in federal circuit court). There have been no lawsuit cases in the 5th Circuit (for LA, MS, and TX) although the emissions from the 5th district are comparable across districts 3, 4, and 6; and 35 lawsuits in the 6th Circuit (for KY, MI, OH, and

¹⁷For instance, *Ohio Edison* was sued in 2003 on the basis of modifications at the Sammis Plant between 1984 and 1998 (Jaber, 2004).

TN). In order to allow and infer that plants in certain regions are less likely to be targeted (such as the 5th district) and plants in some regions are more likely to be targeted (such as the 6th district), we include fixed effects of the federal circuits to allow pro-business districts to have a different effect on the lawsuit hazard.

We chose the c-log-log model instead of alternative discrete-time duration models such as the proportion hazard model. The former allows us to predict not only the conditional hazard rate but also the base year hazard rate, which enables us to predict the unconditional probability of a lawsuit $\hat{\rho}_{it}$. This is important for our analysis since we need to use the unconditional lawsuit probability to estimate the effects of the NSR in Section 3.2. Because δ is identified using cross-sectional variation, the variation of the predicted likelihood of a lawsuit is significantly dependent on the historical emission levels. Since our estimation strategy is based on year fixed effects, the variation in both levels of enforcement and interpretation of the NSR, as well as other macro demand and supply shocks over time affect how base year hazard varies over time. These factors affect how NSR likelihood $\hat{\rho}_{it}$ varies from one year to the next given a plant.

3.2 Estimating Effects of NSR Lawsuits

We estimate how NSR lawsuit risk affects plant emissions and operations using predicted probability $\hat{\rho}_{it}$ from Section 3.1. For the log of total emissions (SO_2 , NO_x or CO_2) from power plant i in year t , we estimate:

$$\ln \text{emiss}_{it} = \beta_1 \hat{\rho}_{it} + \beta_2 \ln Q_{it} + \gamma X_{it} + \alpha_i + \alpha_t + u_{it} \quad (2)$$

where $\hat{\rho}_{it}$ is the predicted probability of facing an NSR lawsuit for plant i in year t . Because NSR likelihoods are generated regressors, we correct the estimated standard errors by bootstrapping both the complementary log-log model and our main estimation equation above. Our study has both coal-fired plants and gas-fired plants which differs from previous studies on NSR.

Our goal is to identify the effect of NSR probabilities on overall emissions, captured by β_1 . We control for the log of gross load power generation, $\ln Q_{it}$, so that β_1 is conditional on the emission reduction from reducing power generation, i.e., *the scale effect*. The vector X_{it} further controls for the natural gas price in a state and by year to control for fuel-switch incentives, in addition to plant and year fixed effects α_i , α_t . In order to separate the effect of averting behavior due to a lawsuit risk from complying behavior due to a lawsuit settlement terms (or expected terms from the allegation), we remove the post-lawsuit years for the plants that have had a lawsuit in our sample.¹⁸

¹⁸In the complementary log-log model, we use observed survival to predict the lawsuit probability not only for other plants but also for a given plant over time. This requires us to include post-lawsuit years for a plant that has had a lawsuit when estimating Equation (1). Those years are not included when estimating Equation (2). For robustness we include those years and control for the post-lawsuit effect and find results robust to the baseline.

The key parameter of interest, β_1 , presents the marginal effect on percentage changes to emissions if NSR lawsuit probabilities increase by one percent holding output constant. The first stage results allow us to understand the NSR effect on emissions via adjusting output. The second stage explains the effect of NSR on emissions independent of the scale effect. If NSR lawsuits could directly cause actions that would reduce emissions given constant output, we would expect β_1 to be negative. It is also possible, that for certain pollutant emissions, most emission reductions are the result of reduced power generation. In this case, we would expect the first-stage coefficients of $\hat{\rho}$ on $\ln Q_{it}$ to be negative. If the scale effect is the only channel, we also expect β_1 to be small or even insignificant from zero. Because higher demand for electricity can lead to a greater need for power generation and therefore more emissions, we expect β_2 to be positive.

It is possible that plants that have experienced emission reductions and plants that have not experienced emission reductions have different unobserved characteristics which are correlated with the NSR probabilities. For example, plants located farther away from metropolitan areas may be subject to a lower enforcement risk. To control for the potential omitted variable bias, we include plant-level fixed effects, which also implicitly accounts for potential “peer effects” for plants within the same state. In addition, we control for year fixed effect to account for year-to-year national variation in emission levels, and year-to-year national changes in the NSR probabilities. Moreover, estimating Equation (2) at the plant level allows us to account for potential substitution within a plant across various electricity generators.¹⁹ Since the c-log-log model allows for correlation of hazard across years within a plant, including plant fixed effects and year fixed effects will not tease out variation in the NSR probabilities.

Furthermore, other policies and regulations that aim to reduce emissions from the power sector can affect the SO_2 , NO_x , and CO_2 emissions. Therefore, we include a dummy variable that equals to one if a state in a year was regulated under the National NO_x Budget Program, and a dummy variable for the Regional Greenhouse Gas Initiative (RGGI), and another for the Clean Air Interstate Rule (CAIR).

The log of power generation may be endogenous for multiple reasons. Plants may adjust output when they reduce emissions, and there are some technologies (such as scrubbers), which we omitted, but can affect both power generation and emission levels. We adopt a demand shifter, state-year level cooling degree days (CDD), as our instrumental variable to predict the log output. In Section 6 we show our first and second stages are robust to using alternative instruments.

To further understand economic factors that drive our main results, we also estimate Equation (2) on other dependent variables such as emission rates, heat rates, a dummy representing

¹⁹We estimate at two alternative levels: 1) at the utility level to account for substitution pattern within a utility company across plants and find similar results; and 2) at the electricity generating unit (EGU) level to directly estimate the effect across EGUs and find similar results, but emissions are noisier at the EGU level.

if they have shut down, and examine how results vary across plants with and without gas capacity. We report these results in Section 4.

4 Estimation Results

4.1 Estimates of NSR Lawsuit Likelihoods

In this section, we present estimates of NSR lawsuit likelihoods using the complementary-log-log model described in Section 3.1. In Appendix Table A.2, we report the estimated parameter $\hat{\delta}$ in column 1 and the corresponding marginal effect in column 2. Our hazard model fits the data well, with an overall Wald Chi-squared equal to 269. We found that historical plant emissions, operations, and characteristics are good predictors for hazard. The Wald Chi-squared for the joint-significance test of plant-varying variables excluding year effects is 97. In particular, we found the first and second moments of historical power generation, as well as plant capacity are strong predictors of NSR lawsuit hazard.

Our estimates suggest that plants with a history of producing more outputs are more likely to be named in a lawsuit. For example, column 2 of Table A.2 implies that an increase in historical utility-level power generation of 50 million megawatt hours (about the average of historical generation and one standard deviation of historical generation) would increase the likelihood of being named in the NSR lawsuit by 5.5 percent. Also, we found the coefficient of historical standard deviation to be negative and significant which implies that consistently heavy power generators are more likely to be named in a lawsuit.

Furthermore, our estimates in Table A.2 suggest that plants located in federal judicial districts 4 (DC, MD, NC, SC, VA, WV), 6 (KY, MI, OH, and TN) and 7 (IL, IN, and WI) are more likely to be named in a lawsuit, when compared with other regions that are less pollution-intensive (for example, districts 1 and 2) or with a more pro-business judicial circuit courts (for example, district 5). The average predicted NSR likelihoods across all state is 2.1 percent, and the median is 0.7 percent, while Tennessee, West Virginia, Kentucky, Indiana, and Ohio have an NSR risk of 11.5, 10.4, 10.2, 8.8, and 7.6 percent respectively.

Using our estimates, we generate the predicted unconditional probability of having a lawsuit $\hat{\rho}$. In Figure 3 Panel A, we show the average predicted likelihood of having a lawsuit across all plants for each year. The average probability gradually increases over time from 1999. The average NSR lawsuit likelihoods experienced a drop in 2007. This is consistent with the fact that we observe few new lawsuits filed from 2005 and 2007 in Figure 1.

Moreover, we show how our estimation allows us to construct better treatment and control groups than using observed lawsuits for our analysis. In Panel B of Figure 3, the light-colored points show the predicted lawsuit risk if a plant has had a lawsuit in our sample period, and

the black points show the lawsuit risk for a plant that never has a lawsuit. In Panel C, we repeat the same exercise and see if lawsuit risks vary if the utility that owns a plant has had a lawsuit in our sample. First, comparing two groups cross-sectionally, we found plants that have never had lawsuits are still subject to a significant positive risk despite that risk is small. It is therefore important to have a probability model and allow the treatment to be continuous across plants in a year. Second, we found that the risk increases over time for both groups and the wedge between these two groups also increases. This evidence suggests that it is important to estimate a dynamic survival model to account for the correlation in unobserved hazard over time within a plant which is not represented in previous studies (e.g., [Bushnell and Wolfram, 2012](#); [Keohane et al., 2009](#)). This exercise also puts the marginal effects of a one-standard-deviation increase in historical power generation. That increase (5.5 percent) is roughly equivalent to the difference in the lawsuit risks between larger and smaller plants in 2015.

4.2 Effect of NSR Lawsuits on Local Pollution and CO₂ Emissions

Using the NSR lawsuit likelihood predicted from Section 4.1, we estimate how NSR risks affect local pollution and CO₂ emissions from 1995 to 2015. Since the lawsuit probability is a generated variable, we correct this variable by bootstrapping both the duration Equation (1) and the main IV Equation (2).

In Table 3 Panel A columns 1–3, we report the estimation of Equation (2) on the log of SO₂, NO_x, and CO₂ emissions, treating power generation (log of gross load of power generation) as an exogenous variable. To control for unobservables that can be correlated with the NSR lawsuit probabilities, we control for plant and year fixed effects. Plant fixed effects capture unobserved plant-level characteristics that are time-invariant and affect compliance costs (e.g., geographic factors). Year fixed effects pick up macro factors that affect time variation in NSR lawsuit probabilities and emissions such as changes in the presidential administration and changes in NSR rules (see Section 2.1).

The OLS results in Table 3 Panel A columns 1–3 suggest that NSR lawsuits have a sizable impact on emission reduction, holding other factors constant. Also, we find a modest scale effect, e.g., bigger plants that have a higher demand for electricity generation are more likely to emit significantly more tonnes of SO₂, NO_x, and CO₂.

A remaining concern is that utility companies can adjust the output across their plants to be more efficient which affects the emission levels. This endogeneity problem not only threatens the identification of $\hat{\beta}_2$, but also the key parameter of interest, $\hat{\beta}_1$. The coefficient of NSR lawsuit likelihoods and the power generation output can be simultaneously identified. To address this problem, we use only the exogenous part of power generation, which is affected by the electricity demand, i.e., using a demand shifter. We adopt the number of cooling degree days (CDD) as our instrumental variable, which captures variation in power generation

that is affected by the demand shocks.²⁰ Therefore, our IV is unlikely to be correlated with unobservables from the supply side.

We report our first-stage result of power generation in Appendix Table A.3 column 1. Our first stage is strong, and it passes the weak instrument test. The F-stat for the (joint) significance of our IV is 34.4.²¹ Our first stage implies that if the number of cooling degree days increases by 100, the gross load of power generation would increase by 6 percent holding other factors constant.²² As for the included variables, a greater NSR lawsuit probability will reduce power generation, albeit not statistically significantly in the case of grossload. A 5-percent increase in the NSR lawsuit probability (about one standard deviation) would decrease the gross load of power generation by about 4.5 percent holding other factors constant. Since gross load includes the electricity intake, we repeat our exercise using net generation in column 2 and find similar results. Our first stage is also robust to alternative demand shifter IVs.

We present our baseline IV results in Panel A of Table 3 from column 4 to 6. Our baseline estimates have signs similar to the OLS results in columns 1 – 3. Comparing the IV results to the OLS results, we find the OLS results bias the estimate upward for SO₂ and slightly upward for NO_x.²³ This implies that we will overestimate the effect of the NSR lawsuit risk on emissions, if we fail to account for the fact that a utility company can allocate power generation from a higher risk plant to a lower risk plant. Since the NSR lawsuit in general target SO₂ and NO_x, we do not see much change in CO₂ coefficient.

First, our baseline IV results suggest a substantial *scale effect* of power generation on emissions. The second-stage coefficient for log output is positive, significant at the one percent level, and fairly large. A one percent increase in the gross load of power generation increases SO₂, NO_x, and CO₂ emissions by 1.0 to 1.2 percent.

Second, we found overlapping regulations and economic conditions affect emissions. In particular, we find that regulation under CAIR will reduce SO₂ and CO₂ emissions, while being regulated under RGGI lead to reduction in SO₂ emissions. Our estimate for the NBP is negative but not significant, which is likely because NBP affect intensive margins and extensive margins differently and the overall effect is not precise when we mix the two channels together.²⁴ In addition, we find that lower natural gas prices lead to a decrease in emissions (as well as emission rates in later specifications).

Third, we found that NSR lawsuit probabilities have a *direct effect on emission reductions* independent of the indirect effect via reducing power generation, holding other factors constant.

²⁰A greater number of cooling degree days would increase the demand for electricity in the summer months.

²¹The Cragg-Donald F-stat is 13.7, and the Kleibergen-Paap F-stat is 7.0. For robustness we tested the joint significance of IVs when we have more than one IV.

²²Since using emission abatement technology requires electricity, it can be relevant to use net generation, which excludes the electricity consumption from gross load generation. We find the main results are robust (not reported).

²³Due to lack of variation, our OLS coefficients are not significantly different from our IV results.

²⁴For example, in Table 3 Panel B we find NBP has a significant effect in reducing SO₂ emissions.

The coefficients are negative for all emissions. The magnitude of our baseline suggests that a one percent increase in NSR lawsuit probability (about 0.2 of the standard deviation) would decrease SO₂, NO_x, and CO₂ by 0.6, 1.2, and 0.5 percent respectively.

Our estimates are significant for NO_x and CO₂ and insignificant for SO₂. Despite a lack of precision for SO₂, we explain in Section 4.3 that all our estimates for SO₂ are consistently negative throughout the paper, and are consistently significant for the intensive margin. The large standard error for SO₂ can be driven by noise in the extensive margin and noise for plants without natural gas capacity. We also show in our robustness analysis that our point estimate is consistently negative across alternative specifications.

Our findings regarding the effect of NSR lawsuit probability on local pollution emissions show that local pollutant emissions are reduced as lawsuit probability increases. This result is consistent with results reported in Keohane et al. (2009), but is in contrast with results reported in both Bushnell and Wolfram (2012) and Evans et al. (2008). The latter two studies both found a null effect with regards to SO₂ and NO_x emission rates. The difference between our results and previous null results may be that Bushnell and Wolfram (2012) focuses on the short window right after NSR reform in 1998, and could also be that we include natural gas plants while previous studies only include coal-fired plants so that we capture the fuel-switch margin. As for Evans et al. (2008), there is a methodological difference in defining both the treatment and counterfactual. Evans et al. (2008) uses an bottom-up economic-engineering model and assume ex-ante which plants shall be affected, while this study defines a continuous treatment that is predicted from a duration model.

Our findings on CO₂ emissions suggest that there are sizable climate co-benefits from regulating local pollutant from the power sector via the New Source Review. We later quantify the economic value of our results in Section 5.

There are other environmental policies that affect the power generation sector, such as the NBP and CAA. Whether our climate co-benefit results can be generalized to these policies depends on how each policy affects plant operations. If other policies also affect channels that the NSR triggers, then it would be important to account for climate co-benefits for those cases. Therefore, it is important to study which channel effectively drive the carbon co-benefits to inform more efficient designs of future climate policies. To answer these questions, we next examine how NSR probabilities affect important margins for plant operations.

4.3 How Have NSR Lawsuits Affected Plant Operations?

In this section, we examine how NSR lawsuits affect various margins of plant operations. We first examine intensive margins such as changes in emission rates and thermal efficiency. Then

we study the extensive margin, i.e., the decision to operate. In Section 5 we use these estimates to conduct a decomposition analysis.

Overall effects on choices in the production function. We begin by examining the essential choices in the production function. Total emissions depend on the scale of production (electricity generation), the emission intensity (emission rate), and the thermal efficiency (heat rate, the amount of heat needed to generate one unit of power). In Section 4.2 we document a substantial scale effect as shown in our first-stage regression, suggesting that NSR lawsuits can affect emissions by incentivizing utility companies to reduce power generation.

We proceed to examine how NSR lawsuits affect emission and operating heat rates. Panel A of Table 4 reports estimates from Equation (1) taking emission and heat rates as dependent variables. Column 1–3 suggest that the effect of lawsuit probability on emission rates are negative, and statistically and economically significant. This result is consistent with the findings in Table 3. A one percent increase in the lawsuit probability reduces the emission rates of SO₂, NO_x, and CO₂ by 1.3, 1.9, and 1.2 percent respectively. In contrast with [Bushnell and Wolfram \(2012\)](#), which found no effect on SO₂ and NO_x emission rates, our findings suggest that NSR lawsuits have effectively incentivized power plants to adopt technologies to reduce emissions. For robustness, in Section 6, we provide direct evidence on scrubber adoption, NO_x control equipment adoptions, and fuel switch induced by NSR lawsuits.

In contrast with emission rates, Table 4 Panel A column 4 shows that NSR lawsuits do not affect heat rate, i.e., a positive effect in improving thermal efficiency. Moreover, the point estimate in Panel B is small, implying there are limited potential *within-plant* improvements. Nevertheless, we find strong evidence that power plants have adopted a less carbon-intensive approach of power generation and some weak evidence of improvements in thermal efficiency. These results can be the result of a fuel-switch, plant retirement, or improvement in turbine technologies, all of which we document next.

Effects on intensive and extensive margins. Next, we study how NSR lawsuits affect plant extensive and intensive margins. As for extensive margins, we focus on analyzing how NSR lawsuits affect a utility company’s decision to shut down a plant. We are interested not only in estimating the marginal effect but also producing consistent operating probabilities to use in our decomposition analysis in Section 5. Therefore, we estimate a logit regression. To estimate the likelihood of operating versus shutting down, we need to isolate the decision within the intensive margin, i.e., the amount of electricity to generate. Therefore, our estimation includes the same set of variables equivalent to the reduced-form version of Equation (2), i.e., we include our demand shifter (CDD) and exclude gross load of power generation.²⁵

²⁵Because year fixed effects take out too much variation for us to identify the parameter for lawsuit probability, we use a quadratic time trend instead when we estimate the Logit model. We keep the plant fixed effects the same as in Equation (2).

Table 5 column 1 reports the coefficients from the logit model and column 3 reports the marginal effects. Our results imply that higher NSR lawsuit probabilities have an effect on shutdown. A one percent increase in the NSR lawsuit risk increases the likelihood to shut down by 1.1 percent. As for our demand shifter, we found that a plant facing a higher demand shock is more likely to operate, consistent with our intuition. To show that NSR lawsuit risks do affect the extensive margins, we repeat our analysis using a linear probability model (LPM) in column 2 and 4 and find a negative and significant effect. We chose the logit model to be our baseline specification for the extensive margin because we need to predict the shutdown probability for our decomposition exercise in Section 5, and the LPM will predict operating probability lower than 0 percent and higher than 100 percent.

As for the intensive margin, we repeat our analysis reported in Panel A in Tables 3 – 4 restricting on the sub-sample of operating plants and report our results in Panel B. We found similar signs and a slightly higher magnitude for our estimates. In addition, our parameter of interest is much more precisely estimated than in Panel A. This implies that the lack of precision in the result in Panel A, especially for SO₂, may come from the mix of data generating processes between the extensive and intensive margins.

In summary, we find that NSR lawsuits affect utility companies via both the extensive and intensive margins. To quantify how much each channel contributes to emission reductions, we conduct a decomposition exercise in Section 5.

Plants with or without the capacity to fuel-switch. Last, we investigate how NSR lawsuits affect plants with and without the gas-fired generating capacity. Fuel-switch has been the key driver of reducing carbon emissions in power generation, since natural gas is half as intensive in carbon as coal on average.²⁶

We start by examining how overall emission reductions, presented in Panel A of Table 3, differ depending on whether or not a plant has gas capacity. In Panel A of Table 6 columns 1 to 3, we estimate Equation (2) with NSR lawsuit probability interacted with a dummy variable that equals one if the plant has gas-fired capacity. Results in column 3 suggest that while NSR lawsuits reduce CO₂ emissions, having gas-fired generating power compensates for this effect. In other words, the NSR lawsuits mostly affect power plants with only coal-fired generating capacity. This result is also consistent with Holland (2012) that finds null results for California plants which are mostly gas-fired. We find similar results for NO_x, in that most emission reduction comes from coal-fired-only plants. As for SO₂, we find most emission reductions are from plants with gas-fired capacity.

To understand what drives the results in Panel A columns 1–3, we study how NSR lawsuit likelihood affects emission technology (measured by emission rate) and thermal efficiency

²⁶According to the carbon dioxide emissions coefficients published by the EIA: https://www.eia.gov/environment/emissions/co2_vol_mass.php

(measured by heat rate) differently between these two sets of plants. We report our results in Panel A of Table 6 columns 4–7. The estimate of $\hat{\beta}_1$ suggests that improvements in emission and heat rates occur primarily in coal-fired-only power plants that do not have any gas-fired generating capacity. In contrast with our baseline in Table 3, we do find a negative and significant effect on heat rate. The result can come from both intensive and extensive margins for the coal-fired-only plants, which we explain later in Panel B. As for plants with gas-fired units, the estimate of the interaction term is positive (but insignificant) for the CO₂ emission rate and positive and significant for the heat rate. These results imply that a higher NSR lawsuit risk induces plants to shift production to the plants with gas capacity, which are relatively more efficient than the coal-fired units, but much more inefficient than the previously operating gas-fired units.

To further quantify the type of fuel switch that drives the results in Panel A of Table 6, we proceed to study how NSR lawsuit probabilities affect extensive and intensive margins for plants with and without gas-fired capacity separately, i.e., the fuel-switch across plants vs. the fuel-switch within operating plants.

To study the cross-plant extensive margin, we repeat our previous logit estimation in Panel A by interacting NSR lawsuit probabilities with a gas-capacity dummy. Panel B of Table 5 columns 3 and 4 show the estimation results and provide evidence of cross-plant fuel-switch. Facing a higher NSR lawsuit risk, coal-only-fired plants are more likely to be shut down and plants that can switch to gas-fired units are more likely to continue to operate. A one percent increase in NSR lawsuit risk will increase the probability of a plant without gas capacity to shut down by 0.12 percent and increase the probability of a plant with gas capacity to shut down by 0.04 percent.

To study the fuel switch within operating plants, we repeat our estimation in Panel A of Table 6 with a gas capacity dummy and report the results in Panel B. Our results are qualitatively similar. In contrast with results in Panel A, we found the effect for heat rate is close to zero and insignificant. The difference between Panel A and B implies that most heat rate improvements that we see for coal-fired-only plants come from the shutdown of coal-fired plants with low thermal efficiency (high heat rate). We investigate the relative importance of each margin in the decomposition presented next.

5 Implications

To understand both the overall contribution to emission reduction from coal- and gas-fired plants and the contribution across various plant operation margins, we decompose emission reduction using our estimation results from the above section.

We begin by considering a one percent increase in the probability of being named in a lawsuit in the year of 2007. We think this is a relatively mild change – from 2007 to 2010, the average predicted probability of being named in a lawsuit increased in total by 6 percent, and a one percent increase translates to about 0.2 of the standard deviation. As the scale is relatively small, our counterfactual and decomposition simulation results imply marginal changes.

Panel A in Table 7 describes the total counterfactual changes in SO₂, NO_x, and CO₂ emissions in 2007 following the increase in the NSR lawsuit risk. We produce the counterfactual using baseline IV estimates in Table 3 columns 4 to 6. As we expect, there is a sizable drop in SO₂ and NO_x emissions, amounting to 44 and 29 thousand metric tons, respectively as these are the regulated emissions targeted by the New Source Review. Importantly, there is also a drop in CO₂ emissions of 0.63 percent, amounting to 10 million metric tons. We interpret this finding as evidence that the New Source Review leads to carbon co-benefits.²⁷

The magnitude of the co-benefits from NSR lawsuits is sizable in comparison to other indirect instruments that reduce CO₂ emissions studied in the literature. Linn et al. (2014) studied the effect of coal prices on operating heat rates and utilization rates. Using their most conservative estimate with generating-unit fixed effects, they found that a \$10 carbon tax will lead to a 0.6 percent decrease in carbon dioxide emission rates, a number that is close to our effect from a one percent increase in the NSR lawsuit likelihood. In addition, if we evaluate the social cost of carbon (SCC) at 42 dollar-per-metric-ton CO₂, the co-benefits from this exercise would result in a social benefits increase of 415 million US dollars. Knittel et al. (2015) found that a one percent increase in coal price also leads to a 0.6 percent decrease in total CO₂ emissions. A more direct approach to reducing carbon dioxide is through renewable portfolio standards (RPSs) which require an electricity network to purchase a certain percentage of power from renewables. Sekar and Sohngen (2014) show that RPSs implemented in 2007 decrease total CO₂ emissions by 2.62 percent – our results are approximately equivalent to one-fifth of their prediction.

After establishing evidence that the NSR leads to a sizable reduction in regulated pollution and unregulated emissions, we aim to understand *how* the risk of NSR lawsuits leads to emission reductions. This is important in determining if the co-benefits that we find can be generalized to other environmental and economic policies, as well as informing the design of new climate policies.

Emission reduction by plants with or without gas capacity. First, we divide our plants into two groups: a group that has no gas-fired generating capacity (group ‘c’) and a group that has some gas-fired generating capacity (group ‘g’). This allows us to understand if the carbon dioxide emissions are coming from a shift from plants without gas capacity to plants with gas capacity. On the other hand, plants with only coal-fired units may be adversely affected by the

²⁷We also produce the counterfactual for emission rates and operating heat rate, and it is available upon request.

enforcement, relative to plants with gas-fired units, as they could not easily shift production towards cleaner units in the short run.

We denote the two groups with the indicator variables d_c and d_g respectively, and denote a plant using i and year using t . Changes in emissions, Δz_t , at time t can be expressed as

$$\Delta z_t = \sum_i \{d_c \Delta z_{it}^c + d_g \Delta z_{it}^g\} \quad (3)$$

In Table 7 Panel B, we show the decomposition results for these two groups of plants based on estimates from Panel A of Table 6. We use the point estimate of the interaction terms for plants with gas-fired units.²⁸ Panel B.3 shows that the estimated carbon co-benefits occur through both coal-fired-only power plants (5.7 million metric ton CO₂ reductions), and power plants with gas-fired capacity (CO₂ by 5.3 million metric ton CO₂ reductions). As we will see in the next decomposition exercise, this is the result of more power plants without gas-fired units being switched off.

The effects on regulated emissions occur in both sets of power plants as well. As for SO₂, Table 7 Panel B.1 shows that the reduction in magnitude is greater for power plants with gas-fired units, contributing 85 percent of total emission changes. NO_x, in contrast, would experience most changes from coal-fired-only plants, which contribute 58.2 percent of total emission changes as shown in Panel B.2.

Emission reduction by intensive and extensive margins. We further analyze the extent of the intensive and extensive margins, in which plants (re-)start or shut down, in explaining emission reductions. We suppress the superscript for coal (c) and natural gas (g) for simplicity. Let η_{it} be a dummy variable which equals one if plant i decides to operate in year t . The expected changes in emissions can be decomposed as.

$$\mathbf{E}(\Delta z_t) = \sum_i \left(\Delta \eta_{it} \cdot \underset{\text{extensive}}{\mathbf{E}z_{it} | \eta_{it} = 1} + \underset{\text{intensive}}{\mathbf{E}\eta_{it}} \cdot \Delta z_{it} \right)$$

The first term describes the emission changes via the extensive margin, and the second term describes the emission changes for the operating plants, i.e., via the intensive margin. To approximate the *expected* emissions, we use the logit estimates in Table 5 columns 1 and 2 to predict operating probabilities $\hat{\eta}_{it}$. We use Panel B of Table 3 to predict conditional emissions for operating plants ($\hat{z}_{it} | \eta_{it} = 1$). The above equation reduces to:

$$\widehat{\Delta z}_t = \sum_i \left(\Delta \eta_{it} \cdot \underset{\text{extensive}}{\hat{z}_{it} | \eta_{it} = 1} + \underset{\text{intensive}}{\hat{\eta}_{it}} \cdot \Delta z_{it} \right) \quad (4)$$

²⁸We do not assume those insignificant estimates are zero since we find consistent point estimates in robust version of Table 6 even though they are not significant.

Table 8 shows the decomposition results. We produce this analysis using estimates from the logit estimates in Table 5 columns 3 and 4 as well as Panel B of Table 6. In this decomposition exercise, we normalize the total effect to match the corresponding numbers to Table 7 Panel B for convenience. Our results remain similar if the normalization is removed.

As shown in Table 8, both the extensive (i.e., shut down of plants) and intensive margins explain sizable shares of the co-benefits. Taking SO₂ for instance, 52% of the reduction is from the extensive margin and 48% of the reduction is from the operating plants. For CO₂, the extensive margin and the intensive margin each explains roughly half of the reduction, with the shutdown of plants contributing 56% of the co-benefits and emission reduction from operating plants contributing 44% of the co-benefits.

Despite the importance of both margins, we found how extensive and intensive margins affect regulated emissions and CO₂ co-benefits vary by plants depending on the presence of gas-fired units. In Table 8, we further separate plants into those with and without gas-fired generating capacity. As for plants without gas capacity, following an increase in NSR lawsuit probability of one percent, shutting down these plants contributes to 44.5 percent of the co-benefits, while operating coal-fired plants contribute to only 14.1 percent of the co-benefits. As for plants with gas capacity, most of the effect comes from the intensive margin: the operating plants with gas-fired units would account for 29.7 percent of the co-benefits, while the extensive margin accounts for 11.7 percent of the total co-benefits. Our results imply most co-benefits result from the shutdown of coal-fired plants without gas capacity and the continuous improvements of those operating plants with gas capacity.

In addition to the unintended co-benefits, we found similar results for the regulated pollutants. We found a sizable reduction in SO₂ and NO_x from both intensive and extensive margins for the coal-fired-only plants, and mostly intensive margin for the gas-fired plants. Our results suggest increasing regulations via NSR lawsuits trigger plants to adjust cross-plant margins and within-plant margins, both of which play an important role for co-benefits and regulated pollutants from the coal-fired-only plants, and the within-plant margin is also sizable from the operating gas-fired plants.

6 Additional Results and Robustness

In this section, we provide direct evidence of an increase in emission abatement technology adoption and robustness to our baseline results.

Direct evidence of technology adoption and fuel switch. One interpretation of our baseline result is that plants facing a higher NSR lawsuit risk would adjust *within-plant* margins to reduce emissions. In Table A.4, we found direct evidence of adoption of SO₂ and NO_x abatement

technologies such as adoption and use of scrubbers. In contrast, we do not find strong evidence of *within-plant* changes in gas share, suggesting the fuel-switch channel is mostly *between-plant*.

Robustness to macroeconomic conditions. Macroeconomic changes might affect both NSR policies and emission outcomes. We ran our analyses excluding recession years (2008 - 2010) to account for any effects of the recession on investment decisions made by plants in Appendix Table A.5 row 1, and we found consistency between the results.

Include settled plants. Our baseline excludes plants after lawsuits are settled. Doing so allows us to interpret the coefficient as avert action in emission reductions and does not allow us to access how NSR affects emissions from a plant after its settlement. Therefore, our counterfactual emissions tend to be a lower bound. In Appendix Table A.5 row 2 we include plants after a settlement is reached. In order to maintain a consistent interpretation, we include a dummy variable that equals one if a plant is settled in order to remove the effect on emissions that results from the legal obligation described in the settlement. We found our results are consistent with the baseline.

Alternative definition of lawsuit dates. In the baseline, we used the first date recorded in the lawsuit milestone database, i.e., "the date a case is referred to the DOJ", to determine the last year a plant was "survived" in the duration model. As explained in Section 2.2, there are different important milestones in the lawsuit dates, and using different dates has different implications in how long a plant survived. In Appendix Figure A.1 we plot the number of lawsuits using alternative definitions. This shows variation across different lawsuit date definitions. We re-estimated our baseline and reported the results in the Appendix Table A.5 rows 3.a to 3.e. We found our results are consistent across definitions although our estimates are smaller and some point estimates taper off when we use a later lawsuit date. These results suggest the importance of using an earlier date that is relevant for a plant's decision-making process. Moreover, using a much later date does not allow us to identify the effect of averting behavior from the effect of complying with the terms of a settlement.

Robustness for the extensive margin estimation. Lastly, since extensive margins can be correlated with decisions of other regional plants, we add an average lawsuit probability from other plants of the same independent system operation (ISO) in the same year to the baseline extensive model. In Appendix Table A.6, we found consistent signs compared to the baseline. The coefficient becomes larger partly due to how this ISO level control is correlated with our key variable of interest.

7 Conclusion

In this paper, we investigate how NSR lawsuits that target SO₂ and NO_x affect unregulated emissions (CO₂) and operation margins for coal- and gas-fired power plants in the US. The

New Source Review, as part of the 1977 Amendment of the Clean Air Act, regulates plant modifications to mitigate agency's differential treatments favoring old facilities under the 1970 CAA in how they produce pollution emissions, mostly SO₂ and NO_x but can affect greenhouse gas emissions via changing plant operation margins. Employing a discrete-time duration model, we found high-profile plants with large historical emissions and power generation are more likely to be subject to NSR lawsuits. In addition, plants in the Rust Belt have a higher NSR lawsuit probability than plants in other areas with a lower emission level or with a more pro-business federal circuit court.

Using our estimates of NSR probabilities, we examine how the NSR affects power plant emissions and operations using a panel data set from 1995 to 2015. We find a higher probability of NSR lawsuits not only reduces SO₂ and NO_x emissions, but also unintendedly reduces CO₂ emissions by a sizable magnitude, even though CO₂ is not regulated by the NSR. We found that the CO₂ emission reduction from a one percent increase in lawsuit risk is comparable to the effect of a \$10/ton carbon tax. This magnitude of carbon reduction suggests that future benefit analyses of the New Source Review should account for climate co-benefits from greenhouse gas emission reductions. It also suggests the importance of accounting for the interaction of policies that regulate the same industry on different inputs such as NSR (on SO₂ and NO_x) and a cap-and-trade program on CO₂ because of the spillover effect.

To further inquire as to whether other environmental policies regarding the power industry would also have led to climate co-benefits, and to inform efficient designs of future climate policies, we examine and decompose how different margins that plants can adjust in response to NSR lawsuit probabilities affect emission reductions. We found that CO₂ reductions come from both sets of plants with and without gas-fired capacity, but the extensive margin explains an important share of the co-benefits for plants without gas-fired units, while effects on operating plants (i.e. the intensive margin) are more relevant for plants with gas-fired units. Therefore, other environmental policies that can induce a sizable fuel-switch are likely to gain climate co-benefits as well, and it is important to account for the co-benefits in future analyses of these policies.

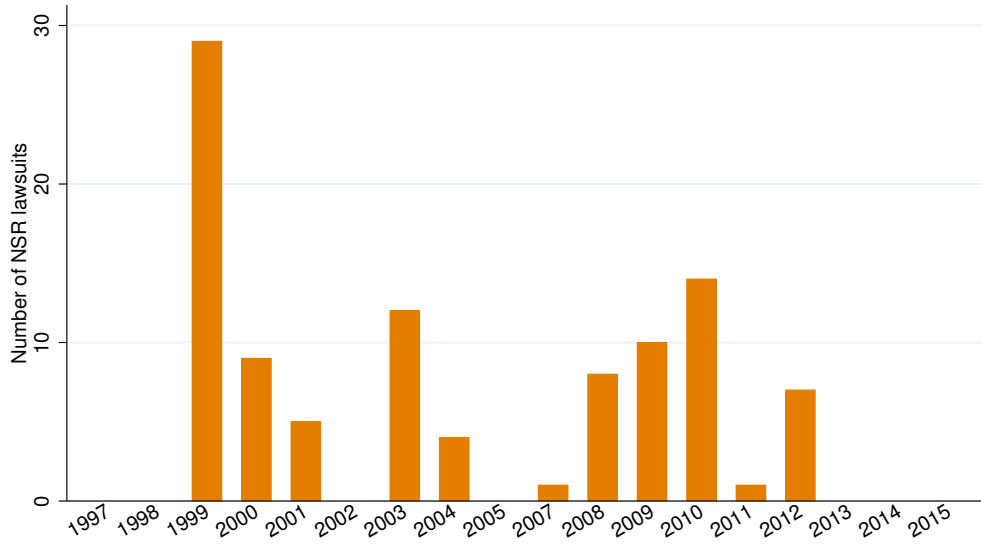
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Figures

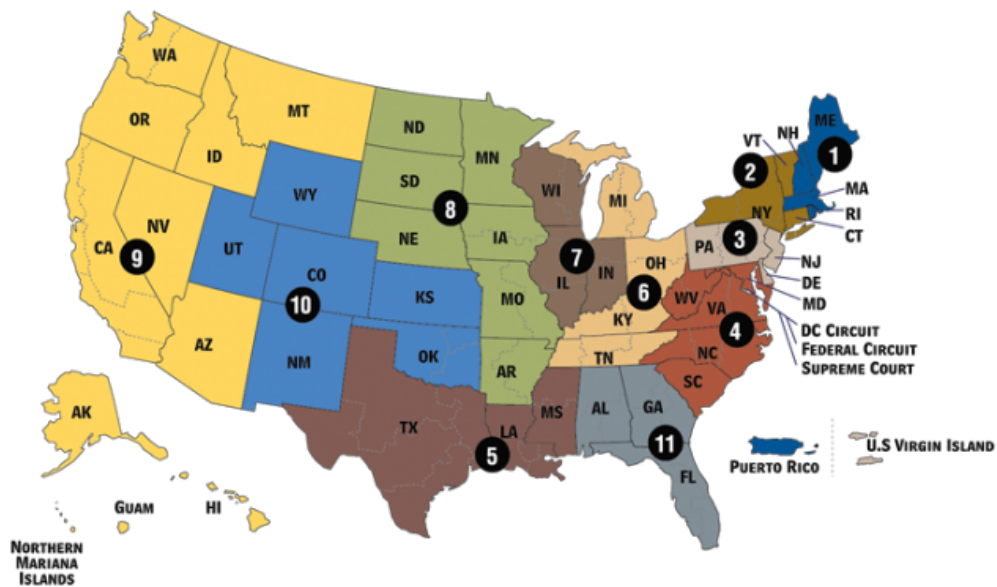
Figure 1: Number of plants involved in an NSR lawsuit, 1997 – 2015



Source: EPA Power Enforcement Web Page and Integrated Compliance Information System - Federal Enforcement and Compliance (ICIS - FE&C) dataset.

Notes: In this figure we use the date referring to DOJ. We plot the figure using alternative dates in A.1.

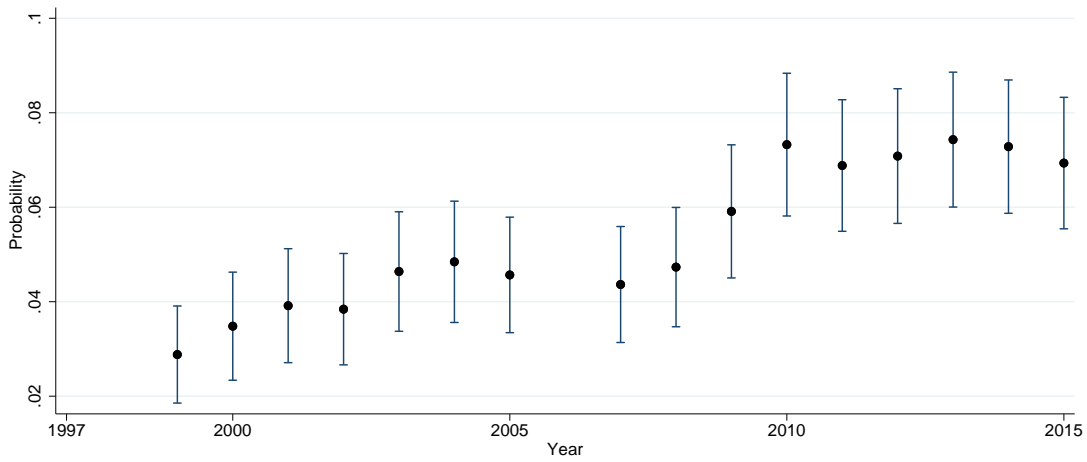
Figure 2: US federal judicial districts



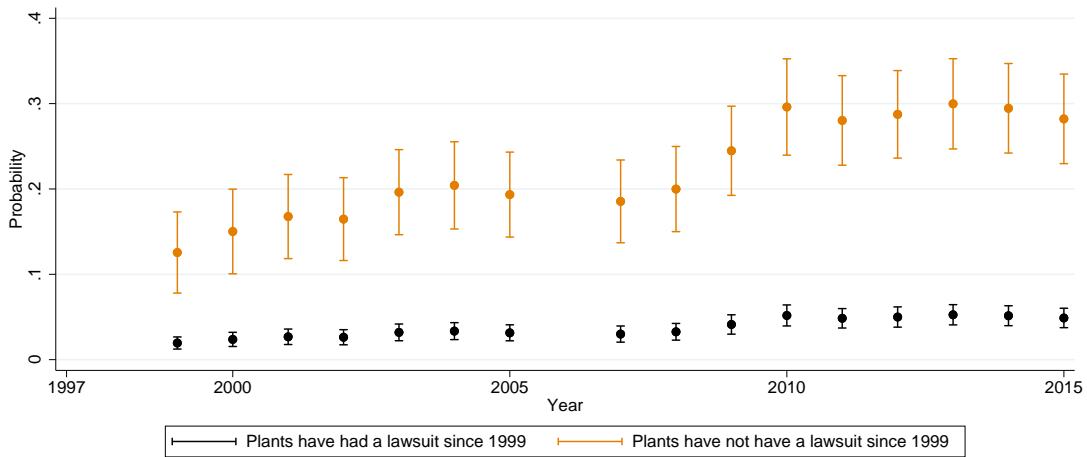
Source : US Court https://www.uscourts.gov/sites/default/files/u.s._federal_courts_circuit_map_1.pdf

Figure 3: Predicted probability of lawsuit, 1999 – 2015

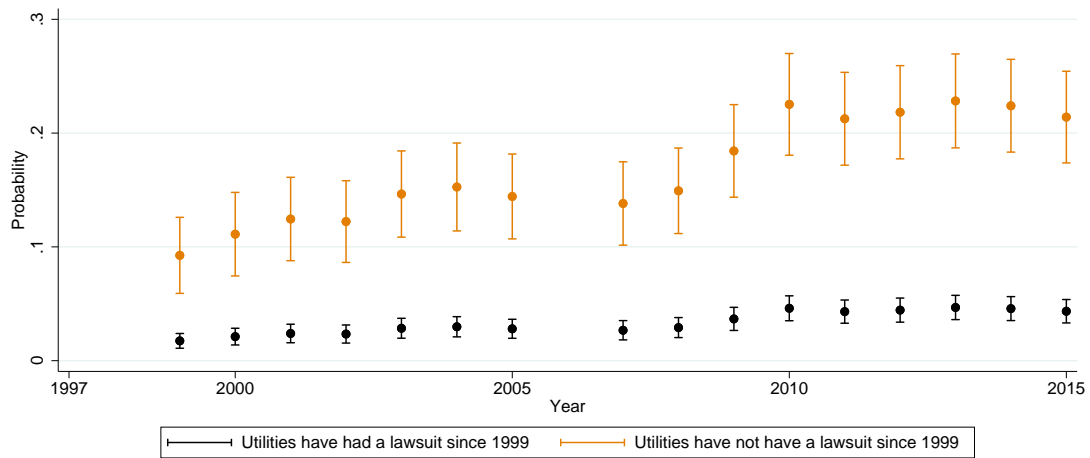
Panel A. Average predicted probability by year



Panel B. If a plant has had a lawsuit since 1999



Panel C. If the utility of a plant has had a lawsuit since 1999



Notes: This figure draws the 95-percent confidence interval of the average predicted probability of facing an NSR lawsuit for each year, based on Equation (1) and estimation results in Appendix Table A.2.

Tables

Table 1: **Number of NSR lawsuits and total emissions by U.S. judicial district**

US Federal Judicial District Number:	Number of Plants with NSR Lawsuit	Total emissions 1999–2015		
		SO ₂ (million metric tons)	NO _x (million metric tons)	CO ₂ (billion metric tons)
Circuit 1: MA, ME, NH, RI, Puerto Rico	1	1.8	0.5	0.6
Circuit 2: CT, NY, VT	0	3.6	1.1	1.0
Circuit 3: DE, NJ, PA, US Virgin Island	2	16.8	4.7	2.8
Circuit 4: DC, MD, NC, SC, VA, WV	8	16.3	6.0	3.7
Circuit 5: LA, MS, TX	0	14.7	7.1	6.2
Circuit 6: KY, MI, OH, TN	35	50.8	19.2	9.8
Circuit 7: IL, IN, WI	24	20.2	7.2	4.6
Circuit 8: AR, IA, MN, MO, ND, NE, SD	10	10.4	5.3	3.4
Circuit 9: AK, AZ, CA, HI, ID, MT, NV, OR, WA, Guam, N. Mariana Islands	1	2.9	4.2	3.3
Circuit 10: CO, KS, NM, OK, WY, UT	1	4.5	4.2	2.7
Circuit 11: AL, FL, GA	2	22.4	8.2	5.8
Total from all circuits	84			

Source: EPA Coal-fired Power Plant Enforcement webpage

Table 2: **Summary statistics of emissions and plant operations, 1999–2015**

	Mean	Std. Dev.
NSR lawsuit (1 - if a plant is in an NSR lawsuit in a year)	0.042	0.203
SO ₂ emissions (Kilo US short tons)	7.0	19.4
NO _x emissions (Kilo US short tons)	3.0	7.4
CO ₂ emissions (Mn. US short tons)	1.9	3.5
SO ₂ emissions rate (lb/mmBtu)	0.39	0.80
NO _x emissions rate (lb/mmBtu)	0.18	0.24
CO ₂ emissions rate (lb/mmBtu)	135.9	448.7
Heat rate (Giga Btu per kWh)	0.11	0.02
Gross load output (Mega Watt Hours, MWh)	2.18	3.56
Number of observations		21,421

Note: A unit of observation is a plant in a year.

Table 3: Effect of NSR lawsuits on emissions

Panel A: Overall effects for all plants						
<i>Dep. var: log of</i>	(1)	(2)	(3)	(4)	(5)	(6)
	SO ₂	NO _x	CO ₂	SO ₂	NO _x	CO ₂
Prob (NSR lawsuit)	-0.011** (0.004)	-0.013*** (0.003)	-0.004** (0.002)	-0.006 (0.006)	-0.012*** (0.003)	-0.005** (0.003)
Log output (grossload)	0.716*** (0.019)	0.874*** (0.012)	1.371*** (0.017)	1.174*** (0.140)	1.042*** (0.080)	1.250*** (0.091)
Policy: NBP	0.021 (0.059)	0.033 (0.026)	-0.040 (0.031)	-0.029 (0.075)	0.030 (0.032)	-0.039 (0.034)
Policy: CAIR	-0.317*** (0.089)	-0.108** (0.051)	-0.104** (0.047)	-0.224* (0.126)	-0.073 (0.056)	-0.129** (0.057)
Policy: RGGI	-0.587*** (0.164)	-0.060 (0.076)	0.058 (0.085)	-0.453** (0.204)	-0.009 (0.094)	0.021 (0.107)
Log natural gas price	0.352** (0.142)	0.122 (0.079)	0.069 (0.089)	0.380** (0.173)	0.137 (0.087)	0.059 (0.106)
Estimator	OLS	OLS	OLS	IV	IV	IV
Plant FE, Year FE	Y	Y	Y	Y	Y	Y
Number of observations	21,421	21,421	21,421	21,421	21,421	21,421
R-square	0.97	0.98	0.99	0.95	0.98	0.99

Panel B: Intensive margin for operating plants						
<i>Dep. var: log of</i>	(1)	(2)	(3)	(4)	(5)	(6)
	SO ₂	NO _x	CO ₂	SO ₂	NO _x	CO ₂
Prob (NSR lawsuit)	-0.004 (0.004)	-0.011*** (0.003)	-0.004*** (0.001)	-0.007 (0.005)	-0.012*** (0.003)	-0.005*** (0.002)
Log output (grossload)	0.947*** (0.028)	0.842*** (0.015)	0.956*** (0.005)	1.365*** (0.113)	1.082*** (0.088)	1.185*** (0.082)
Policy: NBP	-0.051 (0.048)	-0.005 (0.028)	-0.026* (0.014)	-0.109** (0.055)	-0.039 (0.032)	-0.058** (0.024)
Policy: CAIR	-0.367*** (0.093)	-0.101** (0.048)	-0.033 (0.023)	-0.420*** (0.097)	-0.131** (0.056)	-0.061* (0.034)
Policy: RGGI	-0.326** (0.162)	0.001 (0.080)	-0.043* (0.023)	-0.166 (0.169)	0.092 (0.088)	0.044 (0.043)
Log natural gas price	0.291** (0.145)	0.126* (0.075)	0.033 (0.060)	0.317** (0.148)	0.142* (0.078)	0.048 (0.061)
Estimator	OLS	OLS	OLS	IV	IV	IV
Plant FE, Year FE	Y	Y	Y	Y	Y	Y
Number of observations	17,769	17,769	17,769	17,769	17,769	17,769
R-square	0.97	0.98	0.99	0.96	0.95	0.95

Notes: Bootstrapped standard error clustered at plant level in parenthesis. *, **, and *** indicate statistical significance at 10, 5 and 1 percent levels respectively. All columns estimate Equation (2). We bootstrap the duration Equation (1) together with the main Equation (2) to correct for the generated variable – NSR lawsuit probability. The Panel A estimates use the full sample. The Panel B estimates were restricted to operating plants. All estimations include a historical scrubber dummy interacted with a linear and a quadratic time trend. Columns (1) – (3) are estimated using OLS. Columns (4) – (6) report our baseline IV results, in which we instrument log gross load power generation using cooling degree days (CDD).

Table 4: Effect of NSR lawsuits on emission rates and thermal efficiency

Panel A: Overall effects for all plants				
<i>Dep. var: log of</i>	(1) SO ₂ rate	(2) NO _x rate	(3) CO ₂ rate	(4) Heat rate
Prob (NSR lawsuit)	-0.013** (0.005)	-0.019*** (0.005)	-0.012* (0.007)	-0.008 (0.005)
Log output (grossload)	0.393*** (0.102)	0.218* (0.132)	0.429* (0.222)	0.170 (0.139)
Log natural gas price	0.321** (0.154)	0.141 (0.156)	0.060 (0.242)	0.004 (0.173)
Plant FE, Year FE	Y	Y	Y	Y
Number of observations	21,421	21,421	21,421	21,375
R-square	0.94	0.90	0.91	0.89
Panel B: Intensive margin for operating plants				
<i>Dep. var: log of</i>	(1) SO ₂ rate	(2) NO _x rate	(3) CO ₂ rate	(4) Heat rate
Prob (NSR lawsuit)	-0.005 (0.004)	-0.011*** (0.003)	-0.005*** (0.002)	-0.001* (0.000)
Log output (grossload)	0.344*** (0.100)	0.081 (0.085)	0.189** (0.076)	-0.015 (0.015)
Log natural gas price	0.285** (0.134)	0.143* (0.073)	0.046 (0.057)	0.003 (0.013)
Plant FE, Year FE	Y	Y	Y	Y
Number of observations	17,769	17,769	17,769	17,769
R-square	0.93	0.83	0.28	0.74

Notes: Bootstrapped standard error clustered at plant level in parenthesis. *, **, and *** indicate statistical significance at 10, 5 and 1 percent levels respectively. We bootstrap the duration Equation (1) together with the main Equation (2) to correct for the generated variable – NSR lawsuit probability. The Panel A estimates use the full sample. The Panel B estimates were restricted to operating plants. All columns estimate Equation (2) in which we instrument log gross load power generation using cooling degree days (CDD). All estimations include a historical scrubber dummy interacted with a linear and a quadratic time trend, and controls on overlapping policies (NBP, CAIR and RGGI).

Table 5: Effect of NSR lawsuits on extensive margins: Operate or shut down

<i>Dep var: 1 = Operate</i>	(1)	(2)	(3)	(4)
Marginal effects	Logit	LPM	Logit	LPM
Prob (NSR lawsuit)	-0.011* (0.006)	-0.004*** (0.001)	-0.012* (0.007)	-0.004*** (0.001)
Prob (NSR lawsuit) × Gas			0.008 (0.012)	0.000 (0.002)
IV (CDD)	-0.248*** (0.034)	-0.123*** (0.008)	-0.247*** (0.032)	-0.123*** (0.008)
Log natural gas price	0.162*** (0.033)	0.036*** (0.009)	0.162*** (0.031)	0.036*** (0.009)
Plant FE	Y	Y	Y	Y
Linear, quadratic time trend	Y	Y	Y	Y
Number of observations	14,113	21,167	14,113	21,167
Chi(2)	2,880	–	3,437	–
Chi(2)	–	0.72	–	0.72

Notes: Bootstrapped standard error clustered at plant level in parenthesis. *, **, and *** indicate statistical significance at 10, 5 and 1 percent levels respectively. We bootstrap the duration Equation (1) together with the main Equation (2) to correct for the generated variable – NSR lawsuit probability. All point estimates are marginal effects. All estimations include a historical scrubber dummy interacted with a linear and a quadratic time trend, and controls on overlapping policies (NBP, CAIR and RGGI). In column 1 and 3, we estimate a logit regression controlling for factors similar to the first stage of Equation (2). Column 1 reports the coefficients and column 2 reports the marginal effect. In columns 2 and 4 we estimate a linear probability model.

Table 6: Effect of NSR lawsuits on plants with or without the gas capacity

Panel A: Overall effects for all plants							
<i>Dep. var: log of</i>	(1) SO ₂	(2) NO _x	(3) CO ₂	(4) SO ₂ rate	(5) NO _x rate	(6) CO ₂ rate	(7) Heat rate
Prob (lawsuit)	-0.003 (0.005)	-0.011*** (0.003)	-0.005* (0.003)	-0.011** (0.005)	-0.019*** (0.006)	-0.013* (0.007)	-0.008 (0.005)
Prob (lawsuit) × gas	-0.037** (0.019)	-0.007 (0.010)	-0.002 (0.006)	-0.030* (0.016)	0.002 (0.013)	0.007 (0.013)	0.006 (0.010)
Log output	1.186*** (0.156)	1.044*** (0.091)	1.251*** (0.088)	0.403*** (0.106)	0.217 (0.137)	0.426** (0.190)	0.168 (0.156)
Log natural gas price	0.385** (0.178)	0.138 (0.090)	0.059 (0.097)	0.325** (0.146)	0.140 (0.174)	0.059 (0.250)	0.003 (0.174)
Plant FE, Year FE	Y	Y	Y	Y	Y	Y	Y
Num. of observations	21,421	21,421	21,421	21,421	21,421	21,421	21,375
R-squared	0.95	0.98	0.99	0.94	0.90	0.91	0.89
Panel B: Intensive margin for operating plants							
<i>Dep. var: log of</i>	(1) SO ₂	(2) NO _x	(3) CO ₂	(4) SO ₂ rate	(5) NO _x rate	(6) CO ₂ rate	(7) Heat rate
Prob (lawsuit)	-0.005 (0.004)	-0.012*** (0.003)	-0.005*** (0.002)	-0.003 (0.004)	-0.011*** (0.003)	-0.004*** (0.001)	-0.001* (0.000)
Prob (lawsuit) × gas	-0.028* (0.015)	-0.003 (0.008)	-0.005 (0.005)	-0.026* (0.014)	-0.002 (0.008)	-0.004 (0.004)	-0.001 (0.001)
Log output	1.377*** (0.106)	1.083*** (0.086)	1.187*** (0.077)	0.355*** (0.105)	0.082 (0.081)	0.191*** (0.072)	-0.014 (0.015)
Log natural gas price	0.322** (0.146)	0.142* (0.077)	0.049 (0.062)	0.289** (0.125)	0.144** (0.072)	0.047 (0.059)	0.003 (0.013)
Plant FE, Year FE	Y	Y	Y	Y	Y	Y	Y
Num. of observations	17,769	17,769	17,769	17,769	17,769	17,769	17,769
R-squared	0.96	0.95	0.95	0.93	0.83	0.28	0.74

Notes: Bootstrapped standard error clustered at plant level in parenthesis. *, **, and *** indicate statistical significance at 10, 5 and 1 percent levels respectively. We bootstrap the duration Equation (1) together with the main Equation (2) to correct for the generated variable – NSR lawsuit probability. All estimations include a historical scrubber dummy interacted with a linear and a quadratic time trend, and controls on overlapping policies (NBP, CAIR and RGGI). The Panel A estimates use the full sample. The Panel B estimates were restricted to operating plants. We repeat our estimation in Table 3 Columns 4–6 and Table 4 with an interaction of NSR lawsuit probability interacted with a dummy that equals 1 for plants with gas-fired generating capacity.

Table 7: Counterfactual emission reductions if the NSR likelihood increases by one percent in 2007

Panel A: Effects of emission reduction for all plants					
Total emissions	Predicted	Simulated	Difference	Percentage Change	
SO ₂ (thousand metric tons)	6,898	6,855	-43.75	-0.52 %	
NO _x (thousand metric tons)	2,403	2,374	-29.08	-1.21 %	
CO ₂ (million metric tons)	1,912	1,902	-9.87	-0.63 %	
Number of plants					1,146

Panel B: Effects by gas-fired generation capacity					
Total emissions	Predicted	Simulated	Difference	Percentage change	Number of plants
Panel B.1 – SO ₂ (thousand metric tons)					
Plants without gas capacity (percentage change)	4,873	4,859	-14.32 (14.6 %)	-0.29 %	259
Plants with gas capacity (percentage change)	2,028	1,944	-83.79 (85.4 %)	-4.13 %	887
Total	6,901	6,832	-98.11	-1.42 %	1,146
Panel B.2 – NO _x (thousand metric tons)					
Plants without gas capacity (percentage change)	1,662	1,643	-19.08 (58.2 %)	-1.15 %	259
Plants with gas capacity (percentage change)	741	727	-13.72 (41.8 %)	-1.85 %	887
Total	2,403	2,370	-32.79	-1.36 %	1,146
Panel B.3 – CO ₂ (million metric tons)					
Plants without gas capacity (percentage change)	1,144	1,138	-5.71 (51.8 %)	-0.50 %	259
Plants with gas capacity (percentage change)	768	763	-5.31 (48.2 %)	-0.69 %	887
Total	1,912	1,901	-11.02	-0.58 %	1,146

Notes: We simulated counterfactual emissions in 2007 if likelihood of NSR lawsuits increases by one percent. In Panel A, we simulate counterfactuals based on estimates of the coefficient of NSR lawsuit probability on emissions in Table 3. In Panel B, we simulate our results based on Table 6. All numbers are averages weighted by the plant-level gross load.

Table 8: Counterfactual emission reductions from plants with and without gas capacity, by intensive and extensive margins

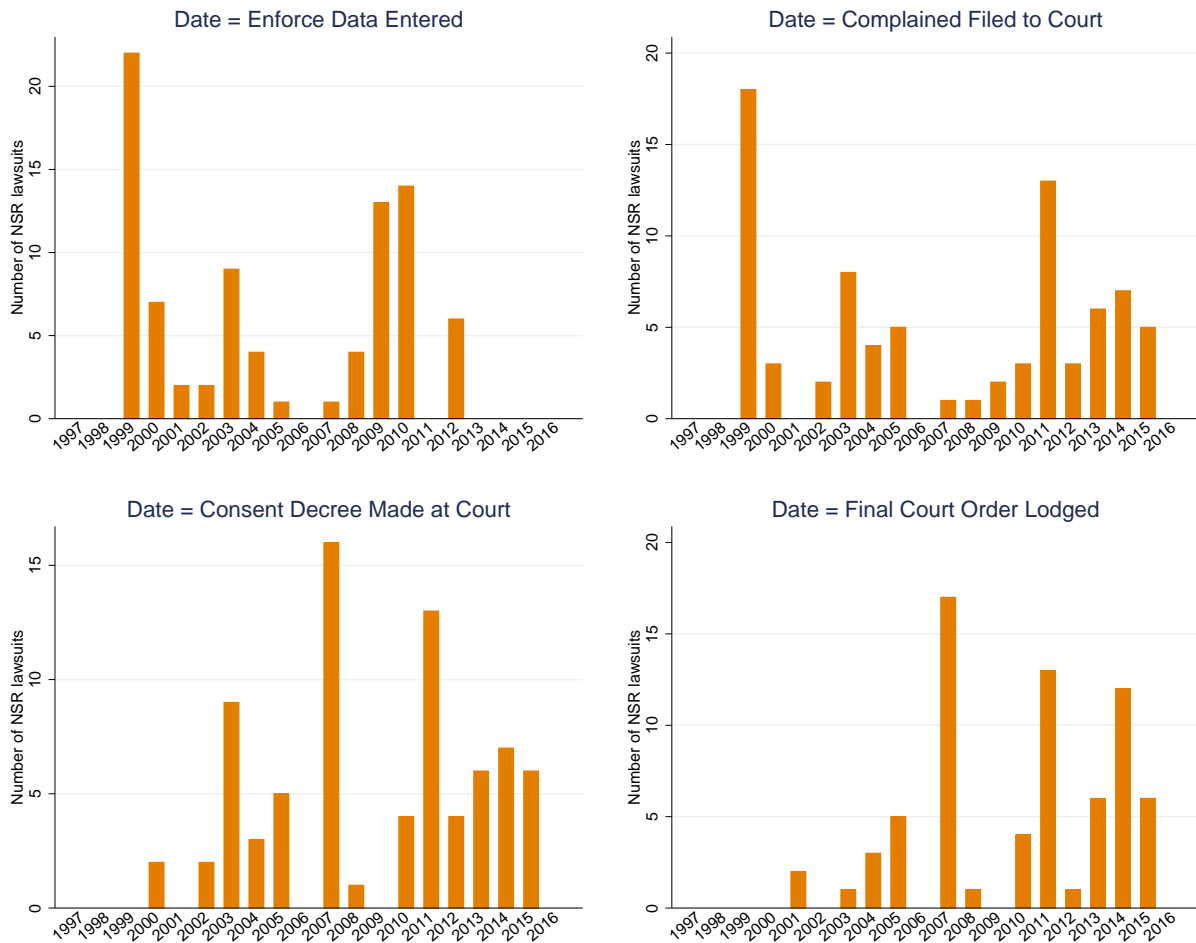
	(1)	(2)	(3)	(4)	(5)	(6)
Change in emissions:	Intensive margins		Extensive margins		Overall effects	
		(percentage changes)		(percentage changes)		(percentage changes)
Panel A. SO ₂ (thousand metric tons)						
Plants without gas capacity	-3.15	-0.06 %	-42.38	-0.85 %	-45.52	-0.91 %
(percentage changes)	(3.21 %)		(43.2 %)		(46.4 %)	
Plants with gas capacity	-44.00	-2.09 %	-8.59	-0.41 %	-52.59	-2.50 %
(percentage changes)	(44.8 %)		(8.76 %)		(53.6 %)	
Overall effects	-47.14		-50.97		-98.11	
(percentage changes)	(48.0 %)		(52.0 %)			
Panel B. NO _x (thousand metric tons)						
Plants without gas capacity	-9.58	-0.57 %	-12.19	-0.72 %	-21.77	-1.29 %
(percentage changes)	(29.2 %)		(37.2 %)		(66.4 %)	
Plants with gas capacity	-7.15	-0.94 %	-3.87	-0.51 %	-11.02	-1.45 %
(percentage changes)	(21.8 %)		(11.8 %)		(33.6 %)	
Overall effects	-16.73		-16.06		-32.79	
(percentage changes)	(51.0 %)		(49.0 %)			
Panel C. CO ₂ (million metric tons)						
Plants without gas capacity	-1.55	-0.13 %	-4.90	-0.42 %	-6.45	-0.55 %
(percentage changes)	(14.1 %)		(44.5 %)		(58.5 %)	
Plants with gas capacity	-3.27	-0.42 %	-1.29	-0.17 %	-4.57	-0.59 %
(percentage changes)	(29.7 %)		(11.7 %)		(41.5 %)	
Overall effects	-4.83		-6.20		-11.02	
(percentage changes)	(43.8 %)		(56.2 %)			

Notes: We simulated counterfactual emissions in 2007 if likelihood of NSR lawsuits increases by one percent. We decompose the counterfactual emissions from Panel A of Table 7 on operate probability and emissions. We further separate the effects by presence of gas-fired generating capacity. Our decomposition is based on results reported in Table 6 and normalized by the group-specific effects reported in Table 7, Panel A.

Online Appendix

A. Additional Figures and Tables

Figure A.1: Number of plants involved in an NSR lawsuit by alternative definitions of lawsuit dates, 1997 – 2015



Source: EPA Power Enforcement Web Page and Integrated Compliance Information System - Federal Enforcement and Compliance (ICIS - FE&C) dataset

Table A.1: Companies and plants sued for violating NSR

Utility Companies	Date Enforcement Data Enter	Date Settlement	Power Plants Sued for Violating NSR
Amer. Electric Power	Oct 01, 1999	Oct 9, 2007	John Amos, Big Sandy, Cardinal, Clinch River, Conesville, Gen Gavin, Glen Lyn, Kammer, Kanawha River, Mitchell, Mountaineer, Muskingum River, Rockspport, Phil Sporn, Picway, Tanners Creek
Illinois Power Company	Oct 21, 1999	Mar 7, 2005	Baldwin, Havana, Henneepin, Vermilio, Woodriver
Southern Indiana Gas & Electricity	Oct 21, 1999	Jun 6, 2003	Cully
Tampa Electric Company	Oct 28, 1999	Sep 10, 2001	Gannon, Big Bend
Alabama Power Company	Oct 28, 1999	Aug 24, 2015	James Miller
Ohio Edison Company	Nov 9, 1999	Mar 18, 2005	Burger, Eastlake, Sammis, Mansfield
Virginia Electric & Power	Apr 3, 2000	Sep 20, 2016	Chesapeake, Chesterfield, Clover, Mount Storm
Duke Energy	Jul 14, 2000	Sep 10, 2015	Allen, Buck, Cliffside, Dan River, Riverbend
PSEG	Oct 25, 2001	Nov 30, 2006	Bergen, Hudson Mercer, Kearny
Minnkota Power Corp	Mar 13, 2002	Apr 25, 2006	Milton Young
Alcoa Inc.	Feb 15, 2002	Feb 17, 2007	Alcoa Allowance
NV Energy	Oc 20, 2002	Apr 2, 2009	Clark
Wisconsin Electric Power	Apr 17, 2003	Apr 1, 2016	Port Washington, Pleasant Prairie, Presque Isle, South Oak Creek, Valley
East Kentucky Power	May 28, 2003	Jul 2, 2007	Spurlock, Dale, Copper
Santee Cooper	Sep 23, 2003	Mar 16, 2004	Cross, Grainger, Jefferies, Winyah
Westar Energy	Sep 30, 2004	Jan 25, 2010	Jefferey
Northern Indiana Pub Ser	Oct 12, 2004	Jan 13, 2011	Bailly, Mitchell, Michigan City, Schahfer
Louisiana Generating	Mar 30, 2005	Dec 20, 2012	Big Cajun
Kentucky Utilities Comp	May 1, 2006	Feb 3, 2009	Brown
Salt River Project	Oct 6, 2007	Aug 12, 2008	Coronado
Consumers Energy Comp	Oct 8, 2008	Sep 16, 2014	Campbell, Cobb, Karn, Weadock, Whiting
Minnesota Power & Light	Jan 26, 2009	Jul 16, 2014	Boswell, Laskin, Taconite Harbor
Dominion Energy	Sep 29, 2009	Apr 1, 2013	Brayton Point, Kincaid, State Line
Amer Municipal Power	Oct 1, 2009	May 18, 2010	Gorsuch
Hoosier Energy	Oct 1, 2009	Jul 23, 2010	Mrom, Ratts
Wisconsin Power & Light	Oct 2, 2009	Apr 22, 2013	Columbia, Edgewater, Nelson Dewey
Wisconsin Public Service	Oct 2, 2009	Apr 22, 2013	Pulliam, Weston
Tennessee Valley Authority	May 5, 2010	Apr 11, 2011	Allen, Bull Run, Colbert, Cumberland, Gallantin, Sevier, Johnsonville, Kingston, Paradise, Shawnee, Widows Creek
Dairyland Power Co-op	Oct 12, 2010	Mar 10, 2014	Alma, Madgett, Genoa
Four Corners Steam	May 16, 2011	Jun 24, 2015	Four Corners Steam
Interstate Power & Light	Jul 9, 2012	Jul 15, 2015	Burlington, Dubuque, Lansing, Kapp, Ottumwa, Prairie Creek, Sutherland, Six Street

Source: EPA Power Enforcement Webpage

Table A.2: First stage duration estimation for NSR lawsuits

<i>Dependent variable: NSR Lawsuit = 1</i>	(1) Coefficients	(2) Marginal Effects
Historical emission average	-0.105*** (0.029)	-0.005*** (0.001)
Historical emission st. dev.	0.106*** (0.028)	0.005*** (0.001)
Historical output average (10 ⁶ mega watt hours)	0.022*** (0.004)	0.001*** (0.000)
Historical output st. dev.	-0.252*** (0.028)	-0.011*** (0.001)
1 = Presence of scrubber before 1995	0.028 (0.087)	0.001 (0.004)
Plant capacity in 1997	0.548*** (0.038)	0.025*** (0.002)
1 = Presence of gas-fired units	-0.806*** (0.091)	-0.036*** (0.004)
US federal judicial district: Circuit 1	0.707 (0.444)	
US federal judicial district: Circuit 3	0.429 (0.297)	
US federal judicial district: Circuit 4	1.860*** (0.246)	
US federal judicial district: Circuit 5	-1.446*** (0.404)	
US federal judicial district: Circuit 6	2.512*** (0.232)	
US federal judicial district: Circuit 7	2.461*** (0.236)	
US federal judicial district: Circuit 8	0.895*** (0.275)	
US federal judicial district: Circuit 9	-0.356 (0.403)	
Year FE	Y	Y
Number of observations	14189	14189
Chi(2)	2090.06	

Notes: Standard error clustered at plant level in parenthesis. *, **, and *** indicate statistical significance at 10, 5 and 1 percent levels respectively. This table reports results of Equation (1). Column 1 reports the coefficients and column 2 reports the marginal effect. US judicial district circuits 2, 10 and 11 were omitted.

Table A.3: First stage results for power generation

<i>Dep var: log of</i>	(1) Gross load	(2) Net generation
Number of cooling degree days (CDD) ('000)	0.605*** (0.125)	0.379*** (0.130)
Prob (NSR lawsuit)	-0.008 (0.008)	-0.015*** (0.006)
Plant FE, Year FE	Y	Y
Number of observations	21,422	15,616
R-squared	0.87	0.53
F-stat (of exclusive var)	34.4	-

Notes: Bootstrapped standard error clustered at plant level in parenthesis. *, **, and *** indicate statistical significance at 10, 5 and 1 percent levels respectively. This table reports the first-stage estimates of Equation (2). We bootstrap the duration Equation (1) together with the main Equation (2) to correct for the generated variable – NSR lawsuit probability. We use the number of cooling degree days as the excluded variable. Other included instruments include a historical scrubber dummy interacted with a linear and a quadratic time trend, as well as controls on overlapping policies (NBP, CAIR, and RGGI). Column 1 report the first stage of our baseline estimation. Column 2 use net generation instead.

Table A.4: Effect of NSR lawsuits on scrubbers, NO_x controls, and gas share

<i>Dep. var:</i>	(1) Scrubber	(2) NO _x control	(3) log FGD energy consumption	(4) log FGD operating cost	(5) Gas share of heat input
Prob (lawsuit)	0.002** (0.001)	0.007*** (0.002)	0.022** (0.010)	0.036** (0.016)	0.003 (0.345)
Log output	0.023* (0.014)	0.077*** (0.028)	0.326* (0.180)	0.378 (0.274)	-1.603 (71.615)
Log natural gas price	0.004 (0.023)	-0.087** (0.036)	-0.352 (0.221)	-0.405 (0.342)	-0.037 (1.503)
Plant FE, Year FE	Y	Y	Y	Y	Y
Num. of observations	21,421	21,421	15,701	15,701	11,400
R-square	0.87	0.59	0.62	0.71	0.97

Notes: Bootstrapped standard error clustered at plant level in parenthesis. *, **, and *** indicate statistical significance at 10, 5 and 1 percent levels respectively. We bootstrap the duration Equation (1) together with the main Equation (2) to correct for the generated variable – NSR lawsuit probability. All columns estimate Equation (2). Flue-gas desulfurization (FGD), known as scrubber, is an abatement technology to remove SO₂. Other controls include a historical scrubber dummy interacted with a linear and a quadratic time trend, as well as controls on overlapping policies (NBP, CAIR, and RGGI).

Table A.5: Effect of NSR lawsuits on emissions: Additional robustness

Panel A: Re-estimate coefficients of Prob (NSR lawsuit) for all plants						
<i>Dep. var: log of</i>	SO ₂	NO _x	CO ₂	SO ₂ rate	NO _x rate	CO ₂ rate
1. Exclude recession	-0.006 (0.006)	-0.011*** (0.003)	-0.005* (0.003)	-0.013** (0.006)	-0.017*** (0.006)	-0.012 (0.008)
2. Include post-lawsuit	-0.006 (0.005)	-0.013*** (0.003)	-0.004* (0.002)	-0.012*** (0.004)	-0.019*** (0.005)	-0.010* (0.006)
3. Alternative lawsuit date						
3.a Enforcement data entered	-0.006 (0.005)	-0.012*** (0.003)	-0.005** (0.002)	-0.013** (0.005)	-0.018*** (0.005)	-0.012 (0.007)
3.b Refer to DOJ (baseline)	-0.006 (0.006)	-0.012*** (0.003)	-0.005** (0.003)	-0.013** (0.005)	-0.019*** (0.005)	-0.012* (0.007)
3.c Complained filed	-0.006 (0.005)	-0.011*** (0.003)	-0.003 (0.002)	-0.011** (0.005)	-0.016*** (0.005)	-0.008 (0.006)
3.d Consent decree	-0.008** (0.004)	-0.009*** (0.002)	-0.001 (0.002)	-0.008** (0.004)	-0.010*** (0.003)	-0.001 (0.005)
3.e Final order lodged	-0.006** (0.003)	-0.007*** (0.002)	-0.001 (0.001)	-0.004 (0.003)	-0.006** (0.003)	0.000 (0.004)
Panel B: Intensive margin for operating plants						
<i>Dep. var: log of</i>	SO ₂	NO _x	CO ₂	SO ₂ rate	NO _x rate	CO ₂ rate
1. Exclude recession	-0.007 (0.005)	-0.011*** (0.003)	-0.006*** (0.002)	-0.005 (0.005)	-0.010*** (0.003)	-0.005*** (0.002)
2. Include post-lawsuit	-0.007* (0.004)	-0.014*** (0.003)	-0.005*** (0.001)	-0.005 (0.004)	-0.013*** (0.003)	-0.004*** (0.001)
3. Alternative lawsuit date						
3.a Enforcement data entered	-0.007 (0.004)	-0.012*** (0.003)	-0.005*** (0.002)	-0.005 (0.004)	-0.011*** (0.003)	-0.004*** (0.001)
3.b Refer to DOJ (baseline)	-0.007 (0.005)	-0.012*** (0.003)	-0.005*** (0.002)	-0.005 (0.004)	-0.011*** (0.003)	-0.005*** (0.002)
3.c Complained filed	-0.005 (0.005)	-0.011*** (0.003)	-0.005*** (0.001)	-0.004 (0.004)	-0.010*** (0.003)	-0.004*** (0.001)
3.d Consent decree	-0.003 (0.003)	-0.008*** (0.002)	-0.002* (0.001)	-0.002 (0.003)	-0.008*** (0.002)	-0.002* (0.001)
3.e Final order lodged	-0.001 (0.002)	-0.006*** (0.002)	-0.001* (0.001)	-0.001 (0.002)	-0.006*** (0.002)	-0.001** (0.001)

Notes: Bootstrapped standard error clustered at plant level in parenthesis. *, **, and *** indicate statistical significance at 10, 5 and 1 percent levels respectively. Panel A shows the overall results and Panel B shows the results for operating plants. We only report the coefficient of lawsuit probability, and the model is equivalent to the model reported in Tables 3 and 4. Coefficients on other variables are omitted for brevity and are available upon request. In row 1, we exclude observations from 2008 to 2010. In row 2, we include years after the lawsuit date and add a post-lawsuit dummy variable. In rows 3, we use alternative lawsuit dates.

Table A.6: Effect of NSR lawsuits on extensive margins, Control for ISO

<i>Dep var: 1 = Operate</i>	(1)	(2)	(3)	(4)
	Coefficients	Marginal Effects	Coefficients	Marginal Effects
Prob (NSR lawsuit)	-0.065* (0.037)	-0.009* (0.005)	-0.074* (0.045)	-0.011* (0.006)
Prob (NSR lawsuit) × Gas			0.067 (0.077)	0.009 (0.011)
IV (CDD)	-1.587*** (0.249)	-0.228*** (0.041)	-1.589*** (0.269)	-0.227*** (0.043)
Log natural gas price	1.057*** (0.270)	0.152*** (0.033)	1.061*** (0.272)	0.151*** (0.033)
Prob (lawsuit) ISO Year	-0.349*** (0.093)	-0.050*** (0.014)	-0.350*** (0.098)	-0.050*** (0.015)
Plant FE	Y	Y	Y	Y
Linear, quadratic year trend	Y	Y	Y	Y
Number of observations	14,113	14,113	14,113	14,113
Chi(2)	2,921	–	2,932	–

Notes: Bootstrapped standard error clustered at plant level in parenthesis. *, **, and *** indicate statistical significance at 10, 5 and 1 percent levels respectively. We bootstrap the duration Equation (1) together with the main Equation (2) to correct for the generated variable – NSR lawsuit probability. All estimations include a historical scrubber dummy interacted with a linear and a quadratic time trend, as well as controls on overlapping policies (NBP, CAIR, and RGGI). We estimate a logit regression controlling for factors similar to the first stage of Equation (2). Columns 1 and 3 report the coefficients while columns 2 and 4 report the marginal effects.