

“Cleansing the air at the expense of waterways?” Empirical evidence from the toxic releases of coal-fired power plants in the United States

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Abstract Environmental policies in the United States have primarily taken the form of media-specific regulations that emphasize end-of-pipe pollution control. This can lead to the shifting of pollution across environmental media, thereby having the potential to solve one environmental problem by creating a new problem. This study uses data from 228 coal-fired power plants that report to the Toxics Release Inventory to conduct an empirical examination of the extent to which media-specific regulation has caused power plants to shift their toxic air releases to waterways, land, or transfers for offsite recycling facilities. Controlling for plant-level fixed effects, scale of production, and environmental inspections and enforcement under air regulation, this study finds that adopting tougher air pollution regulation that designates counties as being in nonattainment status with the National Ambient Air Quality Standards significantly increased toxic releases to waterways and land.

Keywords Regulation · Toxic Releases Inventory (TRI) · Cross-media substitution · Clean Air Act (CAA) · Clean Water Act (CWA) · National Ambient Air Quality Standards (NAAQS) · Inspection · Enforcement

JEL Classification Q53 · Q58

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1 Introduction

Due to stricter air pollution regulations, coal-fired power plants have increased their use of technologies such as scrubbers to prevent the release of toxics into the air. Instead, these technologies turn air pollutants into toxic sludge that is often untreated or inadequately treated and may be discharged into rivers and lakes with minimal effluent limitations ([Clean Water Action 2013](#)).¹ Defined as solid waste, coal combustion residuals captured with scrubbers are exempt under the Resource Conservation and Recovery Act (RCRA).² Public and environmental groups are increasingly concerned about the potential shift of air toxics to other environmental media, particularly waterways ([Duhigg 2009](#)).

This study empirically examines whether stricter air pollution regulation has caused coal-fired power plants to shift their air pollutants (strictly regulated media) to less regulated media (e.g., waterways and land, and transfers to offsite recycling facilities). Concerns about polluters shifting their pollutants from strictly regulated media to less regulated media (also referred to as cross-media substitution) are not unique to the power-generating sector. Other sectors, such as the steel and iron industry, have increased their use of scrubbers and electrostatic precipitators to remove air pollutants due to stricter air regulation. [Greenstone \(2003\)](#) finds that steel and iron facilities reduced their releases to all environmental media, and [Gibson \(2014\)](#) finds that the ratio of water releases to air releases were increased using facility-level data from seven industries that report to the Toxics Release Inventory.

This paper focuses on coal-fired power plants monitored under multiple environmental regulations and is especially relevant since the Environmental Protection Agency (EPA) proposed new regulations for further curtailment of air and effluent emissions from coal-fired power plants (e.g., the Mercury and Air Toxics Standards, the Steam Electric Power Generating Effluent Guidelines, and the national rule for safe disposal of coal ash).³ So far the multimedia pollution regulation on the pulp and paper industry has had limited success ([Fraas and Egorenkov 2015](#); [Gray and Shad-begian 2015](#)). Thus, an empirical examination of coal-fired power plants’ responses to existing media-specific regulations may help policy makers examine substitutions or synergies among existing regulations prior to contemplating new regulations.

The expansion of the Toxics Release Inventory (TRI) in 1998 to include the power-generating sector allows the investigation of toxic releases from coal-fired power plants. The TRI includes the quantities of toxics released to the environmental media and transfers for offsite recycling for each TRI-listed chemical by all coal-fired power plants that meet the TRI reporting threshold.⁴ In contrast to the clean water and clean

¹ EPA finalized the Steam Electric Power Generating Effluent Guidelines in November 2015 ([EPA 2015a](#)).

² Following the coal-ash spill incident at the Tennessee Valley Authority’s Kingston Plant in 2008, the first national management criteria on coal combustion residuals (coal ashes) were finalized in 2015 ([EPA 2015b](#)).

³ The Supreme Court ruled against the EPA’s Mercury and Air Toxics Standards in 2015 ([EPA 2015c](#)).

⁴ Manufacturing facilities that have 10 or more full-time employees and manufacture, process, or use specified chemicals in amounts exceeding 25,000 pounds per year for manufacturing or processing, or 10,000 pounds per year for otherwise use, must submit annual reports to the EPA ([EPA 2015d](#)).

air regulations, the objective of the TRI is to incentivize polluters to reduce toxic releases through disclosing toxic pollution information to the public. Although there are no penalties for power plants emitting large volumes of TRI releases, studies show that the disclosure of toxic releases through the TRI has motivated firms to voluntarily reduce pollution to avoid adverse publicity or reduce regulatory scrutiny (Arora and Gangopadhyay 1995; Hamilton 1995; Khanna and Anton 2002; Konar and Cohen 2001; Sam 2010). Facilities with high levels of TRI releases have undertaken proactive efforts such as adopting environmental management systems and pollution prevention technologies to reduce total TRI releases (Khanna 2001; Khanna and Brouhle 2009; Sam 2010; Harrington 2012; Harrington et al. 2014). These initiatives may prompt power plants to reduce emissions to all environmental media.

However, the full extent to which information disclosure through the TRI could lead to reduction of releases to all environmental media could be limited given the current media-specific regulatory framework. Specifically, some of the TRI-listed chemicals are precursors of regulated air pollutants under the clean air regulation. Power plants faced with higher costs to comply with the CAA relative to the CWA may adopt scrubbers, which shift air toxics into the land or waterways. Thus, an empirical investigation is necessary to examine the net effect of clean air regulation on toxic releases to all environmental media.

The objective of this paper is to investigate the effects of air regulations on the quantities of toxic chemicals released to air, water, land, and transferred for offsite recycling by coal-fired power plants, while controlling for production scale and public pressures. This study uses panel data from 228 coal-fired power plants that reported to the TRI over the period of 1999 to 2011 to estimate the effects on toxic chemicals directly regulated by the clean air regulation and other toxic chemicals that are not regulated by any environmental regulation. In contrast to the existing literature, this study controls for scale of production, plant-specific regulatory deterrence, and general regulatory deterrence under the CAA. Furthermore, it examines the deterrence effect generated from CAA on release to other environmental media and the regulatory spillovers to unregulated toxic pollutants.

This study finds that the tougher CAA regulation designating counties as being in nonattainment status with the National Ambient Air Quality Standards (NAAQS) significantly increased power plants' toxic releases to waterways and land. Additionally, inspection under the CAA on other power plants in the same state significantly increased toxic releases to waterways, whereas enforcement under the CAA on other power plants in the same state reduced toxic releases to waterways.

2 Related literature

Empirical studies on the impact of clean air regulation show that the CAA reduces air pollution, improves the health of the population, and reduces environmental damage to the ecosystem (EPA 1999). At the same time, it also imposes direct compliance costs to polluters. These studies focus on NAAQS and the designation of attainment and nonattainment status to counties. For example, they find that the designation of nonattainment status deterred firms from building new manufacturing plants, thus

reducing capital stocks, labor, outputs, and county tax revenues (Greenstone 2002; List et al. 2003; Carr 2011; Walker 2011).

Studies on environmental regulation and enforcements have focused primarily on regulated pollutants, such as conventional water pollutants (biochemical oxygen demand and total suspended solids) and hazardous wastes, but not on toxic water pollutants. They show that regulatory threats deter future violations, and reduce non-compliance and emissions (Laplante and Rilstone 1996; Nadeau 1997; Stafford 2002; Earnhart 2004; Shimshack and Ward 2005, 2008; Gray and Shimshack 2011; Shimshack 2014). Specifically on air regulation, Gray and Deily (1996) find that steel-making plants are more likely to be in CAA compliance after inspection or if they had received an enforcement action in the past 2 years. Nadeau (1997) focuses on pulp and paper plants to examine the duration of noncompliance with respect to the predicted probability of receiving enforcement and monitoring actions. He finds that the higher probability of receiving enforcement or monitoring actions significantly reduced CAA noncompliance. However, the effects of the predicted enforcement or monitoring actions are statistically significant and negative only for plants in noncompliance. Hanna and Oliva (2010) use plant-level data on TRI releases and CAA inspections and enforcements from 1987 to 2001 to examine the effect of unannounced inspections and penalties on toxic air emissions from manufacturing plants that reported to the TRI. They find that plants reduced air emissions in the years following an inspection. Lim (2016) finds that manufacturing plants in California did not significantly reduce their emissions of nitrogen oxides in response to inspection in the previous period, they did reduce emissions after receiving more enforcement actions in the previous period. However, with the exception of Hanna and Oliva (2010), these studies do not examine the indirect effects of regulation on pollutants released to other environmental media. Hanna and Oliva (2010) find that manufacturing plants reduced toxic releases to the air following an inspection while increasing toxic releases to other media within 5 years. However, they have not examined releases to other media separately nor included the power-generating sector, which was not included in the TRI until 1998.

Earlier studies examining whether there is regulation-induced substitution across media pathways find mixed evidence. Greenstone (2003) models the percentage changes of toxic releases to air, water, and land with respect to a county's attainment status, and finds almost equal reductions in releases to all media due to tougher air regulation. Alberini (2001) models the use of underground storage tanks by gas stations with respect to the use of aboveground storage tanks, and finds that they became substitutes after the imposition of regulations on underground tanks. Sigman (1996) finds that air regulation against chlorinated solvents reduced emissions across all media. But firms may have substituted onsite treatment with offsite treatment of the solvents since transfers for offsite treatment increased when state taxes on solvent incineration increased.

Gibson (2014) conducts a thorough analysis on the cross-media substitution imposed by CAA regulation using all TRI facilities from 1987 to 2010. Under the assumption of constant returns to scale, he models the log ratio between water and air releases with respect to a county's nonattainment status. He finds that the log ratio of water to air releases increased by 44% due to the designation of the nonattainment status for particulates.

This study contributes to the literature in the following ways. This is the first empirical analysis that focuses on coal-fired power plants and their toxic releases to air, water, land and transfers for offsite recycling. Unlike previous studies on environmental regulation that used only a county's nonattainment status under the NAAQS as a proxy for regulatory pressure, this study examines CAA inspections and enforcements on power plants in addition to a county's nonattainment status.

This study uses seemingly unrelated regressions (SUR) with plant-level fixed effects controlling for the production scale and the correlation between releases to air, water, and land. [Gibson \(2014\)](#) has imposed the constant return-to-scale assumption to estimate the effect of the CAA regulation on the log ratio between releases to water and air, and [Greenstone \(2003\)](#) models the percentage changes of toxic releases to air, water, and land with respect to a county's attainment status without controlling for output. While [Greenstone \(2003\)](#) and [Gibson \(2014\)](#) only examine the toxic chemicals that are precursors of the regulated air pollutants, this study extends the analysis to unregulated toxic chemicals to identify the spillover effect from environmental regulation to unregulated toxic chemicals.

3 Toxic emissions from coal-fired power plants and environmental regulations

Coal-fired power plants are one of the largest contributors of air toxics in the United States. The coal combustion process releases nitrogen oxides, sulfur dioxide, particulate matter (e.g., fly ash and dust), mercury, and volatile organic compounds (VOCs) that include various toxic chemical compounds. Coal-fired power plants account for 75% of the acid gas, 60% of the sulfur dioxide, 13% of the nitrogen oxides, 50% of the mercury, and 62% of the arsenic released into the air in the United States ([EPA 2013a](#)). Nitrogen oxides and sulfur dioxide react with water, oxygen, and other chemicals to form acid rain, while nitrogen oxides and VOCs react in the presence of sunlight to form ground-level ozone pollution.

One of the provisions of the CAA is to ensure that ambient air quality meets the federal standards.⁵ Every county in the United States must comply annually with the NAAQS for six criteria air pollutants: carbon monoxide, sulfur dioxide, total suspended particulates (particulate matter), ground-level ozone, nitrogen oxides, and lead ([EPA 2015e](#)). Counties where the air quality does not meet the NAQQS are designated nonattainment areas, and a county can be in attainment for one pollutant and out of attainment for another.

The implementation of the NAAQS is a joint responsibility of the states and the EPA. Facilities in nonattainment counties receive stronger controls ([Greenstone 2003](#)). Particularly, states are required to develop state implementation plans (SIPs) to improve air quality in nonattainment counties. Federal sanctions for states failing to implement SIPs include restrictions to a state's use of highway funds for projects in the nonat-

⁵ These standards "must be set based on science without regard to costs of implementing pollution controls to achieve the standards" and are reviewed every 5 years to determine whether a revision is required ([EPA 2013a](#), p. 3).

tainment areas and requirements to implement federal plans to improve air quality in the nonattainment areas (EPA 2015e).

Each state’s SIP must identify measures for controlling pollution from existing and new stationary sources. After a state adopts a SIP, EPA must review each element of the SIP to approve or disapprove it, which then becomes federally enforceable matter (EPA 2015e). For example, reasonable available control technology (RACT) pollution controls are required for existing major stationary sources (e.g., power plants) in nonattainment areas. All new and modified major stationary sources are required to install the lowest achievable emission rate (LAER) pollution controls regardless of costs in nonattainment areas, meaning that LAER pollution controls are more stringent than RACT pollution controls. Alternatively, new stationary sources can obtain offsetting emissions reductions elsewhere in the nonattainment area with a ratio of 1:1. Once an area has achieved attainment, a state is required to submit a maintenance SIP, demonstrating the capacity to attain, maintain, and enforce any new or revised NAAQS. Furthermore, new or modified major stationary sources in attainment areas are subject to Prevention of Significant Determination New Source Review (PSDNSR) requirements. According to PSDNSR requirements, new or modified major stationary sources must not have a significantly negative impact on air quality and must install best available control technology (BACT). The appropriate BACT is determined in a case-by-case manner, considering environmental, economic, and energy impacts (EPA 2015e).

In the face of tightened national emission standards⁶ and pollution control strategies identified in SIPs for criteria air pollutants, coal-fired power plants have adopted various end-of-pipe pollution control systems, which may shift the air pollutants to water, land or offsite recycling facilities. For example, all coal-fired power plants installed electrostatic precipitators or baghouses (resembling a large vacuum with fabric filters) to remove particulates (Bellas and Lange 2010). Collected particulates and combustion residuals often are released to land. By 2011, around 67% of the coal-fired power plants have installed selective catalytic reduction (SCR) and non-selective catalytic reduction (NSCR) systems to reduce nitrogen oxides (EIA 2013). These systems remove nitrogen oxides by injecting water with ammonia or urea into flue gas (Moretti and Jones 2012). Additionally, all power-generating units constructed after 1978 are required to install scrubbers designed to remove up to 99% of the sulfur dioxide and particulates from the emission streams (Frey 2013). These scrubbers (flue-gas desulfurization systems) remove sulfur dioxides with alkaline sorbents and water. By 2011, the adoption rate for scrubbers was 60% in all coal-fired power plants in

⁶ New power plants built after 1970 are subject to new source performance standards for sulfur dioxides emissions as per the 1970 CAA. The 1990 CAA amendments further mandated power plants to reduce 50% of sulfur dioxides emission by 2010, compared to the 1980 level, through cap and trade program (Ferris et al. 2014; Frey 2013). Regulations for nitrogen oxides became strengthened after 1990 CAA amendments. Emission standards were updated in 1990, 1994, and 1998 in the northeastern states. National standards were expected to achieve 0.4–0.46 lb/million British thermal units (Btu) by 2000 compared to the standard of 0.5–0.6 lb/mmBtu in 1977 (Popp 2010). Furthermore, all power plans constructed after 2005 are required not to exceed 0.11 lb/million Btu of nitrogen oxides, 0.15lb/million Btu of sulfur dioxides, and 0.015lb/Btu of particulate matter (EPA 2006). I use year dummy variables to control for time specific shocks to all power plants.

the United States (EIA 2013). Sorbent materials in scrubbers can be further recycled for reuse, which may increase the amount of waste for recycling (Moretti and Jones 2012). Thus, many critics are concerned that coal-fired power plants are reducing air toxics by increasing emissions to other environmental media and transfers for offsite recycling.

Toxic releases to waterways is a particular concern since coal-fired power plants are the largest source of toxic water pollution, contributing 50–60% of all toxic pollutants discharged to surface water (Clean Water Action 2013). Their wastewaters contain large amounts of toxic metals and nutrients (i.e., arsenic, mercury, selenium, lead, cadmium, boron, bromides, nitrogen, and phosphorus). Many critics are concerned coal-fired power plants are not being held accountable for emitting large amounts of toxic pollutants due to the regulation gap on toxic water pollutants and the lack of stringency of enforcing existing CWA regulation.

The regulation of discharging pollutants into waterways is under the CWA's National Pollutant Discharge Elimination System (NPDES) program, which issues discharge permits to all point source polluters. In contrast with the joint implementation of the NAAQS between EPA and the states under the CAA, administration of CWA compliance monitoring and permitting is mainly at the state level. As a result, the permitting, setting effluent limits, and monitoring of toxic water pollutants are inconsistent across states. A review of the history of 383 coal-fired power plants using the EPA's enforcement and compliance online database found that nearly half of them operate on expired permits and nearly 70% of them do not have effluent limits on toxic metals (chemicals) and nutrients (Clean Water Action 2013). Furthermore, the stringency of enforcement and monitoring of the existing CWA has been low (Anderson 1986). Data from Shimshack and Ward (2008) indicate that the median fine was US\$9000, and there were only 39 fines levied on 251 major polluters over a 12-year period.

To address the regulatory gap on toxic water pollutants, EPA first enlisted 126 toxic “priority pollutants” for developing discharging standards based on “best available technology economically achievable” for specific industry categories, and for developing the NPDES permitting program under the CWA. Based on this list, the EPA finalized the Steam Electric Power Generating Effluent Guidelines for power plants to limit their emissions of toxic metals (chemicals) to waterways in 2015. This rule established new, more stringent discharge limits for wastewater streams from power plants, particularly scrubber wastewater, that are to be completed between 2018 and 2020, depending on when a power plant needs a new CWA discharge permit (EPA 2015a).

There are available technologies that reduce air pollution from coal-fired power plants without necessarily increasing releases to other media. For example, power plants can use dry injections of sorbents (EPA 2015a). This process, together with other end-of-pipe dry-handling methods, has the potential to reduce emissions to waterways and land. Additionally, power plants can use source reduction activities or pollution prevention to reduce releases to all environmental media. For example, as opposed to controlling nitrogen oxides emissions post-combustion, some coal-fired power plants have changed the combustion conditions and temperatures to reduce the emission of nitrogen oxides (Popp 2010). Furthermore, power plants can also substitute high-sulfur

coals with low-sulfur coals or natural gas, which contributes to the decline of sulfur dioxide and nitrogen oxides (EIA 2013; Ferris et al. 2014).

Currently, the TRI is the only dataset that allows one to compare releases to all media for a given set of toxic chemicals over time. Following the TRI expansion in 1998 to include the power-generating sector, a coal-fired power plant subject to TRI reporting must report its onsite toxic releases to environmental media, and its onsite and offsite recycled toxic materials for each TRI-listed chemical. It is important to note that not all TRI releases are directly regulated (EPA 2015g) even though some are precursors of criteria air pollutants (Greenstone 2003). Based on Greenstone (2003) and the TRI regulatory matrix (EPA 2015g), specific TRI chemicals are identified as precursors of particulate matter and ground-level ozone pollutants in this study (i.e., 50 TRI chemicals as precursors of particulate matter, 135 TRI chemicals as precursors of VOCs, and 30 TRI chemicals contribute to both particulate matter and VOCs). The aforementioned end-of-pipe pollution controls, such as scrubbers and baghouses, reduce these toxics released to the air while removing sulfur dioxide, nitrogen oxides, and particulates.

4 Empirical framework

Following previous studies (Holland 2010; Fullerton and Karney 2014; Gibson 2014), this study assumes that a power plant uses multiple pollutants (e.g., releases to air and releases to water) as inputs for producing electricity since releasing pollutants entails costs to comply with environmental regulations. Specially, a coal-fired power plant chooses the amounts of releases to air, water, land and offsite recycling facilities simultaneously. The following system indicates conditional input demand functions for pollutants released to the environmental media and offsite recycling facilities,

$$\ln w_{it} = \vartheta_i + P_{A,it-1}\beta_{11} + \delta_{13}\ln q_{it} + \beta_{14}C_{it} + \sum_{t=2}^{t=T} \gamma_t + u_{1,it} \quad (1)$$

$$\ln a_{it} = \vartheta_i + P_{A,it-1}\beta_{21} + \delta_{23}\ln q_{it} + \beta_{24}C_{it} + \sum_{t=2}^{t=T} \gamma_t + u_{2,it} \quad (2)$$

$$\ln l_{it} = \vartheta_i + P_{A,it-1}\beta_{31} + \delta_{33}\ln q_{it} + \beta_{34}C_{it} + \sum_{t=2}^{t=T} \gamma_t + u_{3,it} \quad (3)$$

$$\ln r_{it} = \vartheta_i + P_{A,it-1}\beta_{41} + \delta_{43}\ln q_{it} + \beta_{44}C_{it} + \sum_{t=2}^{t=T} \gamma_t + u_{4,it} \quad (4)$$

where $\ln w_{it}$, $\ln a_{it}$, $\ln l_{it}$, $\ln r_{it}$ denote the log of toxic releases to waterways, air, land and recycling by plant i at year t . $P_{A,it-1}$ denotes a vector of proxies for regulatory pressures to comply with clean air regulation and $\ln q_{it}$ denotes the log of the output. ϑ_i represents time-invariant plant-specific effect, such as geographic location; γ_t represents the year fixed effect that affects all power plants in a given year t , such as

macroeconomic growth; and C_{it} represent a vector of proxies for time-varying public pressures that vary by the county and state in which a plant is located.

This system of Eqs. (1–4) is estimated through seemingly unrelated regressions (SUR) with plant-level fixed effects. Specifically, the dataset is restructured through stacking observations by equation and adding plant-level dummy variables (see details in Blackwell 2005). Although all four equations use the same set of explanatory variables, using SUR controlling for plant-level fixed effects produces more efficient estimates than estimating the equations one at a time since it accounts for cross-equation correlations in the error components (Hsiao 2014).

4.1 Dependent variables

CAA Water, *CAA Air*, *CAA Land*, and *CAA Recycle*: There are 594 individually listed chemicals and 31 chemical categories in the TRI. Based on the regulation matrix on the TRI-listed chemicals (EPA 2015g) and Greenstone (2003) that identified TRI chemicals as precursors of particulate matter and ground level ozone pollutants, the releases from these CAA-regulated chemicals by environmental media can be calculated for each power plant. The dependent variables *CAA Air*, *CAA Water*, *CAA Land*, and *CAA Recycle* represent the natural log of releases to air, water, land and transfers to offsite recycling facilities from the CAA-regulated chemicals.

4.2 Choice of covariates

Three types of measurements served as proxies for the pressures to comply with the clean air regulation. First, previous studies have used the annual nonattainment status of the county with respect to NAAQS as proxy for regulatory pressures. Similarly, this study focuses on the change of attainment status for particulate matter (PM) and ground-level ozone (ozone) since all counties had reached attainment status for other criteria pollutants by 1998.

PM nonattainment and *ozone nonattainment*: These are dummy variables that equal to 1 if a county fell into nonattainment with PM or ozone, respectively, in a given year, and 0 otherwise. Following previous studies, the change in a county's attainment status as exogenous to a plant's toxic releases and the two variables are lagged by one period in the estimations to allow time for counties and power plants to respond to the regulation (Greenstone 2003; Gibson 2014). The source for each county's attainment/nonattainment status was EPA's Green Book Nonattainment Areas for Criteria Pollutants (EPA 2013b).

Second, environmental enforcements and inspections are used to measure deterrent effects on polluters of conventional air pollutants emitted from the power plants. Data on the inspections and enforcements for clean air programs from the EPA's AIRS Facility Subsystem (AFS) database, which includes plant-level information on inspection, enforcement, and civil penalties under the existing air pollutant regulatory programs (EPA 2012). This database can be linked to the TRI using a unique identifier provided by the EPA, and the total number of CAA inspections and enforcements for each power plant are calculated. Following Lim (2016), two types of enforcement actions are included in the analysis: non-monetized enforcement action including delivering

a notice of noncompliance, issuing EPA or state administrative orders, notices of violation, court consent decrees, and plans for judicial action; and enforcement with civil penalties (fines) (EPA 2012).

CAA inspections, enforcements, and penalties on specific power plants: These explanatory variables represent the number of CAA inspections and enforcements, and the amount of civil penalties on a coal-fired power plant to measure the plant-specific deterrence effect, and reflect all possible regulatory tools to achieve CAA compliance. Based on the empirical framework, prior inspections, enforcements, and penalties under CAA regulation would increase the costs of compliance with CAA regulation, which could reduce toxic air releases while increasing toxic releases to other environmental media. These variables are lagged by one period in the estimations because polluting plants typically form their expectations based on previous sanctions (Hanna and Oliva 2010; Lim 2016; Shimshack and Ward 2005, 2008).

Power plants receiving greater number of inspections or enforcements in the previous period are expected to be more likely to reduce releases (Laplante and Rilstone 1996; Nadeau 1997; Stafford 2002; Earnhart 2004; Gray and Shadbegian 2007; Shimshack and Ward 2005). However, the effect of inspections relative to enforcements and penalties may depend on the empirical context since some studies find that only enforcements and penalties had statistically significant and negative effects on emissions, while other studies find that both inspections and enforcement reduced emissions significantly as reviewed in Gray and Shimshack (2011). In other cases, enforcements and penalties may not induce further emission reductions when the additional abatement costs to meet compliance would far exceed potential penalties (Hanna and Oliva 2010).

Furthermore, the cross-media substitution effects induced by regulatory actions may differ by types of actions. Inspections may motivate a plant to meet compliance, with the plant beginning with the cheapest abatement options. For example, the disposal of air toxics into wastewater or ash ponds may present a cheaper option than transferring toxics to offsite recycling facilities. Hanna and Oliva (2010) find the positive cross-media substitution effect induced by inspection is statistically significant in the 4 years after the inspection. However, this substitution effect became insignificant after 4 years, indicating TRI plants eventually choose to properly dispose toxics in long run. Thus, it is likely that CAA inspections would increase toxic releases to waterways in this analysis. In contrast, CAA enforcements and penalties are directed at violators identified from inspections in previous years, which may force power plants to resort to more expensive abatement options rather than simply disposing of air toxics into wastewater or ash ponds. Thus, it is likely that enforcement actions and penalties would reduce toxic releases to air and waterways, while increase transfers for recycling.

CAA inspections, enforcements, and penalties on other power plants: These variables represent the average number of inspections and enforcements, and average amounts of penalties on other power plants in the same state to approximate the general deterrence effect. Shimshack and Ward (2008) and Keohane et al. (2009) find that an enforcement action on another polluting plant in the same state may have strengthened the reputation of the regulator, and thus may have a general deterrence effect on other polluting power plants in the same state. Thus, CAA regulation actions directed at other power plants in the same state are expected to reduce air toxic releases due

to general deterrence effect but could increase toxic releases to other environmental media.

Sales: To control for the change in production scale at the plant-level, the natural log of sales (dollars) is used.⁷

County's per capita income and unemployment rate: Power plant's location reported in the TRI is matched with its county's annual per capita household income and unemployment rate during the 1998 to 2011 period to approximate public pressures (BEA 2012; BLS 2016). Using data from census tracts, Bell and Ebisu (2012) find that a community's unemployment rate was positively associated with exposure to particulate matter in the United States. Arora and Cason (1998) find that counties with higher unemployment rates (above 10%) had lower total TRI releases, possibly due to reduced economic activities. Counties with higher median household income had higher TRI releases, but the income effect was inconsistent across regions in the United States. It is likely that power plants located in counties with higher unemployment rate or lower per capita income would emit fewer air releases due to lack of economic activities.

State's league of conservation voters (LCV) score: LCV publishes an annual national environmental scorecard, which calculates the average score of a state's House of Representative members on their voting on environmental issues. The annual score (based on a scale of 0 to 100) is calculated by dividing the number of pro-environment votes cast by the total number of votes scored and then averaged by the number of congressional delegates from a state. The LCV score measures the state's congressional representatives' pro-environmentalism in a given year, assuming the voting pattern of the House of Representative members reflect the preference of their constituency (Chakraborti 2016). The state's annual LCV score is included in the analysis to approximate community and public pressure that influenced a power plant's decision on pollution control. Power plants located in a state with higher LCV scores are expected to face greater public pressure to reduce their toxic releases (Shadbegian and Gray 2003).

Table 1 summarizes the variables used in the analysis. Between 1998 and 2011, the major media pathways of toxic emissions from the coal-fired power plants were releases to air and land, followed by releases to water and transfers for offsite recycling.

5 Results

5.1 Toxic chemicals regulated under the CAA

Table 2 summarizes the estimates with four different dependent variables in the system of equations: releases to air, releases to waterways, releases to land, and transfers for offsite recycling from the regulated chemicals under the CAA.

⁷ The U.S. Energy Information Administration (EIA) changed its methodology between 2004 and 2008 on allocating fuel consumption between electric power generation and useful thermal output. As a result, data on thermal output are not comparable before and after the adjustment. EIA and National Establishment Time-Series (NETS) consistently report sales revenue, which is created based on archival establishment data from the Dun and Bradstreet (D&B). I used the sales reported in NETS in this analysis.

Table 1 Summary statistics (1998–2011)

Variable names	Mean	Standard deviation
<i>Releases classified by environmental media and by regulatory status</i>		
Toxic chemicals regulated under the CAA (log)		
CAA water	2.42	3.33
CAA land	4.75	5.72
CAA recycle	0.82	2.44
CAA air	10.32	3.81
Toxic chemicals not regulated by any environmental regulation (in natural log)		
Unregulated water	0.50	1.71
Unregulated land	3.49	5.07
Unregulated recycle	1.67	3.67
Environmental regulation		
PM nonattainment (dummy)	0.15	0.35
Ozone nonattainment (dummy)	0.31	0.46
Plant-specific deterrence		
CAA inspection (count)	0.60	0.63
CAA enforcement (count)	0.05	0.37
CAA civil penalty (log)	0.59	2.38
General deterrence		
Average CAA inspection on other power plants in the same state (count)	2.07	3.27
Average CAA civil enforcement on other power plants in the same state (count)	0.05	0.16
Average CAA penalties on other power plants in the same state (log)	0.71	1.49
Other variables		
Sales (log)	17.18	1.50
County unemployment rate (%)	6.10	2.71
County per capita income (log)	10.38	0.25
State LCV scores (%)	47.43	22.80

First, the designation of a county’s PM nonattainment status significantly reduced toxic air releases from the CAA-regulated chemicals by 52% (Table 2, column 1, row 1).⁸ The designation of nonattainment status on ground-level ozone also decreased a plant’s toxic air releases by around 27% (Table 2, column 1, row 2).

⁸ Since the dependent variable is log of releases, the effect of the dummy variable in terms of percentage change should be $(e^{\hat{\beta}} - 1)$, where $\hat{\beta}$ is the estimated coefficient reported in the regression results (Wooldridge 2010). When $\hat{\beta}$ is small in magnitude, it is close to $(e^{\hat{\beta}} - 1)$. For simplicity, this study reports $\hat{\beta}$ as the approximate percentage change.

Table 2 Effects of CAA and CWA on releases of CAA regulated chemicals

Variables	Dependent variables			
	CAA air	CAA water	CAA land	CAA recycle
PM nonattainment ($t - 1$)	-0.52*** (0.10)	0.06 (0.07)	0.27*** (0.09)	-0.03 (0.08)
Ozone nonattainment ($t - 1$)	-0.27*** (0.09)	0.17*** (0.07)	-0.4*** (0.09)	0.18*** (0.08)
CAA inspection ($t - 1$)	0.03 (0.03)	0.08*** (0.02)	0.01 (0.03)	-0.07*** (0.03)
CAA enforcement ($t - 1$)	0.15 (0.10)	0.09 (0.06)	0.07 (0.08)	0.05 (0.07)
CAA penalty ($t - 1$)	0.01 (0.01)	0.01 (0.00)	-0.01 (0.01)	0.02 (0.02)
Avg. CAA inspections on other power plants ($t - 1$)	0.01 (0.01)	0.02** (0.01)	0.01 (0.01)	-0.01 (0.02)
Avg. CAA enforcements on other power plants ($t - 1$)	-0.11 (0.18)	-0.34*** (0.12)	-0.25 (0.17)	0.04 (0.15)
Avg. CAA fines on other power plants ($t - 1$)	-0.06*** (0.01)	0.01 (0.01)	-0.01 (0.01)	0.02 (0.01)
Sales (log)	0.11*** (0.03)	0.05*** (0.02)	-0.10*** (0.03)	0.07*** (0.03)
County per capita income (log)	1.32*** (0.55)	1.09*** (0.39)	1.93*** (0.53)	-0.25 (0.47)
County unemployment rate (%)	0.02 (0.02)	-0.04*** (0.01)	-0.10*** (0.02)	-0.04** (0.02)
State LCV scores (%)	-1.13*** (0.28)	-0.43*** (0.19)	0.83*** (0.26)	0.08 (0.23)

Table 2 continued

Variables	Dependent variables			
	CAA air	CAA water	CAA land	CAA recycle
Constant	0.73*** (0.11)	0.42*** (0.08)	0.36*** (0.11)	−0.24*** (0.10)
Year dummies	Included	Included	Included	Included
Observations	2736	2736	2736	2736
R ²	0.09	0.03	0.02	0.01

Standard errors are in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Estimated with seeming unrelated regressions controlling for plant-level fixed-effects

It is noteworthy that the pattern of cross-media substitution differed by designation status for PM and ground-level ozone. Releases to land were increased significantly (by 27%) due to the nonattainment status of PM. In contrast, the designation of a county’s ozone nonattainment significantly increased the toxic releases to waterways by 17% and transfers for offsite recycling by 18%, but reduced the releases to land by 40% (Table 2, row 2).

This difference can be explained by the use of abatement methods to remove particulates, sulfur dioxides, and nitrogen oxides, with the latter two contributing to the formation of ground-level ozone. Wet scrubbers with alkaline sorbents or water with ammonia or urea are used to reduce sulfide dioxide and nitrogen oxides (Moretti and Jones 2012). Both processes produce toxic slurries that could be released to waterways. Sorbent materials can be further recycled for reuse (Moretti and Jones 2012), which may increase the amount of wastes for recycling. However, particulates are collected through electrostatic precipitators or baghouses (Bellas and Lange 2010), which are collected with combustion residuals released to ash pounds on land.

Second, receiving one additional CAA inspection in the previous period did not significantly reduce releases to air (Table 2, column 1, row 3). This is consistent with Lim (2016) who finds that manufacturing plants in California did not reduce emissions of nitrogen oxides as the number of inspections increased. However, receiving one additional CAA inspection in the last period significantly increased releases to waterways by about 8%, while reducing transfers for offsite recycling by about 7%, holding other variables fixed (Table 2, columns 2 and 4, row 3). In addition, power plants did not significantly reduced releases to the environmental media or transfers for offsite recycling in response to increases in the number of plant-specific CAA enforcements and the amount of penalties, after controlling for the number of CAA inspections they received in the previous period. This finding is similar to Hanna and Oliva (2010) in which they find that CAA penalties did not significantly reduce toxic air emissions. It is likely that coal-fired power plants that were violators of CAA may incur far greater abatement costs than penalties to reduce toxic air releases.

Additionally, an additional increase in the average number of previous CAA inspections on other power plants in the same state significantly increased the toxic releases to waterways by 2% (Table 2, column 2, row 6). In contrast, while an additional increase

in the average number of previous CAA enforcements on other power plants reduced toxic air releases (though not statistically significantly), it significantly reduced the releases to waterways by 34% (Table 2, column 2, row 7). Moreover, a 1% increase in the average amount of CAA penalties on other power plants also significantly reduced the air releases by 0.06% (Table 2, column 1, row 8). It is likely that enforcements levied on other power plants in the same state in the previous period increased a power plant's probability of sanctions through increasing the creditability of the regulator's willingness to be tough on polluters. Hanna and Oliva (2010) point out that the cross-media substitution effect by CAA inspection declined as polluters eventually used proper pollution abatement methods. Thus, the threat from regulatory enforcement may motivate power plants to resort to abatement options other than discharging air toxics directly into wastewater.

The identified cross-media substitution effects of CAA regulation are economically significant, though the risks to human health and the environment depend on many other factors such as the toxicity of the chemicals and the exposure pathways (i.e., inhalation or ingestion). The sample averages of toxic air, land, and water releases from the CAA-regulated chemicals were 603,159, 183,198, and 2,118 pounds, respectively. Based on the estimates in Table 2, the nonattainment status designation on ground-level ozone pollutants led to a reduction of 138,726 pounds of toxic air releases and increased toxic releases to land and water by 3680 and 525 pounds, respectively, from an average power plant. In contrast, the nonattainment status designation on PM reduced toxic air releases by 235,232 pounds, increased releases to land by 120,632 pounds, but did not affect toxic releases to waterways. One additional CAA inspection on a power plant increased its water releases by 175 pounds, and one additional CAA inspections on other power plants increased its water releases by 44 pounds.

Furthermore, sales were positively associated with air, water, and the amounts transferred for offsite recycling, but were negatively associated with releases to land. Power plants in counties with higher per capita income emitted more releases to air, land and waterways. Though communities with higher income level are more likely to demand pollution reduction, the identified positive association perhaps is due to the greater level of economic activities and power demand. Power plants located in counties that had higher unemployment rate had lower releases to water and land. Consistent with the expectation, power plants located in states with higher LCV scores had lower levels of toxic releases to air and water but higher levels of toxic releases to land from the CAA-regulated chemicals. This may be because combustion residuals (often collected in ash pounds on land) were exempted from solid waste regulations during the study period.

5.2 Precursors of PM

Robustness check is conducted by focusing on precursors of PM, as did Greenstone (2003) and Gibson (2014). These findings are consistent with the main results reported in Table 2, but the magnitudes of the estimated parameters differ because precursors of PM are a subgroup of CAA-regulated chemicals.

The designation of PM nonattainment status resulted in a 13% reduction in air releases and a 24% increase in releases into land (Table 3, columns 1 and 3, row 1). This identified effect differs from Gibson (2014) who finds that the PM nonattainment designation increased the ratio of water to air releases from the precursors of PM by 44%, but did not significantly affect toxic releases to land. However, this study finds that the increase in toxic releases to waterways is due to the designation of ground-level ozone status, which Gibson (2004) does not address. This difference is probably because this study is on coal-fired power plants and Gibson (2014) includes all TRI reporting facilities.

Additionally, having an additional CAA inspection on other power plants in the last period significantly reduces releases to air but significantly increased releases to water (Table 3, row 5); and an increase in the average number of enforcements on other power plants in the last period resulted in a 26% reduction of releases into water and a 29% increase in transfers for offsite recycling (Table 3, row 6). These findings are consistent with findings in Table 2. It indicates that power plants reduce toxic air releases by converting them into wastewater following inspections; while enforcements on other power plants in the same state may have motivated power plants to choose perhaps more sophisticated pollution abatement methods, such as offsite recycling, rather than discharging toxics into wastewater.

5.3 Unregulated toxic chemicals

CAA regulation may also affect releases of unregulated toxic chemicals. The effect would depend on the complementarity or substitutability between unregulated chemicals and CAA-regulated chemicals. For example, the 2014 West Virginia chemical spill resulted in the contamination of drinking water for more than 100,000 residents. The culprit chemical used to wash coal is unregulated. In this case, it would be complementary to toxic air pollutants emitted in the process of generating power. Unregulated chemical releases also would increase if releases to water from the CAA-regulated chemicals increased due to CAA regulation.

Additional analysis on releases to waterways, land, and transfers for offsite recycling from chemicals with no environmental regulations is reported in Table 4. Even through these toxic chemicals are not directly regulated by any environmental regulation, the pattern of regulatory spillover is similar to those of the regulated chemicals in that water releases increased with tougher air regulation.

For unregulated chemicals, the designation of PM nonattainment status did not statistically affect air releases but the designation of ground-level ozone nonattainment status significantly reduced air releases from these chemicals by 49% (Table 4, column 1, rows 1 and 2). Both designations also increase releases to waterways by 10% and 30%, respectively (Table 4, column 2, rows 1 and 2). Releases to land are significantly reduced due to ground-level ozone nonattainment designation by 66% (Table 4, column 3, row 2), but transfers for offsite recycling are significantly increased by 37% and 19% due to designation of PM and ground-level ozone nonattainment status, respectively (Table 4, column 4, rows 1 and 2).

Table 3 Effects of CAA and CWA on releases of precursors for particulate matter

Variables	Dependent variables			
	PM air	PM water	PM land	PM recycle
PM nonattainment ($t - 1$)	-0.13*** (0.06)	-0.12 (0.07)	0.24*** (0.09)	0.06 (0.08)
CAA inspection ($t - 1$)	0.02 (0.07)	0.04 (0.06)	-0.08 (0.11)	-0.06 (0.04)
CAA enforcement ($t - 1$)	0.02 (0.05)	0.01 (0.06)	0.09 (0.10)	-0.01 (0.11)
CAA penalty ($t - 1$)	0.01 (0.02)	-0.002 (0.02)	0.003 (0.03)	0.03 (0.06)
Avg. CAA inspections on other power plants ($t - 1$)	-0.02** (0.01)	0.02** (0.01)	0.03 (0.03)	-0.01 (0.03)
Avg. CAA enforcements on other power plants ($t - 1$)	-0.11 (0.11)	-0.26*** (0.12)	-0.13 (0.17)	0.29*** (0.07)
Avg. CAA fines on other power plants ($t - 1$)	-0.05 (0.03)	-0.01 (0.03)	-0.01 (0.01)	-0.06 (0.06)
Sales (log)	-0.01 (0.02)	0.05*** (0.02)	-0.1*** (0.03)	0.08*** (0.03)
County per capita income (log)	1.32** (0.33)	1.15*** (0.38)	2.61*** (0.51)	0.04 (0.07)
County unemployment rate (%)	-0.01 (0.01)	-0.04*** (0.01)	-0.08** (0.02)	-0.02** (0.01)
State LCV scores (%)	-0.67*** (0.17)	-0.34* (0.19)	0.62*** (0.25)	0.21 (0.23)
Constant	5.61*** (0.22)	3.12*** (0.16)	5.92*** (0.35)	0.65*** (0.15)

Table 3 continued

Variables	Dependent variables			
	PM air	PM water	PM land	PM recycle
Year dummies	Included	Included	Included	Included
Observations	2736	2736	2736	2736
R ²	0.07	0.03	0.02	0.01

Standard errors are in parentheses. *** $p < 0.01$; ** $p < 0.05$, * $p < 0.1$. Estimated with seeming unrelated regressions controlling for plant-level fixed-effects

Table 4 Effects of CAA and CWA on releases of unregulated chemicals

Variables	Dependent variables			
	Unregulated air	Unregulated water	Unregulated land	Unregulated recycle
PM nonattainment ($t - 1$)	−0.07 (0.08)	0.10*** (0.04)	0.04 (0.10)	0.37*** (0.11)
Ozone nonattainment ($t - 1$)	−0.49*** (0.07)	0.30*** (0.03)	−0.66*** (0.10)	0.19* (0.11)
CAA inspection ($t - 1$)	0.08 (0.05)	−0.03 (0.03)	0.04 (0.03)	0.02 (0.04)
CAA enforcement ($t - 1$)	0.01 (0.06)	−0.06 (0.06)	−0.02 (0.08)	−0.04 (0.09)
CAA penalty ($t - 1$)	0.01 (0.01)	−0.01 (0.01)	0.01 (0.01)	−0.03*** (0.01)
Avg. CAA inspections on other power plants ($t - 1$)	−0.03*** (0.01)	−0.01 (0.02)	−0.03*** (0.02)	−0.10*** (0.01)
Avg. CAA enforcements on other power plants ($t - 1$)	−0.54*** (0.14)	−0.01 (0.07)	−0.28 (0.18)	0.48*** (0.20)
Avg. CAA fines on other power plants ($t - 1$)	−0.01 (0.01)	0.001 (0.01)	0.01 (0.01)	−0.08*** (0.02)
Sales (log)	0.001 (0.03)	0.05*** (0.01)	−0.02 (0.03)	−0.11*** (0.04)

Table 4 continued

Variables	Dependent variables			
	Unregulated air	Unregulated water	Unregulated land	Unregulated recycle
County per capita income (log)	4.16*** (0.43)	−0.51*** (0.22)	1.8*** (0.56)	0.71 (0.62)
County unemployment rate (%)	−0.11*** (0.01)	0.002 (0.01)	−0.17*** (0.02)	−0.04** (0.02)
State LCV scores (%)	0.45*** (0.22)	−0.13 (0.11)	1.07*** (0.28)	0.26 (0.31)
Constant	0.90*** (0.09)	−0.13*** (0.05)	0.24*** (0.12)	0.33*** (0.12)
Year dummies	Included	Included	Included	Included
Observations	2,736	2,736	2,736	2,736
R ²	0.07	0.02	0.02	0.02

Standard errors are in parentheses. *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$. Estimated with seeming unrelated regressions controlling for plant-level fixed-effects

Since these chemicals are unregulated, CAA inspections, enforcements, and penalties are not expected to directly affect their releases to air, except though complementing or substituting the CAA regulated chemicals. As expected, plant-specific inspections, enforcements, and penalties do not significantly influence releases to the environmental media, and transfers for offsite recycling from these unregulated chemicals. However, an additional increase in the average number of CAA inspections on other power plants in the same state in the previous period reduced toxic releases to air and land by 3% from these unregulated chemicals. An additional CAA enforcement on other power plants in the same state in the last period significantly reduced the toxic air releases but increase the amounts transferred to offsite recycling from the unregulated chemicals (Table 4, columns 1 and 4, row 7). This suggests that power plants reduce unregulated onsite air releases by transferring toxics to offsite recycling facilities for recycling, which would lead to more appropriate disposal than directly discharging toxics into wastewater.

6 Conclusions

This study presents an empirical analysis of the indirect effects of existing media-specific regulation. Data from 228 coal-fired power plants that report to the TRI are used to examine the extent to which media-specific regulation lead power plants to shift their toxic air releases to other environmental media and transfers for offsite recycling.

One of the key contributions of this study is that both county-level nonattainment designation and the history of environmental inspections and enforcement under the CAA are used to approximate the regulatory pressures faced by the coal-fired power plants. The effects of regulatory pressures on releases to the environmental media and transfers for offsite recycling are examined simultaneously. Furthermore, toxic chemicals are classified into three groups: chemicals regulated under the CAA (primarily Hazardous Air Pollutants), precursors of particulate matter pollutants, and unregulated chemicals.

This study suggests that future research on environmental regulation should take into account the potential spillovers across the environmental media, as well as from regulated and unregulated pollutants. The pattern of substitution differs by type of pollution controls. Specifically, in the study, coal-fired power plants increased their toxic water releases by 17% and transfers for offsite recycling by 18% due to ground-level ozone nonattainment designation, and their releases to land by 27% due to PM nonattainment designation.

There are few caveats with this analysis arising from data limitations. This analysis only applies to the 228 coal-fired power plants that report to the TRI and are included in EPA’s National Enforcement and Compliance History Online Data. This analysis focuses on toxic pollutants, particularly from toxic chemicals identified as precursors of criteria air pollutants. Since permitting and monitoring of toxic water pollutants are inconsistent across states and over time, it is particularly challenging to link enforcement actions with CWA permits information. With the implementation of the new wastewater effluent limits from the coal-fired power plants, future analyses may improve this analysis by controlling discharge permits and effluent limits on both conventional and toxic water pollutants.

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