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Abstract

The US refining industry is a leading producer of sulfur oxide and nitrogen oxide emissions. As a result of the Clean Air Act, it has been subject to a host of environmental regulations that prescribe the production processes firms can employ and limits their emissions based on the permits they hold. Refiners must also produce gasoline that varies in quality by location to meet local, state and federal air quality standards. Empirical evidence suggests that a much larger proportion of firms in the industry have been non-compliant with Clean Air Act statutes than in other industries. We study the link between gasoline content regulation and the compliance behavior of refineries. We find that in areas with more stringent gasoline regulation, there was increased compliance on the part of firms.

JEL-Code: Q530, Q580, L520.

Keywords: Clean Air Act, compliance behavior, energy markets, product regulation, petroleum refining, environmental pollution.

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1. Introduction

The petroleum refining sector is a leading manufacturing industry in the United States in terms of its contribution to the economy. It refines crude oil and produces various transportation fuels, nonfuel products (such as asphalt) and chemical industry feedstock. In 2010, it produced about 37% of total energy consumed nationally and 94% of transportation fuels.[2] It has been subject to significant environmental regulation as a result of the Clean Air Act Amendments of 1990 and has undergone a major structural transformation since then. Many refineries are now large-scale operations owned by firms that are vertically integrated. However, there are a sizable number of independent operations smaller in size, although they only produce a fraction of industry output. For reasons of efficiency, petroleum refineries are usually located near historical crude oil sources, ports and near major urban centers.

The refining industry is unique because it is subject to regulation regarding the environmental impacts of its *operation*s and also its *products*.[3] To improve air quality in dense metropolitan areas, gasoline produced by refineries is regulated ("content" regulation) based on the location of the market where they are sold, and by time of year (ambient temperatures affect pollution). The refining process also releases significant amount of pollutants.

The Clean Air Act has forced refiners to make significant investments in upgrading their facilities. A variety of chemicals produced from refinery operations are subject to federal, state and local regulations on air and water pollution. Inspection of refineries is done both at the federal and at the state level. However, non-compliance with these regulations is quite pervasive.

[2] See http://www1.eere.energy.gov/manufacturing/industries_technologies/petroleumrefining_profile.html

[3] Other industries (e.g., chemicals, drugs and food) are also subject to product regulation, but they may primarily be federal and therefore largely uniform acrosss states. The extent of spatial variability in product regulation may be unique to refining.

Since 2000, the EPA has negotiated 31 settlements with 105 refineries that accounted for over 90% of industry capacity. These settlements have taken the form of civil penalties worth $93 million, investments by refiners of more than $6.5 billion in control technologies and additional environmental projects. These "consent decrees" have had a significant effect on annual emission reductions by the industry, totaling 93,000 tons of nitrogen oxides (NO_X), 255,500 tons of sulfur dioxide (SO_2) and other pollutants such as benzene, volatile organic compounds and particulate matter.[4] Most enforcement activity was completed by 2005.[5]

Refineries face both *process* and *product* regulation under the Clean Air Act. That is, they make changes in their production process and must meet product regulation requirements, as in the case of gasoline. In this paper, we study the effect of product regulation, specifically two programs - the Reformulated Fuels Program (RFG) and the Oxygenated Fuels Program (OXY) - on the compliance behavior of refineries subject to process regulation. Specifically, we measure the impact of enforcement actions and RFG and OXY programs on refiners' compliance with Clean Air Act statutes. We compare the impact of inspections undertaken at the state level and by the EPA at the federal level on compliance as well as on refinery emissions. We use data on US refineries over the period 2003-2006. By focusing on a single industry, we avoid the problem of controlling for inter-industry differences in the stringency of regulation, in the type of pollutants emitted and the technologies used for compliance.

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[4] See EPA webpage on compliance and enforcement case results at http://www.epa.gov/compliance/resources/cases/civil/caa/oil/. The literature on compliance with environmental regulation, which we discuss later in the paper, has mostly focused on water pollution, specifically in industries such as pulp and paper and steel (see Gray and Shimshack, 2011).

[5] See EPA Enforcement: National Petroleum Refinery Initiative (2011) available at http://www.epa.gov/compliance/resources/cases/civil/caa/refineryinitiative-powerpoint021111.pdf

Given the unique nature of this industry, and the extent of noncompliance with regulation, there have been no studies that examine the possible link between product regulation and firm compliance. Moreover, to the best of our knowledge, this paper is the first attempt to study compliance behavior in the refining industry.

We find a clear positive effect of product regulation on firms' compliance with process regulation, i.e., refineries are more likely to be compliant with air quality regulation in regions where they are also subject to product regulation. We control for the endogeneity of product regulation which may arise if refineries participate in lobbying for stricter RFG or OXY programs. We also examine the possibility that gasoline regulation in a given state may affect consumption in other states because of interstate movement of product. The results are robust to this formulation.

In section 2, we describe the regulatory environment in the refining sector. In section 3, we discuss related literature. In section 4, we present the specification of the empirical models. Section 5 contains a description of the data. Estimation results are presented in section 6. Section 7 concludes the paper.

2. Regulation of the refining sector

Throughout the nineties, the petroleum refining sector exhibited one of the highest levels of non-compliance with environmental regulation. Violations of air emissions standards were identified at nearly all refineries inspected (US EPA, 2004).[6] As a consequence, this sector was designated

[6] Compared to 17 other sectors that were also subject to air quality emission regulation, annual emissions from the petroleum refining sector ranked number one for emissions of volatile organic compounds (VOCs) and for sulfur dioxide (SO_2), second for nitrogen oxides (NO_x), fourth for carbon monoxide (CO) and eighth for particulate matter (PM) (US EPA, 2004).

as a “national priority” in 1996 by the Environmental Protection Agency (EPA), which led to an increase in the number of enforcement actions in the following years.[7]

In Table 1, we report the number of facilities in petroleum refining and other manufacturing sectors that reported data on the Toxic Release Inventory database,[8] the share of facilities that were inspected and the number of inspections and enforcement actions taken. This data is reported for two 5-year periods (1990-1995 and 2003-2008). As seen from the table, petroleum refining has been a major focus of regulation in recent years. This sector reported the highest average number of inspections per facility and the highest number of enforcement actions per facility inspected.[9] The increase in the number of enforcement actions undertaken in the refining industry is quite striking. The average number of actions per facility inspected, which was 5.50 over the 1990-95 period, increased to 7.79 over the 2003-08 period. This is much higher than the corresponding figures for the other sectors, which is consistently below 2 over the 2003-08 period. Designation of the petroleum refining sector as a national priority by the EPA may also explain the high enforcement to inspection rate, which peaked at 0.60 during the 2003-08 period - the rate of inspection in the other sectors was always below 0.20.

Several factors may explain the high level of non-compliance in the refining sector. Since 1980, the number of refineries has declined but many of the remaining refineries have expanded their capacity and increased their utilization rate. As individual refineries got larger, aggregate

[7] For a recent comprehensive review of the effectiveness of monitoring and enforcement in the US, see Gray and Shimshack (2011).
[8] The Toxic Release Inventory (TRI) database of the EPA contains information on the annual release of about 650 chemicals by manufacturing and other industries meeting certain mandated thresholds. The goal is to inform and empower communities regarding toxic releases in their jurisdictions. More information can be found at http://www.epa.gov/tri/index.htm
[9] Over the 1990-1995 period, 93% of the facilities had been inspected. This number decreased to 78% in the 2003-08 period. The total number of inspections in this sector remained relatively constant between the two periods, but the ratio of facilities that have been inspected in the latter period decreased because the number of facilities in the TRI reporting system has more than doubled.

emissions from each refinery increased as well. However, this was not always reflected in state permitting activity, since permits did not immediately adjust to the increase in capacity. This may have led to a higher number of refineries being out of compliance at any given time. Thus part of the non-compliance with regulatory requirements identified in the industry may relate to capacity expansion (US EPA, 2004). Another reason for the higher level of non-compliance among refineries may be higher regulatory standards, particularly the requirements imposed by the Clean Air Act Amendments of 1990. These requirements, which make petroleum refining one of the most heavily regulated industries, forced refineries to make substantial investments in upgrading their production processes to reduce emissions and also alter their product mix (US EPA, 1995). Some refineries may have delayed or avoided making these capital investments, contributing to the high incidence of non-compliance.

The petroleum refining industry is quite unique in that the regulatory actions aimed at the industry are not only directed at reducing the environmental impacts of the refineries but also mandate specific product qualities for the purpose of reducing the environmental impacts associated with the downstream use of gasoline. Among them, regulations imposed on the formulation of gasoline are the most important, including the Oxygenated Fuels Program (OXY) and the Reformulated Fuels Program (RFG). These are examples of *product* regulation that specify the type of product that must be sold by refiners.[10]

Following the passage of the 1970 amendments of the Clean Air Act, the EPA established separate National Ambient Air Quality Standards (NAAQs - a minimum level of air quality that must be met by all counties) for four criteria pollutants: carbon monoxide, tropospheric ozone,

[10] A recent paper by Auffhammer and Kellogg (2011) provides a nice description of the goals of EPA's gasoline content regulation especially the RFG and Reid Vapor Pressure (RVP) programs. They show that the two programs did not lead to appreciable reductions in atmospheric ozone levels because given the flexibility accorded to refiners, they reduced a type of chemical that was only weakly related to ozone formation.

sulfur dioxide, and total suspended particulates. As part of this legislation, every county in the U.S. receives separate non-attainment or attainment designations for each of these four pollutants annually. The non-attainment designation is awarded to counties whose air contains concentrations of a pollutant that exceed the relevant federal standard (Greenstone, 2002).

The EPA and state and local government agencies are responsible for administering environmental laws. In most instances, state environmental agencies take the primary role in compliance assurance. This role includes educating the regulated community on the requirements, reviewing and approving necessary permits, inspecting for compliance with applicable laws and permit terms, detecting violations, and taking appropriate enforcement measures.[11]

Under the OXY Program which was implemented in November 1992, all gasoline sold in the 39 carbon monoxide non-attainment areas must have a minimum of 2.7 percent oxygen (by weight) for at least the four winter months.[12] The higher oxygen content lowers the levels of carbon monoxide produced during combustion, leading to less air pollution.[13] This program required significant investments in oxygenate production facilities. The RFG Program required the use of reformulated gasoline by January 1, 1995 in nine U.S. metropolitan areas with the worst ground level ozone problems. Other non-attainment areas can "opt in" to the program as a way of reducing ozone levels. Such reformulated gasoline must have a minimum oxygen content of two percent by weight, a maximum benzene content of one percent by volume, and no lead or

[11] See the EPA Compliance and Enforcement Webpage at http://www.epa.gov/compliance

[12] In most regions, the OXY program was in place from beginning November to end-February. However, some areas implemented them from October to January.

[13] In the carbon monoxide non-attainment areas in California, the winter fuel oxygen content is set at 1.8 to 2.2 percent because higher oxygen levels also increase nitrogen oxide emissions to unacceptable levels (for which the area is also in non-attainment).

manganese along with some other requirements on the emissions mix (see US EPA, 1995, for greater details).[14]

3. Previous Work

Compliance behavior

Analysis of compliance in the industrial sector has been at the core of numerous studies. Helland (1998a) discusses the effectiveness of targeting of firms by regulators for the pulp and paper industry and factors that affect the firm's decision to voluntarily provide information on violations without being inspected. Nadeau (1997) studies the same industry but focuses on the effectiveness of the EPA in reducing the time during which firms are non-compliant, a key goal of monitoring is to reduce this time period as much as possible. Gray and Deily (1996) use plant level data from the steel industry to examine the effect of enforcement on compliance as well as of compliance decisions on enforcement by the regulator (EPA). Laplante and Rilstone (1996) was one of the first studies to deal with the endogeneity of inspections – the idea that the threat of an inspection as well as actual inspections may have an effect on firm emissions.

Earnhart (2007) focuses on the difference between firms' emission levels and the stringency of the permit on the degree of compliance for municipal wastewater treatment plants in Kansas. Earnhart (2004a,b) distinguishes between federal and state inspections and enforcement actions. Shimshack and Ward (2005) find that the reputation of the regulator developed by levying fines has a significant positive effect on compliance both on the targeted plant and on other firms in the state. Related studies have examined absolute pollution levels with or without reference to

[14] Additional programs that aim to control the quality of finished products were part of the Clean Air Act Amendments of 1990. They include the Highway Diesel Fuel Program, the Leaded Gasoline Removal Program, and the Reid Vapor Pressure Regulations of 1989 and 1992. In this paper we focus on OXY and RFG programs, which are the two major programs regulating gasoline content.

permitted levels (Helland, 1998b). The simple distinction between compliance and non-compliance fails to acknowledge the fact that many facilities overcomply with effluent limits (McClelland and Horowitz, 1999; Arora and Cason, 1996; Earnhart, 2007), and may underestimate the impact of enforcement on environmental quality (Shimshack and Ward, 2008).[15] In the empirical application presented in this paper, we will study the compliance status of the plant. Because we do not observe standards, we will not be able to consider overcompliance.

Enforcement actions

Enforcement actions (inspections, administrative orders, notice of violations, warning letters and telephone calls) in general and inspections in particular are acknowledged as factors influencing compliance. Inspections are commonly regarded as most important by the firms (Magat and Viscusi (1990); Gray and Deily (1996)). Since there is generally a lag before firms can make the required capital investments to alter their performance level, inspections at earlier dates are commonly introduced in models describing compliance status or level, in addition to variables measuring current enforcement actions. One obvious question concerns the possible endogeneity of enforcement actions since regulators may reduce enforcement pressure at plants currently in compliance. It therefore appears appropriate to replace observed enforcement pressure at the current period by a measure of enforcement pressure (Gray and Deily 1996) that would be predicted by a set of exogenous variables. Using data on pulp and paper mills over 1982-85, Magat and Viscusi (1990) find that plants that were inspected in the past quarter are more likely to comply with water pollution regulations.[16] Gray and Deily (1996), using data on steelmaking

[15] Theoretical models by Arora and Gangopadhyay (1995), Kirchoff (2000) and Cavaliere (2000) have shown that consumer preferences for environmental quality could generate over compliance as a market outcome.
[16] These authors consider inspections to be one of the most important components of any enforcement program.

plants during the years 1980-1989, show that lagged enforcement (whether measured as inspections or total actions) significantly increases the probability that a plant is in compliance. The coefficient of predicted enforcement in the current period is positive but not significant for either inspections or total actions. This suggests that past inspections have a greater impact on compliance than current inspections and could occur because of the delay between inspection and corresponding investment and other abatement actions taken by the plant.

Laplante and Rilstone (1996) measure the impact of current and past inspections on emissions levels of plants (relative to the standard) in the pulp and paper industry in Québec. Their results suggest that the threat of an inspection as well as actual inspections have an impact on compliance as measured by pollution emissions relative to the standard. Nadeau (1997) shows that both inspections and enforcement actions (orders and penalties) reduce the duration of noncompliant spells but that enforcement actions have a larger effect. Eckert (2004), using data on petroleum storage sites in the province of Manitoba, Canada, between 1983 and 1998, studies the role and effectiveness of warnings as an enforcement tool. She tests whether warnings reduce future violations by increasing the probability of an inspection despite the absence of actual fines. Earnhart (2007) also studied the impact of inspections, enforcement actions, and their threats on the discharges of Kansas wastewater treatment facilities. Using data on pulp, paper and paperboard mills in 28 US states over 14 years, Shimshack and Ward (2008) control for the impact of fines on effluent discharges. They include a dummy variable that indicates the existence of a fine on another plant in the same state, in any of the last 12 months (the “regulator reputation effect”), and they also control for whether the plant in question was fined in the previous year or not. Both types of fine are found to have a significant impact on discharge ratios.

Plant size

The expected impact of the size of the plant, commonly measured by its production capacity, is ambiguous. Other things being equal, plants with larger capacity should produce higher levels of pollution, but may not necessarily be more likely to be out of compliance with EPA standards since allowable discharges are usually a function of output. However, the public may be more sensitive to plants emitting large amounts of pollution, and regulators may inspect such plants more frequently, even if the plant is in compliance (Gray and Deily, 1996). Thus large plants may be under greater enforcement pressure than small plants. Also, if large plants are more efficient in controlling pollution or if there exist economies of scale with respect to pollution control, large firms could less likely be out of compliance (Magat and Viscusi, 1990; Gray and Deily, 1996). In Magat and Viscusi, pulp and paper mills with larger capacity have a lower chance of being out of compliance, but this effect is not statistically significant. In Gray and Deily (1996), larger steel plants were less likely to be in compliance, thus revealing no evidence that scale economies increased compliance in this industry.

Community characteristics

The role of public pressure and preference for cleaner air may exhibit significant variation from place to place, depending on local conditions (Gray and Deily, 1996). Arora and Cason (1996) as well as Becker and Henderson (2000) show that demographic composition (obtained from census data) affected self-reported emissions and air pollution expenditures. Earnhart (2004b) found that community characteristics like unemployment, political factors, community size, and demographics impacted the environmental performance of Kansas wastewater treatment facilities.

Environmental regulation

Several aspects of environmental regulation and its impact on industrial activity have been studied in the literature, including plant location decisions,[17] manufacturing employment (Kahn 1994) and stock of plants in polluting industries (Becker and Henderson 2000). The last two studies, among others, have used NAAQS (National Ambient Air Quality Standards) county non-attainment status as a proxy for environmental regulation. Becker and Henderson (2000) investigate the effects of ozone non-attainment status at the county level on plant locations, births, sizes, and investment patterns using plant data (for 1963-92) from four major polluting industries: industrial organic chemicals, metal containers, plastics, and wood furniture. They find that non-uniformity of regulation over space and time has resulted in non-uniform outcomes. While regulation has curbed emissions, it has also induced relocation of polluting industries from more to less polluted areas; proliferation of small-scale, less regulated enterprises in some industries; and, in regulated areas, the timing of plant investments by new plants has been affected.

The impact of the pollutant-specific, county-level attainment/non-attainment designations on industrial activity has also been studied in Greenstone (2002). Using 1.75 million plant observations from the Census of Manufactures, his results suggest that in the first 15 years after the amendments became law (i.e., 1972-87), non-attainment counties (relative to attainment ones) lost approximately 590,000 jobs, \$37 billion in capital stock, and \$75 billion (1987 dollars) of output in pollution-intensive industries. The effect of other types of regulatory conditions, such as permitted effluent limits, has also been studied. Among others, Earnhart (2007) analyzes the

[17] see Levinson (1996) for a comprehensive survey.

effect of permitted effluent limits on the absolute level of wastewater discharges using data on municipal wastewater treatment facilities in the state of Kansas for the years 1990 to 1998.

4. Model specification

The purpose of this study is to measure the impact of gasoline content regulation on petroleum refineries in terms of their compliance with the Clean Air Act regulations and plant level air quality emissions. In this section we present the models used to examine both compliance and pollution behavior.

The CAA regulation compliance model

We use the following model to measure the compliance of refineries:

$$\text{NOCOMP}_{ijt} = f\left(\text{E-INSP}_{it}, \text{CAP}_{it}, \text{PRODCAP}_{it}, \text{HHI}_{jt}, \text{DEMOG}_{i}, \text{GASREG}_{j}, \text{MBAN}_{jt}\right) \quad (1)$$

where i, j and t respectively, are the indices for the refinery, the state where the refinery is located, and the year. $NOCOMP_{ijt}$ is a dichotomous variable which takes the value 1 if plant i is out of compliance in year t, and zero if it is not. The variable $E-INSP_{it}$ is the expected number of inspections of refinery i in year t and measures the effect of enforcement probability on refinery compliance. In order to control for plant size we include a refinery's total capacity, CAP_{it}. In addition, we control for heterogeneity in production process and technology by including the capacity of non-fuel products by type in the vector $PRODCAP_{it}$. This vector includes refinery capacities for alkylates, aromatics, asphalt and road oil.[18] To control for the

[18] Alkylates, asphalt and road oil are important non-fuel products from the refinery. Refineries also produce other valuable products such as hydrogen, isobutane, isopentane, lubricants, petcoke and sulfur. Refineries are different in

possibility that market power may affect compliance, we include the Herfindahl index which measures the concentration of the refinery sector in state j and year t (defined by HHI_{jt}).[19] Higher levels of concentration can lead to higher profitability. These higher profits may translate into lobbying activity and thus, *ceteris paribus*, a higher industry concentration could lead to less compliance with regulation.[20] This variable enables us to measure differences in the market structure of the refining industry across jurisdictions.

Demographic characteristics of the population in the neighborhood of a refinery could also influence compliance behavior through pressure from the neighboring population, as has been shown in several studies (e.g., Gray and Shadbegian, 2007).[21] We include variables on population age and income, which are constant over the period and collected in the vector $DEMOG_i$.[22]

Finally, we include variables measuring gasoline regulation in the state where the plant is located ($GASREG_j$). Two major gasoline programs, namely the reformulated (RFG) and oxygenated (OXY) gasoline programs are considered. Following Chakravorty et al. (2008), we compute the extent of the RFG and OXY regulation by the share of the population that is under RFG and

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terms of total capacity but also in the type of products they refine. These products are likely to depend on the type of crude oil used, the output mix chosen and involve different production processes, thus emitting a unique mix of pollutants specific to each refinery. The mix of products selected are among the major non-fuel products from the refining process.

[19] The computation of the Herfindahl index is based on the capacities of the refineries operating in the state. Average refinery capacity utilization rates in the period we study have typically been 90% or higher, so the capacity may be a reasonable approximation of refinery output, see http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MOPUEUS2&f=M. Other studies such as Magat and Viscusi(1990) also use capacity as a proxy for firm size.

[20] One avenue by which higher concentration could lead to *increased* regulation is the incentive for incumbent firms to push for regulation that increases entry costs, although it is not clear what that would mean for compliance. The costs of compliance may not be impacted but refineries that make the investments may benefit from higher rents if entry was reduced. Secondly, the compliance costs may be lower for incumbent firms than for potential entrants.

[21] The plant's neighborhood is defined as the population living in areas with the same zip code.

[22] We tried other demographic variables such as the share of ethnic groups, education level, and occupation. Because of multicollinearity problems, these variables had to be removed from the estimation. The only two demographic variables that are retained in the model are the share of population under 5 and the median household income.

OXY programs in the state where the refinery is located. Since the population shares under RFG and OXY are highly collinear, we take the maximum of these two variables as our measure of gasoline regulation, which gives us the proportion of the state population living under at least one of these two programs as our measure of $GASREG_j$. We compute this variable using 2002 data, which predates our sample of 2003-2006, in order to avoid any possible simultaneity problems.

One possible channel through which the difference in gasoline regulation may affect compliance is if the cost of meeting the regulation has declined over time. One of the key requirements of the RFG program (Clean Air Act 1990) is a minimum 2% oxygen requirement, which was mostly met by refiners through blending an oxygenate called MTBE (methyl tertiary butyl ether). Apart from increasing the amount of oxygen in gasoline leading to less pollution during combustion, MTBE also added volume and increased octane of gasoline. MTBE was blended to RFG at about 11 percent by volume. Almost all RFG outside of the Midwest traditionally used MTBE (EIA 2003).[23] Successive states have banned the use of MTBE because of these health concerns beginning in 2004 and ending with a Federal ban in 2007.[24] California which used about a third of all MTBE consumed nationally, was the first state to ban MTBE in 2004 followed by 15 other states in rapid succession (EIA 2003). Most states had banned MTBE use or reduced it to a trace (usually 0.5% of the fuel blend) by 2007. The MTBE ban was followed by the Renewable Fuels Standard which provided a subsidy to refiners for blending ethanol into gasoline. For the purposes of our paper, this issue is pertinent because MTBE is easier to handle than ethanol, is more readily soluble in water (hence the health concerns) and can be transported in existing pipelines. Thus it is possible that given our study period 2003-06, the MTBE ban and transition to

[23] Firms in the Midwest mainly used ethanol for this purpose instead of MTBE.
[24] However traces of MTBE which is suspected to be a carcinogen, have been found in groundwater supplies in RFG regulated areas, due to leakage from underground storage tanks and pipelines.

ethanol as a gasoline blend may have affected the compliance rate of refiners. Since we know the dates of the state bans, we can use this information to see if including the use of MTBE as a variable affects our estimation results. That is, when there was no ban, MTBE was the oxygenate of choice. With the ban on MTBE, refiners have a constrained choice set, which may have affected their compliance costs. To the extent that refineries were forced to make investments in upgrading facilities in order to comply with the MBTE ban, this may have caused them to be more generally compliant with emissions regulations as well. Since states implemented the ban at different times, we can exploit this heterogeneity to test this hypothesis. We include a dummy variable ($MBAN_{jt}$) which captures whether a ban is in place in a state during a particular year.[25]

The refinery emissions model

We develop a model to examine the effects of enforcement and regulation on the actual emissions of refineries. Here the dependent variable is aggregate pollution emissions, EM_{ijt} discharged by refinery i in year t. We choose the same set of explanatory variables that we use for the model analyzing the probability of compliance, written as follows:

$$\text{EM}_{ijt} = f\left(\text{E-INSP}_{it}, \text{CAP}_{it}, \text{PRODCAP}_{it}, \text{HHI}_{jt}, \text{DEMOG}_{i}, \text{GASREG}_{j}, \text{MBAN}_{jt}\right) \qquad (2)$$

By estimating this model in addition to the non-compliance model we allow for the possibility that compliance need not imply actual emissions reductions.

Computing Expected Inspections

In order to estimate the two models described above, we need to construct the variable

[25] Data for dates at which MTBE was banned in different states is available at http://www.epa.gov/mtbe/420b07013.pdf

$E-INSP_{it}$, which measures the expected number of inspections undertaken by either the state or the EPA for refinery i in year t. We do so by first estimating a model of the number of inspections, $INSP_{it}$, and then using the predicted values from that model as our variable $E-INSP_{it}$. The model that we use for this purpose regresses $INSP_{it}$ on the number of inspections that occurred at the plant in period $t-1$, and on plant capacity, along the lines of Laplante and Rilstone.[26] We also include state dummies (I_STATE) to control for state-specific control policies. These dummies may capture state-level regulatory behavior. For example certain states may take tougher regulatory action than other states. As long as these behaviors are constant over time, which is reasonable to expect, then these state-level differences will be controlled for by our estimates. The model used to predict the total number of inspections is given by

$$\mathrm{INSP}_{it} = f\left(\mathrm{INSP}_{it\text{-}1}, \mathrm{CAP}_{it}, \mathrm{I\_STATE}_{j}\right) \qquad (3)$$

Since $INSP_{it}$ takes on relatively few integer values, we use a Poisson regression to estimate (3). Estimation results of the Poisson model are shown in Table 4. The model is estimated using 473 observations. The number of inspections at a given refinery in any year is strongly dependent on the number of inspections undertaken in the year before. The number of inspections is found to decrease with the refinery capacity, but this effect is not significant. A number of state dummies are found significant. These coefficients are used to calculate the predicted number of inspections at each refinery for each year sample.

[26] We tried different specifications for equation (3) and, in particular, we used the ratio of total facilities in non-compliance over the total number of inspections (either state or EPA inspections) in state i for the past four years as explanatory variables, instead of past inspections. We also tried several alternative lag structures with no significant improvement in the fit.

5. Data

The empirical analysis in the paper is done for the period 2003-06. Although it may be possible to obtain a longer time series, the demographic variables used are fixed at their 2000 (levels), so we do not wish to extend the time dimension too far from this date.[27] Historical data on emissions, and Clean Air Act compliance and enforcement statistics at the plant level have been obtained from the AIRS Facility Subsystem (AFS) provided by the EPA. For each plant and each quarter during 2000:Q4-2008:Q1, AFS indicates whether the plant is out of compliance with CAA regulation or not. Based on this information, the indicator variable $NOCOMP_{ijt}$ takes the value of 1 if the plant i has been out of compliance in year t for at least one quarter. We need to aggregate to annual data since several of the independent variables are annual. AFS also reports total air emissions by plant and by year.

AFS includes information on the number of CAA enforcement actions undertaken both at the federal and state levels by plant and year. We focus only on the EPA and state-conducted Full Compliance Evaluations (FCE), which are considered to be the most important.[28] FCE includes comprehensive paperwork review and often, but not necessarily, an on-site inspection.[29] FCEs are credited as inspections in the official Office of Enforcement and Compliance Assurance count.

[27] The EPA completed the bulk of the enforcement activity (covering about 80% of the industry) by 2005. An additional 10% of the industry was subject to enforcement activity during the period 2005-08.

[28] Other types of actions are EPA and state-conducted Partial Compliance Evaluation (PCE) and EPA and state-conducted inspections. Both of these actions: 1) Partial Compliance Evaluations and 2) Inspections can be conducted by the state or the EPA. PCE meets some but not all of the FCE criteria and are not credited as inspections in the official Office of Enforcement and Compliance Assurance count. Inspections are visits to a facility for the purpose of gathering information to determine whether the facility is in compliance. Inspections generally include pre-inspection activities such as obtaining general site information before actually entering the facility.

[29] More precisely, an FCE includes a review of all required reports and the underlying records; an assessment of air pollution control devices and operating conditions; observations of any visible emissions; a review of facility records and operating logs; an assessment of process parameters, such as feed rates, raw material compositions, and process rates; and a stack test if there is no other way to determine compliance with the emission limits.

For each facility and for each year, our measure of total inspections, $INSP_{it}$ is the total number of FCEs undertaken by the state and the EPA.[30]

These plant-level data on compliance and enforcement are merged with data on overall refinery capacity and capacity by product type including alkylates, aromatics, asphalt and road oil, hydrogen, isobutane, isopentane, lubricants, pet coke and sulfur. This data is collected from the Energy Information Administration annual statistics for the years 2003-06.

Since each facility in our sample is identified by its zip code, we are able to match the plant-level data with demographic data from the 2000 Census (*www.census.gov*). These variables, which include population, age, race, education levels, occupation and income, describe demographic characteristics of the population living in the area, as defined by the zip code in which the plant is located. We also built state-specific data including a Herfindahl index (computed from the observed refinery capacities), total state population, state population density, and total number of vehicles in the state.

Overall, the database contains observations for 123 refineries over four years (2003-06).[31] These 123 refineries are located in 29 different states but three of them (California, Louisiana and Texas) account for 57 refineries (see Table 2). About 40% of the refineries in the sample were out of compliance with CAA regulation during this period (Table 3). This percentage was slightly lower in 2006. Polluting emissions per unit of capacity followed a decreasing trend over the study period. Most of the CAA enforcement actions (FCEs) were undertaken by the state but the average number of state and EPA FCEs per facility decreased between 2003 and 2006. Whether

[30] We also used separate variables for the effect of state and federal EPA FCEs. This specification did not perform better than the one presented in the text. EPA inspections were not found significant in general, probably because most of the enforcement actions are undertaken by the state (see Table 3).
[31] The merging of data sets from different sources induced a loss in the number of observations.

state or EPA inspections are more important cannot be tested with our data because of too few EPA inspections, as discussed previously.

6. Results

Compliance with Clean Air Act Regulation

In Table 5, we report the estimation results for the model describing the probability of non-compliance with air quality regulation. Estimated coefficients and corresponding elasticities calculated at the sample mean are shown. We find that a higher number of predicted inspections (variable $E-INSP_{it}$) decreases the probability of being out of compliance. An elasticity of -0.58 indicates that a 1% increase in the number of inspections induces a 0.58% decrease in the probability of non-compliance. The higher the capacity of the refinery and the higher the concentration of the refinery sector in the state, the higher the probability that the refinery is out of compliance. This result is consistent with previous studies that suggest that larger firm size and industry concentration are positively correlated with regulatory non-compliance (see e.g., Gray and Shadbegian, 2007).

The greater the extent of gasoline regulation in the state, the lower the probability of non-compliance. The elasticity is estimated at -0.20, that is a 1% increase in the share of state population under some form of gasoline regulation leads to a 2.0% decrease in the probability of non-compliance. This suggests that gasoline content regulation, which forces refiners to produce a mandated higher-quality fuel, also induces a change in the production process leading to a lower marginal abatement cost of pollution. Figure 1 illustrates how the predicted probability of non-compliance varies with the share of population under gasoline regulation, with the other covariates held at their mean. On average, non-compliance improves from about 50% to less than

30% moving from states with no population under product regulation (16 states in our sample) to those with product regulation impacting nearly all of the population (California, Delaware, and New Jersey). Finally the higher the share of infants in the population, the higher the income of the population living in the neighborhood of the refinery - the plant's neighborhood is defined as the population living in areas with the same zip code - the lower the probability of being out of compliance. The latter could indicate that refineries put more effort into compliance in jurisdictions where the population places a greater premium on environmental quality. The elasticities of the two demographic variables are among the largest of all in magnitude, suggesting that they play a significant role in compliance behavior. Other studies such as Gray and Shabdegian (2007) have also modeled the demographics of the community and have found a positive effect of the share of children for example, on the compliance performance of plants, however these effects, unlike in our case, were generally insignificant. Table 5 also shows that the MTBE ban had no statistically significant effect on compliance.

Total emissions

In Table 6, we report the OLS estimation results of the model predicting the amount of polluting emissions per unit of capacity. The predicted number of inspections has a statistically positive effect on total emissions. The extent of gasoline regulation is not statistically significant, which suggests that even though inspections are affecting compliance they do not appear to be having an effect on refinery emissions. We find that larger firms produce less emissions per unit capacity but that firms located in states where the refinery sector is more concentrated have higher emissions per unit capacity, which is consistent with the hypothesis that firms in concentrated industries are likely to exhibit stronger lobbying power and therefore adopt production technologies that may be dirty and spend less on pollution abatement. Demographic characteristics have the expected sign but the median household income turns out not to be significant. Again, the MTBE ban had no statistically significant effect on emissions.

Robustness checks

The extent of the RFG and OXY programs in each state may be endogenous, for example, if firms lobby the state to introduce regulation beyond the minimum required under Federal guidelines or by introducing a unique fuel (see Chakravorty et al., 2008). In order to control for the possible endogeneity of gasoline regulation in each state, we estimate a model that predicts the extent of gasoline regulation in each state, as follows:

$$\mathrm{GASREG}_j = f\left(\mathrm{POP}_j, \mathrm{DENS}_j, \mathrm{CAR}_j, \mathrm{RECPRO}_j\right) \qquad (4)$$

where $GASREG_j$ is the maximum share of population in state j under the RFG and OXY programs in 2002; POP_j is total population of state j, $DENS_j$ is state population density, CAR_j is the average number of vehicles per capita, and $RECPRO_j$ is the ratio of net receipts over net production of gasoline for the corresponding region or PADD.[32] Chakravorty et al. (2008) consider two different variables measuring gasoline regulation, one for RFG and one for OXY. Here we use the maximum share of population in each state under the RFG and OXY programs in 2002. Because both programs sometimes operate in the same state, we could face some collinearity problems if two distinct variables were used (one for RFG, one for OXY). In terms of instruments, POP, $DENS$, CAR and $RECPRO$ were used in Chakravorty et al. (2008).

[32] Historically, crude oil allocation in the United States has been divided into five petroleum administration for defense districts (PADD). These districts were originally classified during World War II for purposes of administering an oil allocation program. The five PADDs are: West Coast, the Rockies, Midwest, the Gulf Coast and East Coast. For more details, see Chakravorty et al. (2008, Table 1).

The variable $GASREG$ can take on a value of zero with positive probability when states do not impose any regulation on gasoline. We therefore specify this equation as a Tobit model for variables censored at zero. The model is estimated using a Maximum Likelihood procedure. The method used to calculate the predicted share of population under gasoline regulation is described in Appendix A.[33] The model fitting the probability of non-compliance with Clean Air Act regulation and the model measuring total emissions are then re-estimated using the predicted extent of gasoline regulation instead of the observed values. Estimation results for these two models are shown in Appendix B (Tables B1 and B2). The results are found to be robust to the control of a possible endogeneity of the extent of gasoline regulation.

Until now, we have assumed that regulation on gasoline content in a state would have an impact on the compliance of refineries located only in the same state. This is a strong assumption which may be realistic in some regions which produce most of its gasoline for in-state consumption (East Coast for example) but less realistic in others. A significant proportion of gasoline produced in Texas and Louisiana, which host a large number of refineries, is sold to other states.[34] As a consequence, RFG and OXY regulation in states which supply gasoline to other states should be taken into account in our model. Unfortunately, we do not know where the gasoline produced by each refinery is sold. Due to the high transportation cost of gasoline we can assume that refineries will try to minimize the distance between the production facilities and the markets where gasoline is sold. To control for RFG and OXY regulation in other states, we build the following weighted indices of RFG and OXY regulation for the whole country:

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[33] The estimates of the Tobit model for $GASREG$ are not shown here but are available from the authors upon request.
[34] According to the EIA, in 2007, 90 percent of US gasoline was produced domestically. About 45 percent of this volume originated from refineries in the Gulf Coast (mainly Texas and Louisiana).

$$IRFG_i = \frac{\sum_J \left(\frac{1}{d_{ij}} \times RFG_j \right)}{\sum_J RFG_j} \text{ and } IOXY_i = \frac{\sum_J \left(\frac{1}{d_{ij}} \times OXY_j \right)}{\sum_J OXY_j},$$

where d_{ij} is the distance (in miles) between the capitals of state i and state j, RFG_j and OXY_j are the populations in state j under RFG and OXY regulation respectively, and J represents the total number of states in the country.[35] These indices are constructed such that the greater the distance between state i and state j, the lower the impact of regulation in state j on a refinery located in state i. This is an imperfect measure but we believe that it may serve as a reasonable first approximation in the absence of data on gasoline inflows into states from individual refineries. The "new" gasoline regulation variable in state j is defined as

$$GASREG_j = \max\left(IRFG_j, IOXY_j \right).$$

Maximum-likelihood estimation results for the model describing the probability of non-compliance are shown in Appendix C (Table C1). The sign and magnitude of all the factors are found to be the same in the models using the weighted indices for RFG and OXY regulation as the ones we obtained previously without using the weights. Our main finding that more extended gasoline regulation increases the probability of non-compliance is thus found to be robust to the definition of regulation - whether state-specific or national but weighted by the distance between states. Estimation results do not change if we use a different definition of the extent of gasoline regulation. As far as polluting emissions are concerned, we do not find any significant impact of the weighted national index of gasoline regulation (see Table C2).

[35] Distance measures between state capitals are great circle distances ("as the crow flies") computed using latitude and longitude coordinates available from the US Geological Survey. For details regarding how these measures are computed, see *http://www.cpearson.com/excel/latlong.htm*.

7. Concluding Remarks

In this paper we have examined the compliance behavior of firms in the US refining industry. This sector is unique because it is subject to both process regulation in the form of permits for different types of emissions as well as product regulation, which takes the form of specific blends of gasoline that refineries must produce to meet air quality regulation. Product regulation exhibits a high degree of heterogeneity. States and regions with low levels of ambient air quality or higher population densities are likely to impose such regulation. We exploit these spatial differences to show that product regulation has a positive effect on compliance behavior. However, increased compliance does not necessarily imply lower industry emissions.

Because firms may lobby for product regulation, we account for the endogeneity of such regulation in the estimation process. From a policy point of view, our results suggest that different types of regulation in a given industry may be complimentary in the sense that firms may be able to exploit synergies in the production process and improve compliance. For example, in the case of gasoline regulation, it is easy to detect non-compliance since regulation specifies the chemical content of gasoline produced by any refinery. However, by the same token, firms may have an incentive to not comply with the more complex forms of regulation that involve emissions of multiple gases such as sulfur dioxide (SO_2) and nitrogen oxides (NO_X), and other production specifications. Here the potential for non-compliance is significant, as revealed by the data which suggests a markedly high degree of non-compliance in the refining industry relative to other industries. What we show is that an added benefit of gasoline content regulation may be to induce firms to comply, and it is significant for both the programs (RFG and OXY) we have studied.

Our results suggest that seemingly unrelated environmental regulations can have complimentary effects. It suggests that the analysis of the net benefit of these regulations needs to take these "spillover effects" into account. However, more studies need to be done to examine the relationship between different types of regulation, not only in refining but in other industries. More research needs to be done to understand how the marginal abatement cost of firms is altered by different types of regulation, which of course may vary from industry to industry. This information may be used to develop regulatory instruments that are more efficient and provide better incentives to increase compliance behavior.

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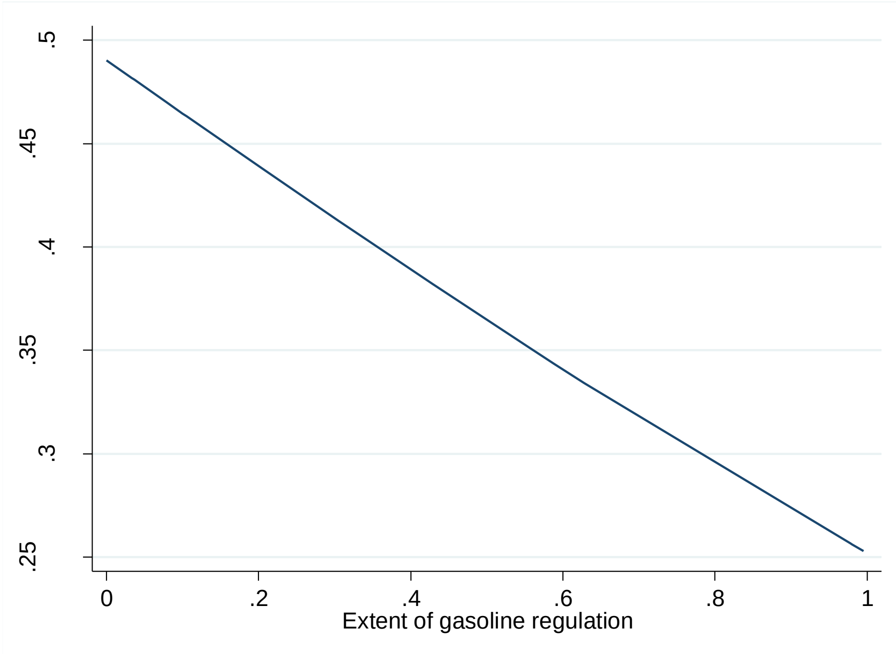

Figure 1. Predicted probability of non-compliance of refineries as a function of gasoline regulation

Table 1. Statistics on enforcement and compliance in selected industries (source: EPA)

	August 1990-August 1995					August 2003-August 2008				
Industry	Facilities in search	Facilities inspected / facilities in search	Inspections / facilities in search	Actions / facilities inspected	Enforcement to inspection rate	Facilities in Search	Facilities inspected / facilities in search	Inspections / facilities in search	Actions / facilities inspected	Enforcement to inspection rate
Pulp and Paper	306	0.87	12.3	1.89	0.13	527	0.79	8.4	1.03	0.10
Inorganic Chemicals	548	0.54	5.5	1.35	0.13	909	0.67	4.8	0.75	0.11
Organic Chemicals	412	0.77	9.4	2.30	0.19	1,189	0.68	5.6	1.08	0.13
Petroleum Refining	**156**	**0.93**	**20.9**	**5.50**	**0.25**	**339**	**0.78**	**10.2**	**7.79**	**0.60**
Iron and Steel	374	0.74	9.5	1.81	0.14	670	0.70	6.5	1.35	0.14
Metal Mining	873	0.39	1.7	0.46	0.10	211	0.69	3.6	0.50	0.10
Non-Metallic Mineral Mining	1,143	0.55	3.0	0.30	0.06	2,579	0.64	2.4	0.35	0.09
Lumber and Wood	464	0.65	4.1	0.77	0.12	2,757	0.68	3.6	0.46	0.09
Furniture	293	0.73	5.2	0.43	0.06	1,353	0.64	3.1	0.40	0.08
Rubber and Plastic	1,665	0.44	2.0	0.53	0.12	3,580	0.65	3.1	0.37	0.08
Stone, Clay, and Glass	468	0.57	5.3	1.12	0.12	2,994	0.60	3.5	0.95	0.16
Fabricated Metal	2,346	0.57	2.3	0.63	0.15	7,299	0.63	2.1	0.29	0.09
Nonferrous Metal	844	0.56	3.7	0.99	0.15	465	0.65	5.1	1.19	0.15
Automobiles	598	0.65	3.7	0.62	0.11	1,760	0.68	3.2	0.31	0.07

Notes: We report yearly averages for the two periods. Data for the years 1990-95 are from the EPA sector notebook whereas data for the years 2003-08 were taken from the EPA website (http://www.epa.gov/tri/). *Facilities in search* are the number of facilities reporting in the Toxics Release Inventory (TRI). *Actions* indicate the number of enforcement actions undertaken in each sector.

Table 2. Distribution of refineries by state in sample

State	Number of plants
Alabama	2
Arkansas	2
California	18
Colorado	1
Delaware	1
Georgia	1
Illinois	2
Indiana	2
Kansas	3
Kentucky	2
Louisiana	16
Michigan	1
Minneapolis	2
Mississippi	3
Montana	4
N. Dakota	1
New Jersey	5
New Mexico	3
Ohio	4
Oklahoma	4
Pennsylvania	6
Tennessee	1
Texas	23
Utah	5
Virginia	1
Washington	4
Wisconsin	1
West Virginia	1
Wyoming	4
Overall	123

Table 3. Descriptive statistics

Variable	Unit of measurement	2003	2004	2005	2006
Number of plants		111	115	117	118
Share of plants out of compliance		0.44	0.44	0.44	0.39
Average polluting emissions per facility	pounds per year	348,245	330,100	298,342	315,041
Average operable capacity per facility	barrels per calendar day	129,809	128,201	129,124	131,268
Emissions per unit capacity		3.06	2.79	2.50	2.48
Average number of state FCEs per facility		0.98	0.73	0.63	0.60
Average number of EPA FCEs per facility		0.08	0.03	0.01	0.03

Table 4. Estimation of the number of inspections - Poisson model

Number of inspections	Coefficient[a]	Std. Error	P>z
Constant	0.405**	0.203	0.045
Number of inspections (previous year)	0.059*	0.033	0.076
Refinery capacity[(b)]	-0.429	0.576	0.457
State dummies:			
Alabama	-0.232	0.373	0.534
Arkansas	-0.443	0.405	0.274
California	-0.929***	0.261	0.000
Colorado	-1.766*	1.021	0.084
Delaware	-16.309	1475.332	0.991
Georgia	-0.726	0.610	0.234
Illinois	-16.368	1006.909	0.987
Indiana	0.061	0.426	0.887
Kansas	-1.068**	0.493	0.030
Kentucky	-0.551	0.429	0.199
Louisiana	-0.278	0.243	0.251
Michigan	-1.769*	1.021	0.083
Minnesota	-0.841*	0.497	0.091
Mississippi	-0.834*	0.431	0.053
Montana	-1.106***	0.406	0.006
North Dakota	-0.216	0.489	0.658
New Jersey	-1.745***	0.495	0.000
New Mexico	-0.815**	0.406	0.045
Ohio	-0.958**	0.394	0.015
Oklahoma	-1.760***	0.541	0.001
Pennsylvania	-0.558*	0.321	0.082
Tennessee	-1.744*	1.024	0.088
Texas	-0.954***	0.264	0.000
Utah	-0.274	0.284	0.333
Virginia	-1.103	0.735	0.133
Washington	-0.973**	0.391	0.013
Wisconsin	-1.792*	1.020	0.079
West Virginia	-0.715	0.611	0.242
Total number of observations	473		
LR chi-squared (30)	98.91		
Prob > chi-squared	0.0000		
Pseudo R-squared	0.0903		

(a) *, **, *** indicate significance at the 10, 5, and 1 percent level, respectively.
(b) in million barrels per calendar day.

Table 5. Probability of non-compliance, maximum-likelihood estimation

Probability of being out of compliance	Coeff[(a)]	Std. Err.	Elasticity[(a)]	Std. Err.
Constant	1.801***	0.480		
Predicted number of inspections	-0.845***	0.190	-0.584***	0.135
Plant capacity[(b)]	1.333**	0.649	0.159**	0.078
Share of alkylate capacity	1.515	1.463	0.089	0.086
Share of aromate capacity	-2.364	2.163	-0.027	0.025
Share of asphalt capacity	-2.521***	0.543	-0.253***	0.059
Herfindhal index	0.111*	0.061	0.132*	0.074
Extent of state gasoline regulation	-0.644***	0.233	-0.201***	0.074
Share of population under 5 years	-0.082**	0.040	-0.562**	0.279
Median household income	-0.020***	0.007	-0.693***	0.234
Ban on MTBE	0.004	0.234	0.000	0.019
Number of observations	473			
LR chi-squared (10)	91.01			
Prob > chi-squared	0.0000			
Pseudo R-squared	0.1406			
Percentage of correct predictions	70%			

(a) *, **, *** indicates significance at the 10, 5 and 1 percent level, respectively.
(b) measured in millions barrels per calendar day.

Table 6. Total polluting emissions, OLS estimation

Total emissions per unit capacity	Coeff[(a)]	Std. Err.	P>t
Constant	3.806***	1.271	0.003
Predicted number of inspections	1.147**	0.520	0.028
Plant capacity[(b)]	-2.939*	1.744	0.093
Share of alkylate capacity	9.146**	3.969	0.022
Share of aromate capacity	-2.800	5.910	0.636
Share of asphalt capacity	-2.745***	0.970	0.005
Herfindhal index	0.408**	0.167	0.015
Extent of state gasoline regulation	0.656	0.599	0.274
Share of population under 5 years	-0.315***	0.105	0.003
Median household income	-0.005	0.018	0.755
Ban on MTBE	-0.530	0.611	0.387
Number of observations	461		
R-squared	0.0831		

(a) *, **, *** indicate significance at the 10, 5 and 1 percent level, respectively.
(b) measured in millions barrels per calendar day.

Appendix A. Calculation of the predicted share of population under gasoline regulation

The model is written as

$$GASREG_{jt} = \max\left(0, \boldsymbol{x}_{1tj}^{'}\beta + \varepsilon_{jt}\right)$$

The predicted gasoline regulation variable is built from the non-conditional expectation of the dependent variable based on the full sample using the following relationship:

$$E(y_i) = Pr(y_i > 0) \times E(y_i | y_i > 0) + Pr(y_i = 0) \times E(y_i | y_i > 0) = \Phi_i \mathbf{x}_i \beta + \sigma\varphi_i$$

where y_i and x_i respectively represent the dependent variable and the vector of explanatory variables, $\varphi(.)$ and $\Phi(.)$ are the standard normal density and probability distribution functions respectively. The non-conditional expectation of gasoline regulation is:

$$E\left(\text{GASREG}_j | \mathbf{x}_j\right) = \Phi\left(\frac{\mathbf{x}_j^{'}\beta + \varepsilon_j}{\sigma}\right)\left(\mathbf{x}_j^{'}\beta + \varepsilon_j\right) + \sigma\varphi\left(\frac{\mathbf{x}_j^{'}\beta + \varepsilon_j}{\sigma}\right)$$

with σ being the square root of the variance of ε_j. Estimation of the Tobit model provides estimates of the β parameters, which are then used to compute the non-conditional expectation used as instrument in the models of interest.

Appendix B. Estimation results of the non-compliance probability model using predicted gasoline regulation

Table B1. Probability of non-compliance, maximum-likelihood estimation

Probability of being out of compliance	Coeff[(a)]	Std. Err.	Elasticity[(a)]	Std. Err.
Constant	2.130***	0.497		
Predicted number of inspections	-0.909***	0.190	-0.631***	0.136
Plant capacity[(b)]	1.287**	0.652	0.154**	0.078
Share of alkylate capacity	1.289	1.473	0.076	0.087
Share of aromate capacity	-2.288	2.166	-0.027	0.025
Share of asphalt capacity	-2.526***	0.561	-0.255***	0.061
Herfindhal index	0.059	0.065	0.071	0.078
Predicted state gasoline regulation	**-0.980*** **	**0.277**	**-0.362*** **	**0.105**
Share of population under 5 years	-0.090**	0.040	-0.619**	0.281
Median household income	-0.019***	0.006	-0.678***	0.229
Ban on MTBE	0.027	0.237	0.002	0.019
Number of observations	473			
LR chi-squared (10)	96.13			
Prob > chi-squared	0.0000			
Pseudo R-squared	0.1485			
Percentage of correct predictions	70%			

(a) *, **, *** indicates significance at the 10, 5 and 1 percent level, respectively.
(b) measured in millions barrels per calendar day.

Table B2. Total polluting emissions, OLS estimation

Total emissions per unit capacity	Coef.[(a)]	Std. Err.	P>z
Constant	3.422***	1.291	0.008
Predicted number of inspections	1.300**	0.509	0.011
Plant capacity[(b)]	-2.916*	1.740	0.094
Share of alkylates capacity	9.558**	3.971	0.016
Share of aromate capacity	-2.986	5.897	0.613
Share of asphalt capacity	-2.946***	0.977	0.003
Herfindhal index	0.500***	0.178	0.005
Predicted state gasoline regulation	**1.280***	**0.706**	**0.071**
Share of population under 5	-0.316***	0.103	0.002
Median household income	-0.008	0.017	0.623
Ban on MTBE	-0.585	0.611	0.339
Number of observations	461		
R-squared	0.0873		

(a) *, **, *** indicates significance at the 10, 5 and 1 percent level, respectively.
(b) measured in millions barrels per calendar day.

Appendix C. Estimation results of the non-compliance probability model using a weighted index of gasoline regulation

Table C1. Probability of non-compliance, maximum-likelihood estimation

Probability of being out of compliance	Coeff[(a)]	Std. Err.	Elasticity[(a)]	Std. Err.
Constant	1.598***	0.479		
Predicted number of inspections	-0.777***	0.174	-0.538***	0.000
Plant capacity[(b)]	1.231*	0.652	0.147*	0.060
Share of alkylate capacity	1.664	1.476	0.098	0.262
Share of aromate capacity	-2.815	2.169	-0.033	0.195
Share of asphalt capacity	-2.445***	0.542	-0.246***	0.000
Herfindhal index	0.080	0.063	0.096	0.207
Weighted index of state gasoline regulation	**-4.112*** **	**1.216**	**-0.188*** **	**0.001**
Share of population under 5 years	-0.069*	0.041	-0.472*	0.094
Median household income	-0.018***	0.007	-0.623***	0.008
Ban on MTBE	0.099	0.240	0.008	0.681
Number of observations	473			
LR chi-squared (10)	95.23			
Prob > chi-squared	0.0000			
Pseudo R-squared	0.1471			
Percentage of correct predictions	71%			

(a) *, **, *** indicates significance at the 10, 5 and 1 percent level, respectively.
(b) measured in millions barrels per calendar day.

Table C2. Total polluting emissions, OLS estimation

Total emissions per unit capacity	Coef.[(a)]	Std. Err.	P>z
Constant	3.997***	1.272	0.002
Predicted number of inspections	1.056**	0.474	0.026
Plant capacity[(b)]	-2.794	1.748	0.111
Share of alkylates capacity	9.066**	3.963	0.023
Share of aromate capacity	-2.510	5.903	0.671
Share of asphalt capacity	-2.727***	0.965	0.005
Herfindhal index	0.435**	0.171	0.011
Weighted index of state gasoline regulation	**3.813**	**2.961**	**0.198**
Share of population under 5	-0.329***	0.107	0.002
Median household income	-0.006	0.017	0.715
Ban on MTBE	-0.632	0.620	0.309
Number of observations	461		
R-squared	0.0840		

(a) *, **, *** indicates significance at the 10, 5 and 1 percent level, respectively.
(b) measured in millions barrels per calendar day.