Gasoline Content Regulation and Compliance Behavior among US Refineries

By

Ujjayant Chakravorty and Céline Nauges[1]

Abstract

The refining industry in the US is a leading producer of sulfur dioxide and nitrogen oxide emissions. As a result of the Clean Air Act, it has been subject to a host of environmental regulations that prescribes the production processes firms can employ and limits their emissions based on the permits they hold. On the other hand, in some regions, refiners have been forced to produce higher quality gasoline 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. In this paper we examine the effect of gasoline content regulation on compliance behavior of refineries. We find that in areas where gasoline content regulation was implemented, there was increased compliance on the part of firms.

Keywords: Clean Air Act, Energy Markets, Product Regulation, Petroleum Refining, Environmental Pollution

This Version: March 2009

[1] Respectively, University of Alberta, ujjayant@ualberta.ca and LERNA, Toulouse School of Economics, cnauges@toulouse.inra.fr.

Gasoline Content Regulation and Compliance Behavior among US Refineries

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 feedstocks. This sector produces about 40% of the energy consumed nationally (EPA 1995). It has also been subject to major environmental regulation as a result of the Clean Air Act Amendments of 1990 and has undergone major transformation in the last two decades. Many refineries are large scale operations owned by firms that are vertically integrated but there are also a sizable number of independent operations smaller in size, although they only produce a small fraction of industry output. For reasons of efficiency, petroleum refineries are usually located near crude oil sources, ports and near consumers.

The Clean Air Act has forced refiners to make major investments in upgrading their facilities. Several federal, state and local regulations on air and water pollution apply. A variety of chemicals are regulated. Inspection of refineries is done both at the federal and at the state level. Compliance procedures are detailed in USEPA (2001). Non-compliance with these regulations has been widespread. Since the year 2000, the EPA has negotiated 24 settlements with refineries that cover 88% of the total US petroleum refining capacity. These settlements have involved 99 refineries and have resulted in major sulfur dioxide (SO_2) and nitrogen oxides (NO_X) emission reductions. Negotiations are currently ongoing with refiners which represent another 7% of national refining capacity. These settlements have taken the form of civil penalties worth $73 million, investments of more than $5 billion in control technologies and refiners undertaking additional environmental projects. These "consent decrees" have had a significant effect on annual emission reductions by the industry, totaling 86,000 tons of NO_X and 245,000 tons of SO_2.

Refineries face both product and process regulation under the Clean Air Act. That is, they make changes in their production process and must meet product regulation requirements such as for gasoline. In this paper, we focus on the impact of product regulation (on gasoline) through the implementation of the Oxygenated Fuels Program (OXY) and the Reformulated Fuels Program (RFG) on the compliance behavior of refineries. Specifically, we measure the impact of enforcement actions (inspections in our case) and RFG and OXY programs on compliance with the Clean Air Act (CAA) and refinery emissions using data on US refineries over the 2003-2006 period. In particular we control for the endogeneity of the regulation which may arise if refineries participate in lobbying for stricter RFG or OXY programs. We also compare the impact of inspections undertaken at the state level and by the EPA at the federal level.

By focusing on a unique industry, we avoid the problem of controlling for inter-industry differences in the stringency of regulations, differences in the nature of pollution, and differences in the technologies for compliance. We find that refineries are more likely to be compliant with air quality regulations in areas where they are also subject to product regulation. This result is quite robust across the two programs (RFG and OXY) we study. We account for endogeneity of product regulation that may arise because of lobbying by firms. These results suggest that product regulation may have reduced the marginal cost of pollution abatement leading to less violation of pollution limits by firms.

In sections 2 and 3, we describe the background and relevant literature. In section 4, we discuss the specification of the empirical models. Section 5 contains a description of the data and estimation results are discussed in Section 6. Section 7 concludes the paper.

2. Background

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).[2] As a consequence, this sector was designated

[2] Ranked against 17 other sectors that are 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 oxide (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.

In Table 1, we report on the number of facilities in petroleum refining and other manufacturing sectors in the industry that reported data on the Toxic Release Inventory database,[3] the share of facilities that have been inspected, the number of inspections and enforcement actions and the ratio of state (to federal) lead actions, over two 5-year periods (1990-1995 and 2003-2008). The years 2003-08 is the period for which we have data and forms the basis for our empirical analysis.[4]

As seen from the table, petroleum refining has been a major focus of regulation, especially in recent years. This sector reported the highest average number of inspections per facility and the highest number of enforcement actions per facility inspected.[5] The increase in the number of enforcement actions undertaken in the petroleum 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 average number of actions per facility inspected in the other sectors, which is always below 2 over the 2003-08 period. Designation of the petroleum refining sector as a national priority by the EPA also explains the high enforcement to inspection rate, which peaked at 0.60 during the 2003-08 period, while in the other sectors, this measure was always below 0.20.

There may be several reasons that 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,

---

[3] 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*

[4] We also use data for the 1990-95 time period available from the EPA, detailed below.

[5] 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 has decreased because the number of facilities in the TRI reporting system has more than doubled.

aggregate emissions from each refinery increased as well. This was not reflected in state permitting activity, since permits were often not adjusted to the increase in capacity. This may have led to a higher number of refineries being out of compliance. Thus part of the non-compliance with regulatory requirements identified in the industry may relate to these capacity expansions (EPA, 2004). One other reason for the higher level of non-compliance among refineries may be the increase in environmental regulation, particularly the requirements imposed by the Clean Air Act Amendments of 1990 (EPA sector notebook, 1995). 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. Some refineries may have delayed or avoided making these capital investments and that may have contributed to the high incidence of non-compliance.

The petroleum refining industry is quite unique in that the environmental requirements aimed at the industry are not only directed at reducing the environmental impacts of the refinery themselves. These requirements also mandate specific product qualities for the purpose of reducing the environmental impacts associated with the downstream use of the product. Among them, the various regulations that have been imposed on the formulation of gasoline are the most important, including the Oxygenated Fuels Program (OXY) and the Reformulated Fuels Program (RFG). These are product regulations that specify the type of product that must be sold by refiners.

The Clean Air Act, originally passed in 1963 (and amended in 1970, 1977, and 1990), is one of the most significant federal interventions into the market in the post-war period. Following the passage of the 1970 amendments, the EPA established separate national ambient air quality standards (NAAQs - a minimum level of air quality that all counties are required to meet) for four criteria pollutants: carbon monoxide, tropospheric ozone, 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 reserved for counties whose air contains concentrations of a pollutant that exceed the relevant federal standard (Greenstone, 2002).

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 response (see the EPA Compliance and Enforcement Webpage).

The OXY Program required that by 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 four winter months. The higher oxygen content lowers the levels of carbon monoxide produced during combustion.[6] 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 (defined as those with more than 250,000 people) 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 manganese, along with other requirements on consequent emissions (see EPA sector notebook for greater details).[7]

3. Previous Studies on Compliance

Analysis of compliance in the industrial sector has been at the core of numerous empirical articles. Compliance with regulations can be defined in various ways: compliance versus non-compliance status (e.g., Helland, 1998a; Nadeau, 1997; Gray and Deily, 1996), compliance levels (Earnhart 2007, Laplante and Rilstone, 1996; Earnhart, 2004a,b; Shimshack and Ward, 2005;

---

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

[7] Additional programs that aim at controlling 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 what follows, we will focus on OXY and RFG programs, which are the two major programs regulating gasoline formulation.

Dasgupta et al., 2001; Shimshack and Ward, 2008), or duration of non-compliance episodes (Nadeau 1997). Other related studies have examined absolute pollution levels with or without reference to permitted levels (Helland, 1998b; Magat and Viscusi, 1990; Earnhart and Shimshack). 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).[8] 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 control for whether the plant overcomplies or not.

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; Gray and Deily). 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 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.[9] Gray and Deily (1996), using data on steelmaking plants during the years 1980-1989, show that lagged enforcement (whether measured as inspections or total actions)

[8] 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.

[9] These authors consider inspections to be one of the most important components of any enforcement program.

significantly increases the probability that a plant is in compliance. The coefficient of predicted enforcement at 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. It is not very easy to control for fines. However, 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 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). Thus large plants may be under greater enforcement pressure than smaller 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 be less likely to be out of compliance (Magat and Viscusi; Gray and Deily). In Magat and Viscusi, pulp and paper mills with larger capacity have lower chances of being out of compliance, but this effect is not statistically significant. In Gray and Deily, 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). Arora and Cason as well as Becker show that demographic composition (obtained from census data) affected self-reported emissions and air pollution expenditures. Earnhart (2004) 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 (see Levinson, 1996 for a review), manufacturing employment (Kahn 1994) and stock of plants in polluting industries (Henderson 1996). 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 in order to avoid stricter regulation in more 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 altered.

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 impact of other types of regulatory conditions, such as permitted effluent limits, have also been studied. Among others, Earnhart (2007) analyzes the 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. Specification of the models

The purpose of this study is to measure the impact of gasoline content regulation (RFG and OXY programs) firstly on compliance with the Clean Air Act (CAA) regulations and secondly on polluting air emissions, for plants in the petroleum refining sector over the recent years (2003-2006).

Model describing plant compliance with CAA regulation

We consider the following model:

$$NOCOMP_{ijt} = f\left(N\text{-}FCE_{it}, CAP_{it}, PCAP_{it}, HHI_{jt}, DEMOG_{i}, GASREG_{kj}\right) \qquad (1)$$

where *i*, *j* and *t* are respectively the indices for the refinery, the state where the refinery is located, and the year. $NOCOMP_{it}$ is a dichotomous variable which takes the value of 1 if plant *i* is out of compliance in year *t*, and zero if it is not. Compliance status of plant *i* in period *t* is assumed to depend on the expected number of inspections occuring at plant i in year t ($N\text{-}FCE_{it}$);[10] plant characteristics including its total capacity (CAP_{it}) and the capacity by product type including alkylates, aromatics, asphalt and road oil.[11] The product-specific capacities (collected in the vector $PCAP_{it}$) are used to control for heterogeneity in production processes and technology. To control for market power in each state, we include the Herfindahl index measuring concentration of the refinery sector in state j and year t (HHI_{jt}).[12] The higher the level of concentration in the industry, the more market power each firm will be able to exercise. It is likely that these higher profits may translate into lobbying activity and thus, *ceteris paribus*, a higher industry concentration is likely to lead to a higher degree of non-compliance with regulation.

In order to control for possible pressure from the population living in the neighborhood of each plant, we include demographic characteristics including data on population age and income. These characteristics, which are constant over the period, are gathered in the vector $DEMOG_i$. Finally, we include variables measuring gasoline regulation in the state where the plant is located ($GASREG_{kj}$). We will consider the role of the two major gasoline programs: $k=RFG, OXY$. The extent of the RFG and OXY regulation will be measured by the share of the population that is under RFG and OXY programs in the state where the refinery is located (see Chakravorty, Nauges and Thomas, 2008). To avoid any simultaneity problem, we consider the share of population under the two programs in 2002 (while we study compliance between 2003 and 2006). Finally, in order to avoid multicolinearity, we will consider only one environmental program at a time and hence estimate separately the non-compliance model for RFG and for OXY.[13]

Model describing total air emissions at the refinery

---

[10] In the empirical application, we will distinguish between state and EPA inspections.

[11] Refineries also produce hydrogen, isobutane, isopentane, lubricants, petcoke, and sulfur.

[12] The computation of the Herfindahl index is based on the capacities of the refineries operating in the state.

[13] We tried different sets of explanatory variables. In particular, we included a measure of the total number of inspections undertaken in the state and other types of demographic variables such as share of ethnic groups, education level, and occupation. Because of multicollinearity problems, some of these variables had to be removed. We present here the best models in terms of overall significance.

The dependent variable is the total amount of pollution emissions (EM_{ijt}) discharged in the air by refinery *i* in year *t*. We choose the same set of explanatory variables as for the model analyzing the probability of compliance. That is,

$$EM_{ijt} = f\left(N\text{-}FCE_{it}, CAP_{it}, PCAP_{it}, HHI_{jt}, DEMOG_{i}, GASREG_{kj}\right) \qquad (2)$$

with k = RFG, OXY.

5. Data

Historical data on emissions, and Clean Air Act (CAA) 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 over 2000:4-2008:1, 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. AFS also reports total air emissions by plant and by year.

AFS includes information, for each plant and each year, on the number of CAA enforcement actions undertaken both at the federal and state levels. We focus on EPA and state-conducted Full Compliance Evaluation (FCE), which are considered to be the most important.[14] FCE includes comprehensive paperwork review and often, but not necessarily, an on-site inspection.[15] FCEs are credited as inspections in official Office of Enforcement and Compliance Assurance counts.

[14] Other types of actions are EPA and state-conducted Partial Compliance Evaluation (PCE) and EPA and state-conducted inspections. PCE meets some but not all of the FCE criteria and are not credited as inspections in official Office of Enforcement and Compliance Assurance counts. Inspections are visits to a facility for the purpose of gathering information to determine whether it is in compliance. Inspections generally include pre-inspection activities such as obtaining general site information before entering the facility.

[15] 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; observing 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, we build variables measuring the number of FCEs undertaken by the state (NS-FCE) and by the EPA (NE-FCE).

These plant-level data on compliance and enforcement are combined with data on overall refinery capacity (CAP) and capacity by product type including alkylates, aromatics, asphalt and road oil, hydrogen, isobutane, isopentane, lubricants, petcoke and sulfur (source: EIA, historical series annually over 2003-2006).

Since each facility in our sample is identified by its zip code, we could match the plant-level data with demographic data from the 2000 Census. These variables, which include population age, race, education levels, occupation, and income, describe demographic characteristics of the population living in the area where the plant is located.

We also built state-specific data including a Herfindahl index (computed from the observed capacities), total state population, state population density, and total number of vehicles in the state.

Overall, our database contains observations for 123 refineries over four years (2003-2006), making a total of 473 observations.[16] These 123 refineries are located in 29 different states but three states (California, Louisiana and Texas) account for 57 refineries (see Table 2). In our sample, around 40% of the refineries were out of compliance with CAA regulation over the 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) are undertaken by the state but the average number of state and EPA FCEs per facility decreased between 2003 and 2006.

6. Estimation and results

Estimation Strategy

[16] The merging of data sets from different sources induced a loss of observations.

As discussed earlier, the probability of a plant being inspected and hence the number of inspections ($N\text{-}FCE_{it}$) occurring at time *t*, whether they are done by the state or the EPA, are likely to be endogenous in models describing non-compliance and emissions levels. This is because the decision of the EPA and the state to undertake an inspection is likely to depend on the probability that the refinery is out of compliance with respect to its current emissions. Also, 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).

Estimation is thus done in two stages. In the first stage, we estimate four models that respectively measure the extent of the RFG and OXY programs in the state (i.e., the share of the population in the state which is under either RFG or OXY) and the number of inspections made by the state and the EPA at refinery *i* and year *t*.

The threat of being inspected, which we measure by the expected number of CAA enforcement actions (FCEs) to occur at plant *i* in year *t* is regressed on the number of FCEs that occurred at the plant in period *t-j*, where *j* = 1 to 4, and on plant capacity, along the lines of Laplante and Rilstone.[17] We also include the extent of RFG and OXY regulation in the state as possible drivers of the frequency of inspections. We estimate separate models for inspections undertaken by the state (NS-FCE) and those undertaken by the EPA (NE-FCE), as follows:

$$NS\text{-}FCE_{ijt} = f\left(NS\text{-}FCE_{it\text{-}1}, NS\text{-}FCE_{it\text{-}2}, NS\text{-}FCE_{it\text{-}3}, NS\text{-}FCE_{it\text{-}4}, PCAP_{it}, GASREG_{kj}\right) \quad (3)$$

$$NE\text{-}FCE_{ijt} = f\left(NE\text{-}FCE_{it\text{-}1}, NE\text{-}FCE_{it\text{-}2}, NE\text{-}FCE_{it\text{-}3}, NE\text{-}FCE_{it\text{-}4}, PCAP_{it}, GASREG_{kj}\right) \quad (4)$$

with $k = RFG, OXY$.

The models describing the extent of the RFG and OXY programs in each state are taken from Chakravorty et al. (2008), given as

[17] We tried different specifications for equations (3) and (4) 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 lag structures for the explanatory factors. The model which is presented here was found to perform the best.

$$RFG_j = f\left(POP_j, DENS_j, CAR_j, RECPRO_j\right) \quad (5)$$

$$OXY_j = f\left(POP_j, DENS_j, CAR_j, RECPRO_j\right) \quad (6)$$

where RFG_j and OXY_j are respectively the 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.[18]

Each of the four variables (**NS-FCE, NE-FCE, RFG, OXY**) can take on a value of zero with positive probability, when the state and the EPA do not undertake inspections in a refinery, and when states do not impose any regulation on gasoline. We therefore specify each of the four equations as a Tobit model for variables censored at zero. The four models are estimated using Maximum Likelihood. From the four sets of estimated parameters, we build four instrumented variables (see Appendix for greater details on the estimation procedure).[19]

In the second stage, the instrumented variables are used instead of the observed variables. The models fitting the probability of non-compliance with CAA regulation are estimated using Maximum Likelihood and the models measuring total emissions are estimated using OLS.

Results:Compliance with CAA regulation

In Table 4, we report the estimation results of the models describing the probability of non-compliance with air regulation, separately for RFG and OXY gasoline programs.

[18] 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 greater details, see Chakravorty et al. (2008, Table 1).

[19] Estimation results from the four Tobit models are not shown here but are available from authors upon request.

The sign and magnitude of the effects appear to be quite similar across the two types of programs. We find that a higher number of state inspections (FCEs) decreases the probability of being out of compliance. EPA inspections are not found significant in their effect on compliance behavior. The latter result is not really surprising since most of the enforcement actions are undertaken by the state (see Table 3). 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 larger firms and firms in concentrated industries exhibiting a higher degree of compliance with regulation.

The greater the extent of the RFG and OXY programs in the state, the lower the probability of non-compliance. It may be the case that gasoline programs, which induced some changes in the production process of refineries, provided incentives to the refineries for investing in less polluting technologies. Finally, the higher the share of young children and the higher the income in the population living in the neighborhood of the refinery, the lower the probability of being out of compliance. The latter could indicate that refineries put more effort into compliance in places where the population places a greater premium on environmental quality.

If the above models are estimated without controlling for the endogeneity of the gasoline content regulation, the extent of the state RFG and OXY programs have a negative but non-significant effect on the probability of non-compliance.

Total polluting emissions

In Table 5, we report the OLS estimation results of the models describing the amount of polluting emissions per unit of capacity, separately for RFG and OXY regulations.

The CAA enforcement actions as well as the extent of gasoline programs are not found significant in any of the two models. We find that larger firms produce more emissions per unit capacity and in states where the refinery sector is more concentrated, firms are likely to produce more emissions per unit capacity, which is consistent with the hypothesis that larger firms and firms in concentrated industries are likely to exhibit stronger lobbying power and therefore adopt production technologies and practices with less pollution abatement. Demographic characteristics have the expected sign but the median household income is not significant.

Robustness checks

Up to now, we 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 places (East Coast for example) but less realistic in others. Gasoline produced in Texas and Louisiana, which host a large number of refineries, is sold to other states. As a consequence, RFG and OXY regulation in all states where these refineries sell gasoline 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 in the country:

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

where d_{ij} is the distance (in kilometers) between state i and state j capitals, RFG_j and OXY_j are the population in state j under RFG and OXY regulation respectively, and J represents the total number of states in the country.[20] These indices are built such that the greater the distance between state i and state j, the lower the impact of the regulation in state j for 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. Maximum-likelihood estimation results for the model describing the probability of non-compliance are shown in Table 6. The sign and magnitude of all the factors are found to be the

[20] 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 computational details, see http://www.cpearson.com/excel/latlong.htm.

same in the models using the weighted indices for RFG and OXY regulation as the ones we obtained previously. Our main finding that more extended RFG and OXY regulation increases the probability of non-compliance is thus found to be robust to the definition of the regulation - whether state-specific or national but weighted by the distance between states. As far as polluting emissions are concerned, we do not find any significant impact of the weighted national index of RFG and OXY regulation.[21]

7. Concluding Remarks

In this paper we examine the compliance behavior of firms in the refinery 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. Our analysis shows that the incidence of product regulation has a positive effect on compliance behavior. However, increased compliance does not necessarily imply lower emissions by the refinery industry.

Because firms may lobby for product regulation, we adopt a method that accounts for the endogeneity of such regulation in the estimation process. From a policy point of view, our results suggest that different types of regulation on 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 SO2 and NOX, 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 manufacturing sectors. What we show is that an added benefit of gasoline content regulation may

[21] These results are not shown here but are available from the authors upon request.

be to induce firms to comply, and it is significant for both the programs (RFG and OXY) we have studied.

In industries where the cost of regulation enforcement is high, the existence of product regulation may save on enforcement costs. In other words, a side benefit of product regulation may be the increased compliance on the part of firms. However, more studies need to be done to examine the relationship between different types of regulation, not only in refining but in other industries. This is especially true for industries that are subject to different types of regulation.

References

Arora, S., Gangopadhyay, S., 1995. Toward a theoretical model of voluntary overcompliance. *Journal of Economic Behavior and Organization* 28, 289–309.

Arora, S., Cason, T., 1996. Why do firms volunteer to exceed environmental regulations? Understanding participation in EPA's 33/50 program. *Land Economics* 72, 413–452.

Becker, R., Henderson, V., 2000. Effects of Air Quality Regulations on Polluting Industries. *Journal of Political Economy* 108(2), 379-421.

Cavaliere, A., 2000. Overcompliance and voluntary agreements. *Environmental and Resource Economics* 17, 195–202.

Chakravorty, U., Nauges, C., Thomas, A., 2008. Clean air regulation and heterogeneity in US gasoline prices, *Journal of Environmental Economics and Management*, 55(1), 106-22.

Dasgupta, S., Hettige, H., Wheeler, D., 2000. What improves environmental compliance? Evidence from Mexican industry. *Journal of Environmental Economics and Management* 39, 39–66.

Dasgupta, S., Laplante, B., Mamingi, N., Wang, H., 2001. Inspections, pollution prices, and environmental performance: evidence from China. *Ecological Economics* 36, 487–498.

Deily, M.E., Gray, Wayne, 1991. Enforcement of pollution regulation in a declining industry. *Journal of Environmental Economics and Management* 21, 260–274.

Earnhart, D., 2004a. Regulatory factors shaping environmental performance at publicly-owned treatment plants. *Journal of Environmental Economics and Management* 48, 655–681.

Earnhart, D., 2004b. The effects of community characteristics on polluter compliance levels. *Land Economics* 80, 408–432.

Earnhart, D., 2007. Effects of permitted effluent limits on environmental compliance levels. *Ecological Economics*, 178 – 193.

Eckert, H., 2004. Inspections, warnings, and compliance: the case of petroleum storage regulation. *Journal of Environmental Economics and Management* 47, 232–259.

Gray, W. B., and Deily, M. E., 1996. Compliance and Enforcement: Air Pollution Regulation in the U.S. Steel Industry. *Journal of Environmental Economics and Management*, 31, pp. 96-111.

Greenstone, M., 2002. The Impacts of Environmental Regulations on Industrial Activity: Evidence from the 1970 and 1977 Clean Air Act Amendments and the Census of Manufactures. *Journal of Political Economy*, 110(6), 1175-1219.

Helland, E., 1998a. The enforcement of pollution control laws: inspections, violations, and self-reporting. *Review of Economics and Statistics* 80, 141–153.

Helland, E., 1998b. The revealed preferences of state EPAs: stringency, enforcement, and substitution. *Journal of Environmental Economics and Management* 35, 242–261.

Kahn, M. E, 1994. Regulation's Impact on County Pollution and Manufacturing Growth in the 1980's. Manuscript. New York: Columbia Univ., Dept. Econ.

Kirchhoff, S., 2000. Green business and blue angels. *Environmental and Resource Economics* 15, 403–420.

Laplante, B., and Rilstone, P., 1996. Environmental Inspections and Emissions of the Pulp and Paper Industry in Quebec. *Journal of Environmental Economics and Management* 31, 19-36.

Levinson, A., 1996. Environmental Regulations and Manufacturers' Location Choices: Evidence from the Census of Manufactures. *Journal of Public Economics* 62, 5-29.

McClelland, John, Horowitz, John, 1999. The costs of water pollution regulation in the pulp and paper industry. *Land Economics* 75, 220–232.

Magat, W. A., and W. K. Viscusi, 1990. Effectiveness of the EPA's Regulatory Enforcement: The Case of Industrial Effluent Standards. *Journal of Law and Economics*, Vol. 33, No. 2, pp. 331-360.

Nadeau, L.W., 1997. EPA effectiveness at reducing the duration of plant-level noncompliance. *Journal of Environmental Economics and Management* 34, 54–78.

Shimshack, J., Ward, M., 2005. Enforcement and environmental compliance: a statistical analysis of the pulp and paper industry. *Journal of Environmental Economics and Management* 50, 519–540.

Shimshack, J., Ward, M., 2008. Enforcement and over-compliance. *Journal of Environmental Economics and Management* 55, 90–105.

USEPA, 2001. Clean Air Act: Stationary Source Compliance Monitoring Strategy. Washington DC.

USEPA, 2004. Compliance and enforcement national priority: Petroleum refining.

Appendix

The four models can be written as follows:

$$NS\text{-}FCE_{it} = \max\left(0, \boldsymbol{x}_{1it}^{'}\beta_1 + \varepsilon_{1it}\right)$$

$$NE\text{-}FCE_{it} = \max\left(0, \boldsymbol{x}_{2it}^{'}\beta_2 + \varepsilon_{2it}\right)$$

$$RFG_i = \max\left(0, \boldsymbol{x}_{3i}^{'}\beta_3 + \varepsilon_{3i}\right)$$

$$OXY_i = \max\left(0, \boldsymbol{x}_{4i}^{'}\beta_4 + \varepsilon_{4i}\right)$$

The four instrumented variables are built from the non-conditional expectation of the dependent variable based on the full sample using the following relationship:

$$E\left(y_i\right) = Pr\left(y_i > 0\right) \times E\left(y_i \middle| y_i > 0\right) + Pr\left(y_i = 0\right) \times E\left(y_i \middle| y_i > 0\right) = \Phi_{\mathrm{i}}\mathbf{x}_i\beta + \sigma\varphi_i$$

where y_i and $\mathbf{x_i}$ respectively represent the dependent variable and the vector of explanatory variables in each of the four models, $\varphi(.)$ and $\Phi(.)$ are the standard normal density and probability distribution functions respectively. For example, the non-conditional expectation of RFG is:

$$E\left(\mathrm{RFG}_i \middle| \mathbf{x}_{3i}\right) = \Phi\left(\frac{\mathbf{x}_{3i}^{'}\beta_3 + \varepsilon_{3i}}{\sigma_3}\right)\left(\mathbf{x}_{3i}^{'}\beta_3 + \varepsilon_{3i}\right) + \sigma_3\varphi\left(\frac{\mathbf{x}_{3i}^{'}\beta_3 + \varepsilon_{3i}}{\sigma_3}\right)$$

with σ_3 the square root of the variance of ε_{3i}. Estimation of the four Tobit models provides estimates of the β parameters, which are then used to compute the four non-conditional expectations, themselves used as instruments in the models of interest.

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

	August 1990-August 1995						August 2003-August 2008					
Industry Sector	Facilities in search	Facilities inspected / facilities in search	Inspections / facilities in search	Actions / facilities inspected	Enforcement to inspection rate	Percent state lead actions	Facilities in Search	Facilities inspected / facilities in search	Inspections / facilities in search	Actions / facilities inspected	Enforcement to inspection rate	Percent state lead actions
Pulp and Paper	306	0.87	12.3	1.89	0.13	78%	527	0.79	8.4	1.03	0.10	90%
Inorganic Chemicals	548	0.54	5.5	1.35	0.13	76%	909	0.67	4.8	0.75	0.11	81%
Organic Chemicals	412	0.77	9.4	2.30	0.19	66%	1,189	0.68	5.6	1.08	0.13	86%
Petroleum Refining	**156**	**0.93**	**20.9**	**5.50**	**0.25**	**66%**	**339**	**0.78**	**10.2**	**7.79**	**0.60**	**87%**
Iron and Steel	374	0.74	9.5	1.81	0.14	72%	670	0.70	6.5	1.35	0.14	86%
Metal Mining	873	0.39	1.7	0.46	0.10	47%	211	0.69	3.6	0.50	0.10	75%
Non-Metallic Mineral Mining	1,143	0.55	3.0	0.30	0.06	76%	2,579	0.64	2.4	0.35	0.09	99%
Lumber and Wood	464	0.65	4.1	0.77	0.12	79%	2,757	0.68	3.6	0.46	0.09	92%
Furniture	293	0.73	5.2	0.43	0.06	91%	1,353	0.64	3.1	0.40	0.08	92%
Rubber and Plastic	1,665	0.44	2.0	0.53	0.12	78%	3,580	0.65	3.1	0.37	0.08	89%
Stone, Clay, and Glass	468	0.57	5.3	1.12	0.12	70%	2,994	0.60	3.5	0.95	0.16	90%
Fabricated Metal	2,346	0.57	2.3	0.63	0.15	80%	7,299	0.63	2.1	0.29	0.09	85%
Nonferrous Metal	844	0.56	3.7	0.99	0.15	76%	465	0.65	5.1	1.19	0.15	83%
Automobiles	598	0.65	3.7	0.62	0.11	80%	1,760	0.68	3.2	0.31	0.07	88%

Notes: We report yearly averages for the two periods. Data for the 1990-1995 period are taken from the EPA sector notebook. Data for 2003-2008 are taken from the EPA website. This TRI data has been adapted from *http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/data_refresh.html*

Table 2. Number of refineries by state in our sample

State	Number of plants
AL	2
AR	2
CA	18
CO	1
DE	1
GA	1
IL	2
IN	2
KS	3
KY	2
LA	16
MI	1
MN	2
MS	3
MT	4
ND	1
NJ	5
NM	3
OH	4
OK	4
PA	6
TN	1
TX	23
UT	5
VA	1
WA	4
WI	1
WV	1
WY	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 of 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. Probability of non-compliance, maximum-likelihood estimation[(a)]

	RFG		OXY	
Probability of being out of compliance	Coef.[(b)]	P>z	Coef.	P>z
Constant	1.295	0.005	1.706***	0.001
Number of state inspections	-0.256**	0.047	-0.235**	0.050
Number of EPA inspections	4.974	0.572	10.403	0.456
Total capacity	1.45E-06**	0.019	1.39E-06**	0.024
Share of alkylates capacity	1.615	0.265	1.771	0.223
Share of aromate capacity	-2.009	0.352	-2.176	0.313
Share of asphalt capacity	-2.400***	0.000	-2.357***	0.000
Herfindhal index	0.109*	0.070	0.108*	0.079
Extent of state regulation (RFG or OXY)	-0.542**	0.046	-2.223	0.117
Share of population under 5	-0.088**	0.026	-0.086**	0.028
Median household income	-0.000***	0.000	-0.000***	0.000
Number of observations	473		473	
LR chi2(10)	71.03		71.01	
Prob > chi2	0.0000		0.0000	
Percentage of correct predictions	62		61	

(a) The number of state inspections, the number of EPA inspections and the extent of the state regulation on gasoline are replaced by their predicted values (using parameters obtained in the first-stage models).
(b) *, **, *** indicates significance at the 10, 5 and 1 percent level, respectively.

Table 5. Total polluting emissions, OLS estimation[(a)]

	RFG		OXY	
Total air emissions per unit of capacity	Coef.[(b)]	P>t	Coef.	P>t
Constant	4.830**	0.000	4.518***	0.000
Number of state inspections	0.327	0.312	0.126	0.335
Number of EPA inspections	-18.216	0.323	0.660	0.439
Total capacity	0.000**	0.017	-3.81E-06**	0.017
Share of alkylates capacity	8.25E+00**	0.039	11.158***	0.003
Share of aromate capacity	-4.204	0.481	-4.160	0.472
Share of asphalt capacity	-3.317**	0.001	-2.355**	0.011
Herfindhal index	0.344**	0.041	0.244*	0.100
Extent of regulation (RFG or OXY)	0.739	0.296	-2.004	0.296
Share of population under 5	-0.304**	0.004	-0.281***	0.006
Median household income	-0.000	0.696	-0.000	0.896
Number of observations	461		461	
Fisher test of overall significance (p-value)	0.0001		0.0001	

(a) The number of state inspections, the number of EPA inspections and the extent of the state regulation on gasoline are replaced by their predicted values (using parameters obtained in the first-stage models).
(b) *, **, *** indicate significance at the 10, 5 and 1 percent level, respectively.

Table 6. Probability of non-compliance, national index of RFG and OXY regulation[(a)]

	RFG		OXY	
Probability of being out of compliance	Coef.[(b)]	P>z	Coef.	P>z
Constant	1.254***	0.006	1.027**	0.029
Number of state inspections	-0.246*	0.055	-0.226*	0.057
Number of EPA inspections	5.862	0.483	9.007	0.432
Total capacity	1.38E-06**	0.025	1.30E-06**	0.036
Share of alkylates capacity	1.856	0.205	1.973	0.181
Share of aromate capacity	-2.326	0.282	-2.885	0.186
Share of asphalt capacity	-2.382***	0.000	-2.295***	0.000
Herfindhal index	0.099*	0.097	0.102*	0.080
Index of regulation (RFG or OXY)	-2.013***	0.009	-2.082***	0.003
Share of population under 5	-0.079**	0.046	-0.070*	0.079
Median household income	0.000***	0.001	0.000**	0.011
Number of observations	473		473	
LR chi2(10)	73.86		77.63	
Prob > chi2	0.000		0.000	
Percentage of correct predictions	61		63	

(a) The number of state inspections and the number of EPA inspections are replaced by their predicted values (using parameters obtained in the first-stage models).
(b) *, **, *** indicate significance at the 10, 5 and 1 percent level, respectively.