What we Know About What we Know About Toxic Polluter Behavior from the TRI: Evidence from (almost) Twenty Years of TRI Data in The Petroleum Refining Industry.

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(Preliminary)

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#### Abstract

Using the TRI to understand polluting behavior can pose challenges due to the limited number of chemicals that are reported, the potential confounding effect of several regulatory programs that affect TRI substances, the lack of output information, and judgements regarding appropriate measures of releases. In an effort both to help illustrate and clarify these issues, I study TRI data from the petroleum refining industry using a balanced panel of 199 refineries from 1988-2003. I find that (1) although both aggregate and toxicity-weighted releases exhibited large declines over the period of study, the pattern of releases were substantially different, strongly suggesting that any inference that is drawn from the data will be sensitive to the measure of releases; and (2) regulatory programs can affect TRI releases both directly and indirectly. The direct effect occurs because emissions of several TRI substances are simultaneously regulated under the CAA and CWA (and other environmental programs and policies. The indirect effect occurs when regulatory programs induce changes in the set of inputs or the production process, leading to changes in TRI releases of substances from the TRI will not necessarily remove the confounding effects of these regulatory programs.

#### What we Know About What we Know About Toxic Polluter Behavior from the TRI: Evidence from (almost) Twenty Years of TRI Data in The Petroleum Refining Industry.

#### 1. Introduction

The Toxic Release Inventory (TRI) was introduced as part of the 1986 Emergency Planning, Community Right to Know Act (EPCRA) and requires all manufacturing facilities with at least ten full time employees that either use or manufacture more than a given threshold level of a listed TRI substance to report their releases of that substance to a publicly maintained data base. The TRI is the only data base available on toxic releases in the United States, and is one of only a few such collections worldwide. As such, it is much relied upon by both researchers and policy makers interested in studying toxic releases. Since data collection began in 1987, of the approximately 2,000 scholarly articles listed with JSTOR that use TRI data, at least 400 are dedicated to studying the effects of various environmental programs on toxic releases.<sup>1</sup> This paper is devoted to studying what we know about the TRI data themselves.

Using the TRI to understand polluting behavior can pose challenges. For example, although there are over 75,000 different chemical substances currently registered with the EPA under the Toxic Substances Control Act, the TRI collects data on a small fraction (< 1%) of them. Nothing is known about toxic releases from unlisted sources, including, in particular, whether or not polluters are substituting away from TRI-listed substances to TRI-unlisted substances as a means of reducing their reported toxic releases.

Inferences from the data may be further complicated by the multiple layers of environmental regulation facing toxic polluters. Although the releases of many TRI substances face no formal

<sup>&</sup>lt;sup>1</sup> The majority of papers look at the health effects associated with toxic substances reported under the TRI.

regulation, some do face regulation under the Clean Air Act (CAA) or the Clean Water Act (CWA), or fall under the jurisdiction of international agreements such as the Montreal Protocol, or a voluntary program such as TRI 33/50. The possibly confounding nature of such regulatory and environmental programs can make it difficult to determine causation associated with changes in polluter behavior. Aside from the complications of the data themselves, other choices, such as how to measure toxic releases -- toxicity-weighted or unweighted releases; normalized by output or not -- will obviously affect how we interpret the data. But how such measurement choices interact with the other TRI data issues identified above is not clear. Using TRI data for policy analysis without a good understanding of how such data issues might affect our understanding of releases may lead to flawed conclusions and misguided policy prescriptions.

In an effort both to illustrate and to clarify these issues, in this paper I examine TRI data from the petroleum refining industry. Petroleum refining is particularly well suited for this study for several reasons, including that (1) there are few facilities; (2) the production process is well understood, with limited possibilities for substitution across inputs, and (3) there are a small number of well-defined inputs and outputs associated with that process. These characteristics help to simplify many of the data issues that can arise.

Using a balanced panel of 119 petroleum refineries over 17 years of reporting<sup>2</sup> and a core set of TRI reporting substances, what I find is that the observed pattern of toxic releases differs substantially between toxicity-weighted and unweighted releases, suggesting that strong priors about which measure to use are important. Both sets of measures show large reductions (albeit of different

<sup>&</sup>lt;sup>2</sup> Although the first year of TRI reporting was for reporting year 1987, that year's data are considered unreliable and are not used in this analysis.

magnitudes) in releases during the sample period, but when output levels are taken into account, the pattern of releases can change significantly. I also find evidence that the CAA and CWA can affect TRI releases in at least two ways. One is through the direct regulation of several TRI reporting substances; the other is through the collateral effects of their regulation on non-CAA or CWA regulated TRI reporting substances. The latter finding is of particular interest, as it shows that it may not be sufficient simply to "net-out" CAA/CWA regulated substances to remove the confounding effects of these regulations on toxic releases.

The paper is organized as follows. In Section 2, I provide a brief description of the refining process. Section 3 provides background on developments in the petroleum refining industry and relevant environmental regulations, and in Section 4 I describe my data sources and provide some descriptive statistics. In Section 5 I examine some of the common measures that are used to study the TRI and explore how environmental programs and output can affect how our interpretation of the data. Concluding remarks are provided in Section 6.

#### 2. Petroleum Refining

I begin with a brief description of the refining process. Much of this section is based on information that can be found in the OSHA Technical Manual, Section IV, Chapter 2, and the EPA Sector Notebook on Petroleum Refining.

Petroleum refining takes crude oil and, through a distillation (fractionalization) or "cracking" process, produces consumable petroleum products. The major refinery products include gasoline; kerosene, liquified petroleum gas, distillate fuels (such as diesel fuels and home heating oils) and residual fuels (for marine vessels); coke and asphalt; solvents (including benzene, toluene, and xylene); petrochemicals (ethylene, propylene, butylene, isobutylene), and lubricants.

Refining begins by "desalting" the crude oil to remove some of the impurities -- in particular corrosive salts and metals. This process mixes heated crude oil with water to dissolve the salts, and then separates the water from the de-salted crude oil. Crude oil desalting can lead to TRI air, water, and land releases. Once that is done, processing of the crude oil can then take place.

Refining itself begins with distillation or fractionalization, which takes the de-salted crude oil and separates it into different hydrocarbon groups. This is usually done by heating the crude in a heat exchanger, placing the crude oil in atmospheric distillation towers, and then exploiting the fact that different hydrocarbon groups condense at different temperatures. The crude is vaporized, and then separated by condensing the vapor on several trays, each kept at a different temperature. As each hydrocarbon group has its own condensation temperature, they condense on different trays. The distillation process produces air borne hydrocarbon releases, as well as volatile organic compounds and particulate matter; toxic water releases include oil, hydrogen sulfide, chlorides, and phenol.

Once the crude has been separated into different components, those components may undergo additional processing. A wide variety of "downstream" processes may be used for different components. These include thermal cracking or visbreaking, coking, catalytic cracking, catalytic hydrocracking, hydrotreating, alkylation, isomerization, polymerization, catalytic reforming, solvent extraction, merox, dewaxing, and propane deasphalting. The general function of the downstream processing is to "…change the size and/or structure of hydrocrarbon molecules." (OSHA page 9.) (For a listing of the pollution typically generated from each of these processes, refer to the EPA Sector Notebook on Petroleum Refining, Exhibit 15.)

Once downstream processing has occurred, formulating and blending may take place. This involves combining processed hydrocarbon groups (or "fractions") with additives to produce

"finished" products, such as motor gasoline or jet fuel. Pollution releases in the form of fugitive air emissions are the most common form of pollutant from the formulating and blending process.

#### 3. Relevant Events in Recent Petroleum Refining History

Between 1986 and 2003, a number of important world and regulatory events occurred that had significant effects on domestic petroleum refineries. These are outlined briefly below.

#### A. Events Affecting Domestic Petroleum Markets

Crude oil is the single most important input to the petroleum refining industry. As such, fluctuations in crude oil prices can have dramatic effects on refinery output levels. During the 1990s, crude oil prices were subject to a higher than normal volatility due to the Persian Gulf Crisis (1990-1991). In particular, both domestic and imported crude oil acquisition cost by refiners spiked in 1990 due to the Iraqi invasion of Kuwait, and then the Gulf War. Prices started to decline in 1991, and continued this trend through 1994. Demand for oil then rose dramatically in the late 1990s. (The U.S. economy was growing at a rate of more than 4% and China's growth rate was in excess of 8% during the early and mid-1990s.) U.S. oil consumption rose from 17 million barrels of oil per day in 1990 to over 19 million barrels per day in 1998. Prices then started to rise again, peaking in 1996, and 1997, before falling, by 33% for domestic crude and 37% for imported crude, in 1998. That was when the Asian economic crisis occurred, and Asian Pacific oil consumption declined.

The sudden rise in domestic crude oil costs in the year 2000 is attributed to gasoline content regulations, in particular, the requirement of "reformulated" gasoline (described below), which increased the costs of production. But by 2001, as the U.S. economy was weakening and OPEC had increased production levels, crude oil prices again started to fall. The September 11, 2001 terrorist attacks further weakened the U.S. economy, lowering the demand for crude. By 2003, crude oil

prices (both domestic and imported) had recovered, partly because of improving economic conditions in both the U.S. and Asia.

#### B. Gasoline Content Regulations

Several gasoline content regulations went into effect between 1989 and 2003 that affected both the market structure of petroleum refineries and their production processes. Those developments are described below.

*Reid Vapor Pressure, Phase I.* In 1989, Phase I of the Reid vapor pressure (RVP)<sup>3</sup> standards, designed to control volatile organic compound releases as well as other airborne precursors of ozone, went into effect. Refiners complied with Phase I requirements primarily by reducing their use of "normal" butane (also referred to as n-butane or unbranched butane) blended into motor gasoline. Butane is a low-cost gasoline blending component that has a relative high RVP and high octane. It is not a TRI-listed substance. To compensate for the loss of volume and octane in the refined gasoline, refiners increased crude oil inputs, and increased their use of catalytic cracking and alkylation. Both catalytic cracking and alkylation units release air pollutants, including hydrocarbons and particulate matter, and water pollutants, including metals, ammonia, cyanide, and sulfuric acid.

*Oxygenated Gasoline*. The 1990 Clean Air Act Amendments introduced several additional gasoline content regulations. The first of these to become effective was the oxygenated fuels program (effective Nov. 1, 1992), which required all motor gasoline sold in most of the 39 areas designated as carbon monoxide non-attainment areas to contain a minimum of 2.7% oxygen by weight during the last 4 winter months. Adding oxygenates to motor gasoline lowers the level of carbon monoxide produced. The oxygenate components most commonly used are methyl tert-butyl

<sup>&</sup>lt;sup>3</sup> Reid vapor pressure is a standard measure of gasoline volatility.

ether (MTBE),<sup>4</sup> ethanol, and methanol. MTBE and methanol are TRI listed substances.

Because of concerns over significant groundwater contamination from MTBE and the potential health hazards of that substance,<sup>5</sup> by 2000, a small number of states had instituted a limit on MTBE content in gasoline sold in their states, and by 2003, some states (including California) had banned the use of MTBE in gasoline sold in their state.

*Reid Vapor Pressure, Phase II.* Also in 1992, Phase II of the RVP requirements became effective. That regulation imposed nationwide maximum summer volatility standards on gasoline (with stricter restrictions in southern areas of the country that did not meet the Federal ozone standards). Refiners met these standards by increasing their downstream processing by blending higher octane, low RVP components into their products (Sector Notebook, pg. 83). Some refiners also made large capital investments to produce high-octane, lower RVP blending components to meet the standard. RVP standards became even more stringent as of 1995 with the introduction of reformulated gasoline requirements.

*Low Sulfur Diesel, Reformulated Gasoline.* In 1993 (Oct. 1), low sulfur diesel fuel standards were put in place as part of the highway diesel fuel program, and reformulated gasoline (RFG)<sup>6</sup> requirements were imposed, effective as of January 1, 1995. RFG laws required the nine metro areas with the worst ozone problems to sell the clean gasoline during the summer months. Counties

<sup>&</sup>lt;sup>4</sup> Refineries may either purchase MTBE or manufacture it themselves. MTBE is produced by reacting methanol with isobutylene. Isobutylene is produced from butane, which is derived from crude oil.

<sup>&</sup>lt;sup>5</sup> Although MTBE is not considered toxic at low concentrations and has not been classified as a human carcinogen, MTBE is highly water soluble and can move rapidly into groundwater. Even at low concentrations, MTBE can be detected orally in drinking water making the water unpotable. There are growing concerns that MTBE may be hazardous at higher levels of concentration.

<sup>&</sup>lt;sup>6</sup> Reformulated gasoline is gasoline that is specifically blended to burn more cleanly (i.e. emitting lower levels of smog-producing pollutants as well as toxic pollutants) than conventional gasoline.

that were not required to use RFG had the option of "opting in" to the program. Several counties did choose to voluntarily opt in, but a number of them then opted out of the program right before the standards were to become effective. The result was an excess supply of reformulated gasoline. Regulators then required counties that had voluntarily opted into the RFG program to remain in the program until a specified date, and to provide advance notification of opting out, so that refineries could adjust their production of RFG accordingly. In total, approximately one third of the gasoline market in the U.S. now requires RFG.

RFG requirements limit benzene, which is a component of crude oil and is also produced during the refining process (and is a TRI listed substance), to a maximum of 1 percent by volume; mandates an oxygen content of at least 2 percent by weight; prohibits the use of lead and manganese (both TRI listed substances); and requires deposit control additives. The core RFG requirements for 1995 - 1999 prohibit any increase in NOx emissions and mandate a year-round reduction of toxic air pollutants (TAPs), and a summer reduction of VOCs, of 15 percent below 1990 "baseline" gasoline. By 2000, TAP and VOC emissions were to be reduced by a minimum of 20%.

The RFG standard that has been the most difficult to meet has been that involving benzene. The benzene requirement has two components: the first is a 1% maximum benzene content in motor gasoline, and the second is a 15% reduction in exhaust benzene. According to Zyren, Dale, and Riner (1996), these requirements can be achieved in one of two ways. The first is to reduce formate<sup>7</sup> benzene production by eliminating benzene and the benzene precursors, methylcyclopentane and

<sup>&</sup>lt;sup>7</sup> Formate is the high-octane liquid product that comes from the downstream catalytic reforming process.

cyclohexane, from the naptha (reformer feed).<sup>8</sup> This can be done by "pre-fractionating" the naptha. Benzene content can be further reduced if lower-benzene content inputs (known as C6 cyclics) are used in the production process, at least if fuel switching is possible.

The second method is to remove or convert the formate benzene in the reformate product. The recovered benzene can then be used to produce chemical feedstock or converted to a gasoline blending component or a petrochemical through hydrogen saturation or alkylation.

*California*. The state of California imposed its own set of more stringent RVP and clean gasoline standards during this period. In 1992, California Clean Gasoline, Phase I was in effect, imposing more stringent RVP standards and additional controls on gasoline detergents and control additives. In 1996, California's Phase II clean gasoline standards were put in place. Those standards also were more strict than those of RFG Phase II, which became effective in 2000.

Finally, in 1995, leaded gasoline sales were prohibited nationwide.

To a large degree, the environmental regulations put in place during the 1990s led to consolidation in the petroleum refinery industry. The number of major U.S. energy companies went from 19 in 1990 to 10 in 2000. During that time, 47 U.S. refineries were shut down. Total operating capacity, however, rose by 6%. The gasoline content requirements led to the construction of oxygenate production facilities. At least 33 refineries had facilities producing oxygenates by 1992. Production of fuel ethanol was concentrated in the Midwest corn belt area, whereas MTBE production was concentrated along the Gulf coast. Inventories were built up during the summer of 1992. The blending to accomodate winter oxygenated gasoline requirements began in August of that

<sup>&</sup>lt;sup>8</sup> Petroleum naphtha is an intermediate hydrocarbon element that is produced from the distillation of crude oil. It is catalytically reformed, which re-arranges or re-structures the hydrocarbon molecules, to produce a high-octane component of gasoline.

year.

#### C. Other Relevant Environmental Regulations

This section describes additional regulations and agreements affecting toxic releases.

*Clean Air Act and Clean Water Act:* A sizeable subset of TRI substances is regulated under the Clean Air Act and its amendments.<sup>9</sup> Such air pollutants may be regulated as hazardous air pollutants under the National Emissions Standard for Hazardous Air Pollutants, or as conventional pollutants (fine particulate matter or volatile organic compounds) under the National Ambient Air Quality Standards. In general, both regimes impose technology standards. The Clean Water Act also affects a subset of TRI chemicals, although the set of co-regulated substances is significantly smaller. CWA regulated substances also face technology based standards. In most instances, the applicable standards are industry and (typically) state-specific.

*TRI 33/50*: TRI 33/50 was a voluntary program initiated by the EPA in 1991 to reduce releases of the 17 most common TRI substances.<sup>10</sup> The EPA invited over 6000 companies to participate. Participants were asked voluntarily to reduce their releases of those substances by 33% (from a 1989 baseline) by 1992 and 50% by 1995. Reductions in all 17 substances exceeded the 50% goal one year in advance of the program's final target date. It should be noted that all TRI 33/50 chemicals are listed as hazardous air pollutants and face regulation under the Clean Air Act

<sup>&</sup>lt;sup>9</sup> The TRI provides a data flag that indicates whether a substance is regulated under the CAA, but does not do so with respect to the CWA. The data flag for the CAA substances, however, is inaccurate, as documented in Bui and Kapon (2012). In this paper, I use the TRI Regulatory Matrix, Appendix E, to determine whether a substance is regulated under the CAA or the CWA.

<sup>&</sup>lt;sup>10</sup> The 17 "high-priority" substances were: benzene, cadmium and compounds, carbon tetrachloride, chloroform, chromium and compounds, cyanide and compounds, dichloromethane, lead and compounds, mercury and compounds, methyl ethyl ketone, methyl isobutyl ketone, nickel and compounds, tetrachloroethylene, toluene, 1,1,1-trichloroethane, trichloroethylene, and xylenes.

and its amendments.

*The Montreal Protocol:* The Montreal Protocol is an international agreement that was signed in 1987 and took effect on January 1, 1989. Signatories to the Protocol agreed to a phase-out plan for the use (consumption and production) of chlorofluorocarbons (CFCs) and hydrochloro-fluorocarbons (HCFCs), both categories of substances that are monitored by the TRI. The plan allowed for an increase in "Group 1 of Annex A" substances up through 1992 (but the increases were capped at 150% of 1986 levels), but then required a rapid phase-out with a target of being at no more than 25% of 1986 levels by 1994, and complete phase out by 1996. Slower phase-out plans were fixed for other substances.

#### 4. Data Sources and Description

Toxic release data are taken from the EPA-TRI website (www.epa.gov/tri/tridata) for reporting years 1987-2003, with additional regulatory and chemical information taken from the EPA TRI Data Release Appendix E (Regulatory Matrix: TRI Chemicals in Other Federal Programs). The data are collected at the facility level, by chemical. Because reporting chemicals, threshold reporting levels, and required reporters changed during this period, I restrict my analysis to the subset of chemicals that were subject to reporting for all years 1988-2003 and for which the reporting threshold did not change. This set of chemicals will be referred to as the "base" set of 1988 chemicals.

The refineries that I study are the set of facilities that list SIC 2911 (or NAICS 324110) as their primary industry code in the TRI. This yields 2843 facility-year observations from 1988-2003 in the unbalanced panel, with a high of 193 facilities reporting in 1990 to a low of 161 facilities reporting in 2003. The balanced panel consists of 1904 facility-year observations with 119 petroleum refineries reporting in each of the 17 years. The balanced panel of facilities captures approximately 84% of all petroleum refining (TRI) releases of the base 1988 chemicals over the sample period.

Descriptive statistics for the unbalanced and balanced panels are summarized in Table 1. There are 248 unique facilities in the unbalanced panel. Average annual facility level releases from that set of reporters (1988-2003) was 268,252 pounds. Air releases made up approximately 86% of the total, whereas water releases were only 1.3%.

Due to changing market conditions, some of it driven by environmental regulation, entry and exit occurred frequently during the sample period. (See Table 2.) In total, 44 facilities that reported TRI releases in 1987 exited the sample before 2003; 43 facilities were both late entrants and early exiters from the sample; and 31 were late entrants, but remained in the sample through at least 2003. A total of 11 facilities were in the data set in 1987, exited for one or more years, and then re-entered. All four of those groups report smaller average annual facility level TRI releases than the unbalanced panel as a whole, at least in part because they are smaller in terms of operating capacity. A priori, one would expect that early exiters would be more pollution intensive than surviving facilities and that entrants would be less pollution intensive than surviving facilities as well, and those expectations are substantiated by the data.

Once facilities that enter or exit are removed from the sample, the balanced panel consists of 119 unique facilities that are, on average, dirtier than those in the unbalanced panel, with marginally more water and land releases (as a percentage of total releases) than facilities in the unbalanced panel. (See Table 1.) Some of these differences may be due to the size of the facilities in the two data sets. Data on refinery capacity (operating and idle) are taken from Volume I of the Petroleum Supply Annual for 1987-1995, 1997, and 1999-2003.<sup>11</sup> The capacity data is linked to the TRI by name and location information.

The link between the TRI and the DOE is not a one-to-one match. As noted in *Ranking Refineries: What Do We Know About Oil Refinery Pollution From Right-To-Know* (1995), that is because of differing definitions of "petroleum refining." The DOE defines the petroleum refining industry as comprising "establishments engaged primarily in producing gasoline, kerosene, distillate fuel oils, residual fuel oils, and lubricants through straight distillation of crude oil, re-distillation of unfinished petroleum derivatives, cracking, or other processes." The Census uses a slightly different definition. According to the Census, "...this industry comprises establishments primarily engaged in refining crude petroleum into refined petroleum. Petroleum refining involves one or more of the following activities: (1) fractionation; (2) straight distillation of crude oil; and (3) cracking."

Facilities in the TRI self-report into industry categories, according to their own understanding of these classifications. These (albeit slight) differences in industry definition can sometimes lead to different industry classifications for the same facility. As it is beyond the scope of this paper to reconcile these differences, I simply take the definitions and resulting classifications of facilities as given, with the understanding that the number of matched facilities may be affected by this issue.

The unbalanced TRI data set that is matched to DOE capacity data ("unbalanced" TRI-DOE) consists of 2000 facility-year observations (with 55 facility-year observations reporting an operating capacity of 0 between 1988 and 2003). This accounts for 203 unique refineries, for which I observe between 118 (2003) and 168 (1989) matched facilities in each year (See Table 3.). They account

<sup>&</sup>lt;sup>11</sup> Refinery level data on operating capacity were not collected in 1996 or 1998.

for 79.5% of all TRI releases in the unbalanced panel. Over-all, the set of facilities that could be matched with DOE capacity data are similiar to those in the over-all sample. Average facility level releases are somewhat larger (at 303484 pounds per year) than those in the unmatched unbalanced panel, probably reflecting that smaller facilities are less frequently captured in the DOE data set. But the proportion of air, water and land releases are very similar (85% for air, 1.4% for water) across the two data sets.

The balanced panel of TRI data matched with the DOE capacity data ("balanced TRI-DOE") is an *unbalanced* panel due to missing DOE capacity data for some of the TRI-defined refineries and consists of 1450 facility-year observations and 118 unique facilities. Those facilities account for about 80% of releases from the balanced TRI panel. On average, facility level releases are a little larger than those in the balanced TRI panel, with air releases accounting for 76.8% of total releases (somewhat lower than in the balanced panel), and water accounting for 1.4% (about the same as in the balanced panel). As suggested above, facilities in the balanced TRI-DOE data set are, on average, larger than those in the unbalanced TRI-DOE data set, which may explain part of the the differences in average releases observed in Table 1.

#### 5. What Do We Know About TRI Releases?

Aggregate TRI releases from the balanced panel of petroleum refineries for the 1988 set of base chemicals are shown in Figure 1. Between 1988 and 2003, aggregate releases fell by almost 60% nationwide. (See Table 3.) The downward trend in releases is reasonably steady over this period, with small increase in 1989, when releases increased by 5%, and a more substantial (12%) increase in 1992.

#### Figure 1. Aggregate TRI Releases by Refineries



In Figure 2, aggregate releases are broken down by pollution media. Not surprisingly, TRI air releases dominate toxic releases from refineries, which are known to be air pollution intensive. For the most part, air releases declined steadily over the sample period. In 1988, air releases were approximately 88% of total TRI releases, falling to 80% by 2003. Over the sample period, air releases fell by 61%. Toxic water releases make up a small fraction of TRI releases from petroleum refineries. In 1988, they were just 1.1% of total releases, but by 2003 this percentage more than doubled to 2.5%. Over-all, water releases fell by 6.5%.

TRI air releases did increase marginally in 1989 (2.7%), but did not increase in 1992 (-5.7%). Although difficult to discern from the plot, water releases increased by 87.6% in 1989 and by 25% in 1992; land releases (not shown) by approximately 16% in 1989, and by more than 225% in 1992. Figure 2. TRI Refinery Releases by Media



What might have caused the increases in observed releases in 1989 and 1992? Those years correspond to when RVP Phase I (1989), RVP Phase II (1992), oxygenated gasoline (1992), and California Clean Gasoline Phase I (1992) regulations came into effect. The data certainly suggest that these regulations were responsible for the increases in toxic releases in those years.

More specifically, the 1989 data show that two of the largest increase in releases were for hydrogen fluoride and carbonyl sulfide, pollutants that are produced by alkylation units. Alkylation is part of the downstream processing used to produce higher octane gasoline. Increased use of alkylation units was one way in which refiners responded to the 1989 RVP standards. (See ICF: Environmental, Health, and Safety Guidelines: Refining. April 30, 2007.)

By 1992, it is well documented that refiners were starting to build both capacity and inventory to meet the oxygenated gasoline and RFG requirements. Both MTBE and methanol exhibited among the highest increases in 1992 amongst TRI-listed substances, as did asbestos, which

is commonly used to line pipes in refineries and is a good indicator of refinery construction. Furthermore, MTBE is generally released to water and land, which could explain the sharp increases in releases for those two types of media with no corresponding increase in air releases. Taken together, the data are consistent with the hypothesis that gasoline content regulations from the CAA (and California Clean Gasoline) were responsible for those increases.

#### B. Toxicity-Weighted Release Trends

One drawback to using TRI data aggregated across all chemicals is that it does not take into account differences in toxicity. In particular, some TRI substances have been recognized as being carcinogenic, or as having adverse developmental or reproductive effects. If policy makers are primarily concerned with reducing the human health risks associated with toxic pollution, their interest may lie more with "toxicity-weighted" measures of aggregate releases rather than with unweighted measures.

Toxicity-weights can be found for toxic substances in a number of places, including the California EPA Office of Environmental Health Hazard and Assessment, EPA's Integrated Risk Information System (IRIS), EPA's Office of Pesticide Programs, and the EPA's Agency for Toxic Substances and Disease Registry. Here, I make use of toxicity weights compiled by the EPA's Risk Screening, Environmental Indicators group -- weights that only account for cancer risks -- that can be found at http://www.epa.gov/oppt/rsei/pubs/index.html. I apply the inhalation toxicity weight to TRI air releases and the oral toxicity weight to all other forms of pollution media. The toxicity weights that are used are not absolute; they are only comparative in nature.

Figure 3 depicts both the toxicity-weighted and unweighted TRI releases during the period 1988-2003.



Figure 3. TRI Refinery Releases: Unweighted and Toxicity-Weighted

In both cases, significant improvements can be observed over the sample period, although they are much larger for the toxicity-weighted releases (-91.9% versus -57.5%). But the details of the trend for toxicity-weighted releases differ from those for unweighted releases. (See Table 3.) In particular, toxicity-weighted releases (right hand panel) fell sharply in 1990, and then rose in both 1991 and 1992. Between 1992 and 1998, weighted releases continued to fall, before showing a slight upward trend that continued through 2002. Unweighted releases, however, showed a marked increase in 1989 and 1992, but declined through the rest of the sample period.

In years in which aggregate releases were falling, but toxicity-weighted releases were rising (or, vice versa), on the whole, refiners were substituting away from (toward) less toxic substances and toward (away from) more toxic substances. It is worth noting that, with RFG production, we observe decreases in benzene and increases in hydrogen fluoride, carbonyl sulfide, MTBE, and methanol. Benzene has a toxicity index of 100, and MTBE has an index of 1. The other substances

(hydrogen fluoride, carbonyl sulfide, methanol) have indices of zero, so the production of RFG appears to be less toxic than the production of conventional gasoline. But RFG also is known to lower fuel efficiency, necessitating higher consumption and therefore production. Hence, even with the production of a cleaner gasoline, the increase in quantity produced during the build up of inventory in 1992 resulted in an increase of both aggregate releases, as well as toxicity-weighted releases.

Regardless of the exact nature of these differences, there are obvious implications for those who use the data. Researchers must have strong priors about which measure (toxicity-weighted, or unweighted releases) is appropriate to use, as the different measures may lead to different conclusions. That is made even more clear when toxicity-weighted and unweighted releases are broken down by pollution media. (See Figures 4 and 5.) Given that air releases constitute the majority of toxic releases by refineries, their weighted releases look very similiar to those for aggregate toxicity-weighted releases, with the over-all decline in toxicity-weighted air releases of 93% compared to the 61% decrease in unweighted air releases. That, however is not the case for water releases. For unweighted TRI water releases, releases in 2003 are only modestly below the levels reported in 1988 (-13%), but on a toxicity-weighted basis, petroleum refineries were emitting significantly lower levels of toxicity into the environment (-67%). Furthermore, we can see that the years in which unweighted releases increase (1989, 1992, 1997, 2000) do not necessarily correspond to years in which toxicity-weighted releases increase (1989, 1991, 1998, 2001).



Figure 4. TRI Refinery Air Releases: Unweighted and Toxicity Weighted





### C. Geographic Trends

As with many pollution intensive industries, petroleum refining largely is clustered

in a small number of regions. The major refining centers in the U.S. are in California, Texas, and Louisiana. In terms of operating capacity (measured in barrels/day), in 2011, California refineries made up approximately11% of US refining capacity, while Louisiana accounted for 19%, and Texas for 28%, for a total of 57% (and accounting for approximately 60% of TRI releases by refineries). There are significant differences in both environmental quality and regulation in those three regions. The different regions also serve different petroleum markets; in particular, the California refiners largely supply the California market. Those considerations could lead toxic pollution trends to vary by region. To see whether this is the case, I look at toxic releases grouped by geographic region.

Releases (toxicity weighted and unweighted) from the three regions are depicted in Figures 6-8. TRI releases from California make up just under 7% of nationwide releases, whereas Texas accounted for approximately 41%, and Louisiana another 13%.

Several things are worthy of note. First, trends in both toxicity weighted and unweighted releases differ significantly across region, but all regions show reductions in both weighted and unweighted releases. California had reductions in (unweighted) aggregate releases of 46%, Texas of 58%, Louisiana of 52%, and in the rest of the U.S, 61%. Second, it appears that the rise in nation-wide releases observed in 1989 is not due to increases in releases in California, Texas, or Louisiana but to increases occurring in the rest of the US. The increase in nationwide releases in 1992, in contrast, can be attributed to increases in Texas and Louisiana.

*California.* TRI releases in California are heavily influenced both by Federal oxygenated gasoline and California RFG requirements. In 1992, both oxygenated gasoline and California RFG Phase I requirements went into effect. Phase I required more stringent RVP standards than those adopted in Phase II of the federal RVP program; set regulations for detergents and deposit control

additives in motor gasoline; proposed standards for lead levels in gasoline and set out to eliminate all leaded gasoline sold in the state by 1994; and regulated the sulfur and manganese content in motor gasoline. In 1996, Phase II of California's RFG program became effective, setting specifications for sulfur, aromatics, oxygen, benzene, T50, T90, olefins, and RVP. Phase 3 of the California RFG set out to eliminate MTBE from California gasoline by December, 31, 2002.

*MTBE.* Although the use of MTBE as an oxygenate agent was not mandated by California RFG requirements, MTBE was the oxygenate most commonly used to meet their oxygenated gasoline requirements. (See Table 5.) That is reflected in the release levels of MTBE during this period, which rose quite steadily from 1988 through 1999 (with small reductions in 1994 and 1998), before starting to fall in 2000. A particularly large increase in MTBE releases in 1996 corresponds to the adoption of California RFG Phase II rules and the build up of RFG gasoline inventory. The reduction in MTBE releases (and use) post 2000 appears to be related to refiner anticipation of the California Phase 3 MTBE ban in motor gasoline.

*Benzene*. Benzene levels are restricted by the California regulations, and benzene releases fell steadily from 1989 through 2000, again with small exceptions in 1995 and 1998 (which were similar to that seen for MTBE). Unfortunately, California refiners did not increase their use of hydrogen fluoride alkylation units to boost the octane level of the gasoline after reducing their benzene levels, and we cannot observe in the data whether sulfuric acid alkylation units were used instead, as sulfuric acid is not a TRI-listed base substance.<sup>12</sup>

We can, however, observe what happened to releases of manganese, manganese compounds,

<sup>&</sup>lt;sup>12</sup> Certain forms of sulfuric acid were delisted from the TRI list of toxic chemicals in 1993, and therefore, are not included in the base set of 1988 chemicals.

and lead. Manganese-based additives were banned from use in motor gasoline as part of California's RFG Phase I program. Lead in motor gasoline was banned after 1996. This is all well reflected in the data: releases of manganese compounds fell dramatically after 1992, and releases of manganese and lead fell to zero by 1997.

*Texas*. Similar to releases seen for the nation as a whole, toxic releases from refineries in Texas show a strong decline between 1988 and 2003. There is, however, a break in the trend that occurs between 1990 and 1992. The spike in releases in 1992 corresponds to an increase in MTBE releases of 97%, and an increase in methanol of 163%, over the previous year. (See Table 6.) Asbestos releases also peaked in 1992 and 1993 at 1.71 and 1.69 million pounds, respectively, capturing the high level of refinery construction in the state to meet anticipated RFG demand. Benzene releases fell steadily between 1990 and 2001, before rising in 2002 and 2003.

We also observe a large, one-year decline in MTBE releases in 1994 (-43%), which could reflect the unexpected over-capacity of RFG gasoline that arose before RFG requirements were to come into effect, when several counties which opted in to the RFG program suddenly decided to opt out. The drop in MTBE releases in Texas in 1994 is mirrored, but to a much smaller degree, in Louisiana (-25%). California, which should not have been affected by this event had a decrease in MTBE releases of 10%, while MTBE releases in the rest of the U.S. rose by 27%.

*Louisiana*. One interesting fact about the Louisiana refineries is that they did not report releases of asbestos (friable) in any year other than in 1987. But it is known that Exxon constructed a 7,000 barrel per day MTBE unit at its refinery in Baton Rouge in 1993 (Oil and Gas Journal, Volume 90, issue 36). One explanation for the "missing" asbestos releases is that there is also a chemical plant at Exxon's Baton Rouge refinery. If the refinery and chemical plant report TRI releases separately, and the MTBE is produced at the chemical plant, its releases would not be reported by the refinery. Iin fact, we observe that although MTBE releases more than doubled in 1992 in anticipation of the upcoming RFG requirements, releases of methanol used to produce MTBE, declined. This suggests that Louisiana refineries may not have been producing their own MTBE but purchasing it elsewhere.<sup>13</sup>

That aside, the peaks and valleys of reported TRI releases in Louisiana are all mirrored by the peaks and valleys of the primary substances associated with RFG: benzene, MTBE, and methanol. (See Table 7.)

*Rest of the US.* Although almost 40% of U.S. refining capacity is outside of California, Texas, and Louisiana, only 11% of MTBE production capacity is located here. And of that 11%, little of it is produced at refineries. Yet, outside of California, the demand for RFG gasoline (and oxygenated gasoline) is the greatest in the Northeast. How did they meet their RFG needs? Ethanol is an oxygenate that is not a TRI-listed substance and is used in lieu of MTBE. As such, we would not expect TRI releases in areas such as the Northeast to be affected by gasoline content regulations to the same degree as the other regions. (See Table 8.) In fact, the data reflect little, if any, addition of MTBE capacity; there were, for example, no reported asbestos releases). Both MTBE and methanol releases are flat (or declining) throughout the sample period.

<sup>&</sup>lt;sup>13</sup> That, of course, raises the question as to how (or if) we ought to measure releases associated with MTBE production that occurs off-site.

Figure 6. Toxicity Weighted and Unweighted TRI Releases from California Refineries



Figure 7. Toxicity Weighted and Unweighted TRI Releases from Texas Refineries



Figure 8. Toxicity Weighted and Unweighted TRI Releases from Louisiana Refineries



Figure 9. Toxicity Weighted and Unweighted TRI Releases from Rest of the US Refineries



D. Other Environmental Regulations and Policies

Although the handling, transportation, storage, and disposal of toxic substances are

all heavily regulated, toxic *releases* are largely unregulated, except insofar as they face simultaneous coverage under some other pollution regulation or policy. For petroleum refineries, the releavnt additional regulations and policies are the CAA, the CWA, the TRI 33/50 program, and the Montreal Protocol.

Substances regulated under the CAA (directly, or as hazardous air pollutants (HAPs)) and the CWA usually face technology based standards, (generally determined at the state level and uniform across industry); they may also be directly monitored by regulators through continuous emissions monitoring systems (such as for PM and VOCs). So, in addition to what may drive polluters to alter their toxic releases, changes in release of those substances may also be influenced by (1) formal regulatory measures on emissions (such as those introduced in the 1990 Clean Air Act Amendments), and (2) the fact that their toxic releases can be (more) easily monitored and verified by regulators.

In Table 9, summary statistics are provided for the breakdown of TRI substances that are coregulated under a separate environmental policy. Over the sample (excluding 1987), CAA substances (by weight) make up 61.9% of total releases, whereas CWA, TRI 33/50,<sup>14</sup> and Montreal Protocol substances are 0.19%, 43.11%, and 0.22% of total releases, respectively. Between 1988 and 2003, CAA substances fell by 63%, MP by 99%, and TRI 33/50 by 66%. CWA substances, on the other hand, rose by 32%.

Figure 10 graphs TRI CAA and non-CAA releases over time. Notably, CAA substances dominate TRI air releases; while both show significant declines over time, CAA substances fell by more (64%) than non-CAA substances (55%). Furthermore, non-CAA substances rose in 1989, and

<sup>&</sup>lt;sup>14</sup> Bearing in mind that the 33/50 substances are a proper subset of those regulated under the CAA.

remained higher than their 1988 levels until 1993, whereas CAA air releases fell steadily over this period, except for in 1990, when they rose slightly.

Figure 10. TRI CAA and Non-CAA Air Releases



CWA and non-CWA water releases are depicted in Figure 11. In contrast with air releases, TRI water releases are dominated by non-CWA substances. Also, the pattern of TRI releases between the two groups of water-bourne substances do not look very similar. Non-CWA releases declined by 6.5% between 1988 and 2003, while CWA substances increased by 32%.

The small decline in TRI non-CWA water releases can be traced directly to an increase in releases of approximately 35 TRI substances, 2 of the largest being MTBE and methanol. Those two substances are not regulated under the CWA (although they are regulated under the CAA). If releases from these two substances are backed out of the total releases for non-CWA substances, then the reduction in that subset of chemicals between 1988 and 2003 would be approximately 35%, as

opposed to the 7% reduction when those two chemicals are included.

Figure 11. TRI CWA and Non-CWA Water Releases



Figure 12. TRI 33/50 and Montreal Protocol Releases from Petroleum Refineries



Figure 12 illustrates the reduction in releases from TRI 33/50 and Montreal Protocol substances. For TRI 33/50 substances, there is a steady decline over most of the sample period, with the sharpest decline occuring between 1992 and 1995, which were the program years. For the set of Montreal Protocol substances, the sharpest decline occurs between 1994 and 1996 when the U.S. was required to meet the agreed upon reductions on CFC production and consumption.

If all CAA, CWA, and Montreal Protocol substances (recalling that all TRI 33/50 air releases are also regulated under the CAA) are netted out, we are left with Figure 13, which shows the trend of TRI substances that face no formal emissions regulation. Net releases decline by 46.7%, somewhat less than gross releases (58%), but still a substantial decline. The jumps in gross releases observed in 1989 and 1992 remain here, driven by releases (primarily in water) affected by the gasoline content regulations. That is, there is a set of substances *not* regulated by the CAA, CWA, MP, or TRI 33/50, that *are* affected by gasoline content regulations. The most important of these are hydrogen fluoride, MTBE and methanol water releases. What this suggests is that "netting-out" formally regulated substances may not be enough to prevent a potential confounding effect from regulation.

Figure 13. TRI Refining Releases Net of CAA, CWA, TRI 33/50 and MP co-regulated substances.



If we remove these 3 non-CWA, RFG- related substances from the net TRI releases depicted in Figure 13, the picture would not look very different, because water releases make up only a small portion of over-all TRI releases. If, however, we look at the effect of removing those 3 substances from *net* water releases (water releases minus CWA, MP and TRI 33/50 releases), we arrive at Figure 14 (and see Table 10). Now, we can see that, from 1988-2003, although TRI water releases only declined by 6.5%, net TRI releases declined by a mere 2.0%. But once we remove the three RFG-related substances, TRI water releases declined by 24.8%. Note that in this case, the indirect effect of the regulation leads to underestimations for the impact of the TRI, which is not usually thought to be the case.

# Figure 14. TRI Water Release, Net of Coregulated Pollutants ("Net Water") and Net of RFGrelated Substances ("Net Water - RFG")

![](_page_33_Figure_1.jpeg)

#### *E. Output*

Changes in output, both in the quantity produced and in the product mix, may have an important impact on toxic releases. Reductions in output, all other things being equal, should lead to a reduction in releases. So it is possible that observed reductions could simply reflect reductions in output. To address that possibility, releases can in principle be normalized by output, yielding a pollution "intensity" measure. In practice, however, this is not quite as straightforward as one might hope. Even assuming the availability of data, with a multi-product industry it is difficult to know what the appropriate normalization factor would be. For present purposes, I use refining operating capacity as a proxy for output.<sup>15</sup> Operating capacity was both high and rising over much of the

<sup>&</sup>lt;sup>15</sup> The TRI includes a "production ratio" variable which purports to measure how production in year t relates to production in year t-1. This variable is highly suspect -- with value ranges that sometimes are inplausibly large or implausibly small, and is not recommended for use.

sample period, as were capacity utilization rates, which were approximately 85% in 1988 and rose to 92% by the early 2000s. (Petroleum Supply Annual.) My prior is that this measure would tend to over-estimate the actual output level, leading to an downward bias in the pollution intensity measure.

Since there are relatively few petroleum refineries matching their TRI release data to operating capacity data from the Department of Energy (published by the Energy Industry Adminstration (EIA)) is relatively easy. The caveat, however, as noted in Section 4, is that the definition of a "petroleum refinery" used by the DOE, EIA, and others differs somewhat from one another, and complete matches are usually not possible. The balanced panel of TRI facilities when matched to DOE capacity data yields an unbalanced panel of 1450 facility-year observations from 118 facilities. To provide a consistent set of facility-year observations to compare the effects of normalizing TRI releases by operating capacity, in Figure 15 I show aggregated, un-normalized releases for those 118 facilities, but *only* in those years for which there is operating capacity data in the left-hand panel, and normalized by output releases for the same matched facilities in the right-hand panel. (See Table 11.)

![](_page_35_Figure_0.jpeg)

Figure 15. Aggregate TRI Releases Normalized by Operating Capacity

What Figure 15 illustrates is that, for these facilities, both aggregate releases and pollution intensity were falling. In 1989, when we observed a moderate increase in TRI releases that appeared to be due to RVP Phase I regulations, pollution intensity also rose significantly. That is consistent with refiners having to use more crude oil inputs (to replace the lost volume due to the reduction in butane) to produce the same volume of output, as well as having to utilize more pollution intensive downstream processing to increase the octane levels in the gasoline.

In 1992, in contrast, when facilities were building RFG inventory and aggregate releases again jumped, pollution intensity barely rose at all. That is, the increase in releases was due almost entirely to increased production, exactly what we would expect given that refineries were increasing output to build up inventories of RFG.

The regional graphs of pollution intensity are also of interest. For California, 17 facilities are captured in the balanced TRI-DOE data set with 213 facility-year observations. (See Figure 16.)

The over-all pattern between aggregate releases and releases normalized by output is very similar, although it appears that between 1995 and 2000, not only are aggregate releases increasing, but so is pollution intensity. This is consistent with higher production levels of California RFG -- a more pollution intensive good to produce.

Figure 16. TRI Releases from 17 California Petroleum Refineries

![](_page_36_Figure_2.jpeg)

A total of 24 Texas refineries are included in the balanced TRI-DOE data set, with 256 facility-year observations. Here, we see that in 1989 and 1990, when aggregate releases rose modestly in the first year and then more significantly in the second, the exact opposite is observed when we look at releases normalized by output. That is, in 1989, there is a very large increase in pollution intensity level, almost surely related to RVP Phase I regulations, and then virtually no additional change in intensity level the following year. In 1992, both aggregate releases and pollution intensity rose, reflecting the same behavior as that captured in the national picture.

Only 13 facilities in Louisiana are captured in the balanced TRI-DOE dasta set (166 facility-

year observations). For those facilities, although their aggregate releases were very volatile, and showed virtually no change between 1988 and 2003, their pollution intensity significantly worsened over the same period. We know that output levels were not systematically falling during this period, so that suggests that those facilities were simply becoming more pollution intensive over time. It is difficult to determine why that might be the case without further investigation.

Figure 17. TRI Releases from 24 Texas Petroleum Refineries: 1988-2003

![](_page_37_Figure_2.jpeg)

![](_page_38_Figure_0.jpeg)

#### Figure 18. TRI Releases from 13 Louisiana Petroleum Refineries: 1988-2003

#### 6. Conclusion

The TRI is an extraordinarily rich dataset that provides unique opportunities for researchers and policymakers to learn about the behavior of toxic polluters from a wide range of U.S. industries. But the data are also complex, and it is critical to understand their limitations to avoid drawing invalid inferences.

By limiting my focus to petroleum refineries, I an able to show that both toxicity-weighted and unweighted aggregate releases exhibited large declines over the period of study, but that the pattern of releases were substantially different. This strongly suggests that any inference that is drawn from the data will be sensitive to the measure of releases (weighted or unweighted) chosen. I also find that changes in output levels, as measured by operating capacity, resulting from changes in market conditions and environmental regulations, explain some of the largest decreases (and increases) in toxic releases. Because that is so, it may be important to find appropriate normalization factors. The use of the production ratio variable that is collected in the TRI for this purpose is not recommended.

Another useful insight is that regulatory programs can affect TRI releases both directly and indirectly. The direct effect occurs because several TRI substances are simultaneously regulated under the CAA or CWA, or under environmental programs or agreements such as the TRI 33/50 or Montreal Protocol. TRI air releases from refineries are dominated by CAA substances whereas, TRI water releases are dominated by non-CWA substances. Over the sample period, reductions in air releases were due largely to reductions in CAA substances, although non-CAA air releases also fell. Why the differential response? There are many possible (and plausible) explanations: it could, for example, be because of CAA regulations of emissions, or it could be because CAA substances are more easily verifiable by regulators.

TRI water releases exhibited a similar pattern. There were reductions in TRI water releases for CWA-based substances (7%), while non-CWA TRI water releases showed not a reduction but an increase of more than 30%. So it is possible that regulatory measures affecting water emissions had an effect on CWA TRI water releases as well.

The indirect effect of formal regulatory programs observed in the refinery data occurred when it induced changes in the set of inputs and the production processes, leading to changes in TRI releases of substances that are not directly regulated by those programs. That was the case for both oxygenated and RFG gasoline requirements. Although the gasoline content regulations were aimed at reducing carbon monoxide, benzene, and ozone precursors (pollutants that are regulated under the CAA), they had the possibly unanticipated effect of increasing releases of MTBE, methanol, and other TRI substances that are not regulated under the CWA (although they may be under the CAA). When we take into account these indirect effects on non-CWA water releases of MTBE and methanol, non-CWA water releases declined by more than 25% (instead of just 7%). This finding illustrates the difficulty in trying to control for the confounding effects of regulatory policies when using the TRI. Simply "netting-out" co-regulated pollutants may not be sufficient, and it is not necessarily evident whether we would be under- or over-estimating the impact of the TRI.<sup>16</sup>

Finally, regional differences in TRI trends were driven, at least in part, by how refiners chose to meet clean gasoline requirements. Availability of cleaner inputs (e.g. lower sulfur crude, or crude with lower C6 cyclics) and the choice of oxygenate agents (MTBE versus ethanol) were important determinants of TRI releases. In areas where MTBE was the preferred oxygenate, we observe higher levels of toxic releases associated with the build up in inventory to meet RFG requirements. These same patterns were not evident in areas where ethanol was used.

What can we learn from what happened in the petroleum industry, and can we generalize the results found here to other industries? That is not easy to say, as both the limited ability to substitute across inputs as well as the limited number of inputs used in refining makes it easier to identify how different policies affect them. In an industry that has many more multiples of products or substitution possibilities, being able to "track" the indirect effect of policies on input choices may be more challenging. But the lessons of taking pains generally in examining the data; of having strong priors about which sets of measures to use; of finding good output-normalization variables; and of being sensitive to the direct as well as the possibly indirect confounding effects that other regulatory programs may have, are things to keep in mind for all TRI-reporting industries.

<sup>&</sup>lt;sup>16</sup> Currently, I am working on a project that estimates the direct and indirect effects of gasoline content regulations on TRI releases, not just in the refining industry, but also in the chemical industry.

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Unbalan	Unbalanced Panel		ed Panel
Mean	Std. Dev.	Mean	Std. Dev.
268251.9	524565.7	335609.5	592821.3
231636.1	444227.4	286953.1	495286.7
3586.819	14572.06	4639.706	16686.11
33028.98	167340.2	44016.63	200898.3
2	65	1	19
2844		1904	
	Unbalan Mean 268251.9 231636.1 3586.819 33028.98 2 28	Unbalanced Panel           Mean         Std. Dev.           268251.9         524565.7           231636.1         444227.4           3586.819         14572.06           33028.98         167340.2           265           2844	Unbalanced Panel         Balance           Mean         Std. Dev.         Mean           268251.9         524565.7         335609.5           231636.1         444227.4         286953.1           3586.819         14572.06         4639.706           33028.98         167340.2         44016.63           265         1           2844         19

Table 1.TRI Releases by Petroleum Refineries, 1988-2003

Panel I:		Early Exit			
Variable	Obs	Mean	Std. Dev.	Min	Max
Total(lbs)	291	148404.6	303054.9	0	2781833
Air (lbs)	291	131362.4	285407.9	0	2683359
Water (lbs)	291	2616.718	13424.61	0	180020
Land (lbs)	291	14425.43	62652.15	0	686216
Oper. Capacity (bpd)	211	41639.19	54796.85	0	329000
Panel II:			Late Entry, Early	Exit	
Variable	Obs	Mean	Std. Dev.	Min	Max
Total(lbs)	190	34763.9	96805.51	0	786279
Air (lbs)	190	33824.48	96719.04	0	786279
Water (lbs)	190	135.1526	428.0929	0	2544
Land (lbs)	190	804.259	3836.984	0	33489
Oper. Capacity (bpd)	62	40199.19	60596.78	0	213000
Panel III:			Late Entry		
Variable	Obs	Mean	Std. Dev.	Min	Max
Total(lbs)	306	138440.6	363483.7	0	2504610
Air (lbs)	306	126645	340365.8	0	2404110
Water (lbs)	306	538.6534	2049.263	0	15053
Land (lbs)	306	11256.94	50356.35	0	660660
Oper. Capacity (bpd)	155	98047.76	133183.7	0	437000
I I J (I'')					

Table 2.Select Descriptive Statistics On TRI Releases by Facilities Excluded from the<br/>Balanced Panel

Panel IV:		Early Exit, Re-Entry			
Variable	Obs	Mean	Std. Dev.	Min	Max
Total(lbs) Air (lbs) Water (lbs) Land (lbs) Oper. Capacity (bpd)	152 152 152 152 152	208909 190840.1 2729.88 15339.05 67734.63	324282.7 300307.3 9155.252 33586.44 59085.2	0 0 0 0 0	2205916 2002687 77730 182256 250000

Table 3. TRI-DOE Matched Sampl
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	Unbaland	ced Panel	TRI-DOE	Balanced	Balanced	TRI-DOE
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Total(lbs)	303458.4	560602.3	283248.8	402965.8	351506.2	612821.5
Air (lbs)	262063.1	474135.2	240794.5	346905.4	299860.1	511192.7
Water (lbs)	4273.817	16862.98	5169.992	17595.44	5033.837	18572.18
Land (lbs)	37121.47	185709.3	37284.39	120179.9	46612.28	215788.3
Oper. Capacity (bpd)	98289.1	97377.5	102498.9	98850.1	111613.1	97196.7
Facilities	20	)3	6	9	11	8
Observations	20	00	90	56	14	50

Year	Total (pounds)	Air (pounds)	Water (pounds)	Total (Toxicity)*	Air (Toxicity)*	Water (Toxicity)*
1000			<1 <b>.</b>			
1988	5.39E+07	4.74E+07	613009	1.14E+12	1.13E+12	2.32E+09
1989	5.67E+07	4.87E+07	1149938	1.16E+12	1.15E+12	3.09E+09
1990	5.43E+07	4.72E+07	857072	3.88E+11	3.40E+11	1.74E+09
1991	5.00E+07	4.55E+07	482836	7.10E+11	6.95E+11	2.20E+09
1992	5.63E+07	4.29E+07	604484	8.67E+11	8.53E+11	1.69E+09
1993	4.29E+07	3.83E+07	458106	4.42E+11	4.34E+11	1.51E+09
1994	3.98E+07	3.46E+07	426520	2.81E+11	2.73E+11	1.27E+09
1995	3.83E+07	3.29E+07	384432	2.01E+11	1.88E+11	1.30E+09
1996	3.77E+07	3.39E+07	364318	1.52E+11	1.37E+11	7.29E+08
1997	3.74E+07	3.21E+07	493862	1.25E+11	1.09E+11	5.82E+08
1998	3.37E+07	2.95E+07	387696	1.24E+11	1.05E+11	9.51E+08
1999	3.24E+07	2.77E+07	346618	1.43E+11	1.17E+11	6.04E+08
2000	2.91E+07	2.38E+07	609683	1.23E+11	1.07E+11	9.59E+08
2001	2.75E+07	2.30E+07	523318.3	1.48E+11	1.38E+11	1.12E+09
2002	2.63E+07	2.03E+07	559027.1	1.65E+11	1.38E+11	1.01E+09
2003	2.29E+07	1.84E+07	573080	9.92E+10	8.38E+10	7.21E+08

Table 4.TRI Releases From Petroleum Refineries: Toxicity Weighted and Unweighted,<br/>1987-2003

\* Toxicity weighted releases

Year	Benzene	MTBE	Methanol	Lead	Manganese	Manganese Compounds
1988	258635	34678	12075	491	1701	18341
1989	207319	38619	15454	439	1600	16080
1990	190318	48856	6798	976	16099	1044
1991	171350	65106	29423	35576	14898	1048
1992	141796	160036	66774	1617	17248	180
1993	98098	194720	167883	2231	17408	210
1994	62639	175103	173509	1811	17430	220
1995	66326	179374	121081	2732	18100	
1996	53589	289462	2160381	1055	15370	0
1997	50366	462549	1331792			750
1998	55878	414365	1266174			950
1999	50361	705422	1139549			251
2000	44067	355813	824621			0
2001	45697	346435	530840	0		
2002	51533.6	290071	572277	30		2042
2003	54530.91	118757	470192.2	0.1		0

Table 5.Select TRI Releases from California Petroleum Refineries, 1988-2003 (pounds)

Year	Benzene	MTBE	Methanol	Lead
1000	2067741	502806	244156	5016
1988	2007741	592896	344130	5016
1989	21/4413	656090	210549	9/12
1990	2989754	696428	355489	1476
1991	2679109	595754	139095	2499
1992	2034180	1176225	365945	1505
1993	1854730	1307718	177955	647
1994	1650358	744383	189590	1123
1995	1454279	997929	342596	1409
1996	1137092	810231	2571163	18
1997	1224143	552201	3215086	
1998	1132195	460013	4659624	60
1999	1218994	565970	4283303	1438
2000	1039263	558671	2096477	2004
2001	674124	500370	2283994	7456.4
2002	1215170	556994	377088	2190.5
2003	890273.8	444032	330968	3279.8

Table 6.Select TRI Releases from Texas Petroleum Refineries, 1988-2003 (pounds)

Year	Benzene	MTBE	Methanol	Lead
1000	0.00000	114224	(2211	705
1988	969829	114334	63211	795
1989	653447	138654	29744	2193
1990	780141	172318	59650	10
1991	747119	209660	155776	
1992	786999	440221	148735	
1993	532650	568784	175161	32000
1994	381289	424346	162728	
1995	336214	488431	194050	84
1996	288665	371677	214689	73
1997	240170	238504	121611	0
1998	271550	194885	173169	
1999	199757	165907	122509	
2000	223949	187221	106823	
2001	258523	240825	110378	658
2002	318383	112240	107788	442
2003	291394.5	107465.9	111088.3	

Table 7.Select TRI Releases from Louisiana Petroleum Refineries, 1988-2003 (pounds)

Year	Benzene	MTBE	Methanol	Lead
1988	2247920	446908	166051	34493
1989	2410115	536958	163711	22052
1990	2331154	523723	120646	2112
1991	2130980	593804	168393	300
1992	1897279	568668	253708	190
1993	1683596	462385	302480	10810
1994	1490716	587860	394765	1463
1995	1272713	646785	463905	110
1996	1266950	657497	1782135	44
1997	1157836	641266	1175107	58
1998	1028803	541086	794245	121
1999	946744	485740	683192	563
2000	1080614	676182	761181	500
2001	967541	460641	544910	2920.76
2002	747235.1	396186.6	403396.5	8880.87
2003	719741.5	382213.6	331921.8	9918.58

Table 8.Select TRI Releases from Rest of the U.S. Petroleum Refineries, 1988-2003<br/>(pounds)

Year	Total	CAA	CWA	TRI 33/50	Montreal Protocol
1988	5.39E+07	3.58E+07	63840	2.78E+07	190026
1989	5.67E+07	3.31E+07	181448	2.63E+07	163679
1990	5.43E+07	3.41E+07	176817	2.66E+07	177216
1991	5.00E+07	3.18E+07	70662	2.35E+07	187802
1992	5.63E+07	3.12E+07	48426	2.38E+07	167195
1993	4.29E+07	2.83E+07	71106	1.95E+07	132876
1994	3.98E+07	2.42E+07	72721	1.77E+07	153063
1995	3.83E+07	2.28E+07	56338	1.56E+07	104731
1996	3.77E+07	2.52E+07	31207	1.37E+07	51579
1997	3.74E+07	2.32E+07	29847	1.36E+07	46705
1998	3.37E+07	2.20E+07	38951	1.24E+07	15186
1999	3.24E+07	2.12E+07	33715	1.17E+07	17859
2000	2.91E+07	1.75E+07	63410.76	1.09E+07	7805
2001	2.75E+07	1.72E+07	110444.8	1.04E+07	8788
2002	2.63E+07	1.46E+07	96213.27	1.21E+07	3740
2003	2.29E+07	1.32E+07	84075.47	9189305	2082

Table 9.TRI Releases by Environmental Program, 1988-2003 (pounds)

Year	Water	Net Water	Net Water - RFG
1988	613009	466945	410299
1989	1149938	867447	775617
1990	857072	634194	444730
1991	482836	368650	327712
1992	604484	521775	413116
1993	458106	342107	213249
1994	426520	306076	193869
1995	384432	291308	173875
1996	364318	307625	151850
1997	493862	435450	192035
1998	387696	287312	154089
1999	346618	285895	115968
2000	609683	483152	273507
2001	523318.3	388949	264712
2002	559027.1	431480.7	311724.7
2003	573080	457527.1	308408.9

## Table 10.TRI Water Releases: 1988-2003 (pounds)

	US		CA		TX		LA		Rest of US	
Year	Total (lbs)	Intensity (lbs/bpd)								
1988	4.73E+07	471.1385	3433788	28.40595	1.88E+07	136.7102	3654559	16.49676	2.14E+07	289.5255
1989	5.59E+07	689.1391	3178236	28.65579	1.93E+07	241.7699	6212678	29.8489	2.72E+07	388.8645
1990	5.36E+07	628.4563	2458249	19.69867	2.27E+07	246.4393	6013950	33.07037	2.24E+07	329.248
1991	4.85E+07	450.1857	2245038	19.02129	2.09E+07	133.3463	5966351	28.84896	1.94E+07	268.9691
1992	5.50E+07	456.8737	2409035	19.7008	2.75E+07	163.6425	6760033	34.67585	1.83E+07	238.8546
1993	4.13E+07	374.3244	2452855	19.01459	1.77E+07	134.6347	5622779	28.80101	1.55E+07	191.8741
1994	3.50E+07	361.4372	1843829	15.43784	1.29E+07	109.7676	4429667	18.58763	1.58E+07	217.6441
1995	3.68E+07	360.4659	1859453	15.6948	1.63E+07	131.0331	4414255	19.08908	1.41E+07	194.6489
1997	3.34E+07	305.243	3462261	24.82858	1.25E+07	75.15131	3502044	22.04855	1.39E+07	183.2145
1999	2.57E+07	223.0657	2951906	21.40442	9976033	53.17468	3282060	22.58491	9441518	125.9017
2000	2.08E+07	176.8067	2477164	16.69988	5556511	34.16856	3677981	26.36394	9094227	99.57435
2001	2.03E+07	190.0826	1848932	12.4396	5694611	42.11239	4367012	38.06231	8395129	97.46833
2002	1.89E+07	160.2707	1697321	12.24362	5367459	27.8811	4199252	25.03158	7593714	95.11438
2003	1.73E+07	146.0328	1700228	12.30874	5245788	28.15483	3596636	30.26831	6781959	75.3009

Table 11. TRI Releases by Geographic Region: Aggregate Releases and Normalized by Operating Capacity \* #

\* Operating capacity is given in barrels per calendar day (bpd) of production
# Data in this table only includes facilities in the balance panel for which operating capacity data are available for that year.