U.S. TRADE IN TOXICS:

THE CASE OF CHLORODIFLUOROMETHANE (HCFC-22)

by

Randy A. Becker *
U.S. Bureau of the Census

and

John P. Tang *
U.S. Bureau of the Census

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Abstract

This paper explores whether environmental regulation affects where pollution-intensive goods are produced. Here we examine chlorodifluoromethane (HCFC-22), a chemical designated as toxic in 1994 by the U.S. Environmental Protection Agency's Toxics Release Inventory (TRI). Trends show a decline in the number of domestic producers of this chemical, a decline in the number of manufacturing facilities using it, and an increase in the number (and share) of facilities claiming to import it. Transaction-level trade data show an increase in the import of HCFC-22 imports since its TRI listing – an increase that is faster than that of all non-TRI listed chemicals. This is suggestive of a pollution haven effect. Meanwhile, we find that the vast majority of U.S. imports of HCFC-22 come from OECD countries. However, an increase in the share of imports from non-OECD countries since the chemical's listing suggests a shift of production to countries with more lax environmental standards. While the findings here are suggestive of regulatory effects, more rigorous analyses are needed to rule out other possible explanations.

* Any opinions and conclusions expressed herein are those of the authors and do not necessarily represent the views of the U.S. Census Bureau. All results have been reviewed to ensure that no confidential information is disclosed.

1. Introduction

Do changes in environmental regulation affect where pollution-intensive goods are produced? It has been argued that variations in environmental policy lead to the emergence of "pollution havens," with polluting activity relocating to areas with less stringent regulation.[1] This issue, often raised amid international trade negotiations, is increasingly relevant with rising globalization and heightened awareness of environmental hazards.

This paper begins to examine United States trade in toxic chemicals. In particular, we explore the pattern of trade in chemicals designated as toxic by the U.S. Environmental Protection Agency's Toxics Release Inventory (TRI) program. Following the deadly industrial accident at a Union Carbide plant in Bhopal, India and a chemical release at a similar plant in West Virginia, the Emergency Planning and Community Right-to-Know Act (EPCRA) was signed into law in 1986. The act required industrial facilities to report to TRI the quantity of releases and transfers of certain toxic chemicals. These data are made available to the public under the premise that this information creates incentives for companies to improve their chemical management and reduce toxic releases. TRI data collection began in 1988 with 332 chemicals listed as toxic and has increased coverage to the current 666.

In this paper, we begin to explore two basic questions. First, we examine whether the TRI program has resulted in the relocation of industrial activity – what is sometimes called the *pollution haven effect*. If TRI increases the costs associated with producing, using, and processing a particular chemical, then for a given level of domestic use, we might expect domestic production to be replaced by an increase in (net) imports. We might also expect this effect to be stronger for chemicals that are more toxic and/or are released into the environment in greater quantities (and therefore are more noticeable to the public). Second, we examine where

[1] See Jaffe *et al.* 1995, Copeland & Taylor 2004, Brunnermeier & Levinson 2004, and Taylor 2004 for surveys.

these imports originate. A popularly held belief – sometimes called the *pollution haven hypothesis* – is that pollution-intensive industrial activity relocates to lower-income countries, which tend to have less-stringent environmental policies. Others have argued that countries' factor endowments have a greater influence in explaining the pattern of trade in pollution-intensive goods.

In this paper, we describe the trends over the period 1992-2005 in the trade of one particular chemical listed in TRI: chlorodifluoromethane, also known as HCFC-22. This chemical was added to the TRI list in 1994, after the start of our trade data in 1992. This allows us to explore the treatment effect of TRI listing/regulation via a differences-in-differences approach.

The trade data we use here are the universe of transaction-level import and export records from U.S. Customs and Border Protection, as processed by the Foreign Trade Division of the U.S. Census Bureau. For each of the nearly 700 million unique commodity shipments into and out of the United States between 1992 and 2005, we have information on the exact commodity, its quantity (dollar value, physical units, and shipping weight), transaction date, country (or state) of origin, state (or country) of destination, ports of entry and exit, mode of transport (land, sea, or air), whether it is a related party transaction, and so forth.

In this paper, we use only the import transaction data. We are among the very first researchers to use these data, and the first to use these data to explore the relationship between trade and the environment. And our advantage over the previous literature in this area is that we observe trade at the commodity-level, instead of the industry- or subsector-level, and our measure of regulation is also at the commodity-level. We therefore do not have concerns regarding the composition of a subsector's output, some of which may be pollution-intensive and

subject to regulation, others segments of which may not be.

The results presented here are suggestive of a pollution haven effect. We find declines in reported emissions of HCFC-22 in the years following TRI listing, suggesting that TRI is having its intended regulatory effect, of providing facilities with incentives to reduce their toxic releases. Evidence from the TRI itself suggests a decline in the number of domestic producers of HCFC-22, a decline in the number of manufacturing facilities using HCFC-22, and an increase in the number (and share) of facilities claiming to import HCFC-22. This pattern is consistent with a pollution haven effect, and the trade data lend further support. In particular, we find that pounds and value of HCFC-22 imports have increased since its TRI listing, have increased faster than that of all non-TRI listed chemicals, and that these increases have outpaced the increase in all other chemicals at a greater rate following HCFC-22's listing than before.

In terms of these imports' countries of origin, we find that the vast majority of U.S. imports of HCFC-22 come from OECD countries. This suggests that factors other than environmental policy play a role in determining this trade. However, the dramatic increase in the share of HCFC-22 imports from non-OECD countries since the chemical's listing on TRI relative to those of OECD trade partners suggests a shift of production to countries with more lax environmental standards. Whether this is entirely due to environmental regulation, and whether this result generalizes to other environmental pollutants, remains to be seen. Nevertheless, this finding makes it difficult to reject the pollution haven hypothesis out of hand.

The paper proceeds as follows. In Section 2, we discuss some of the prior literature on trade and the environment, with a particular focus on studies related to the idea of pollution havens. The TRI program is discussed in Section 3. In Section 4, we describe our research questions. A discussion of the trade data we employ in our analyses is contained in Section 5, as

is a discussion of chlorodifluoromethane (HCFC-22). We present our findings in Section 6 and offer some concluding remarks in Section 7.

2. Previous Literature

A growing literature examines the impact of trade (and freer trade) on the environment. The effect of trade on the environment, from a theoretical standpoint, is ambiguous. Grossman & Krueger 1993 present a useful framework for discussion (which they claim to borrow from a report by the Commission of the European Communities from a few years earlier).[2] They describe three distinct ways through which trade can impact the environment. First, there is a simple *scale effect*. All else being equal, if trade spurs an increase in economic activity, then it unambiguously leads to an increase in pollution. Second, there is a *composition effect*. That is, trade alters the composition of industrial activity in nations, according to their comparative advantage. Some industries are obviously more polluting than others. Whether pollution decreases worldwide as a result of freer trade is ambiguous, depending on whether polluting activity shifts towards or away from countries with greater environmental regulation, which in turn may depend on whether traditional sources of comparative advantage (e.g., factor endowments) outweigh advantages of laxer environmental regulation. Finally, there is a *technique effect*. Specifically, the stringency of a nation's environmental regulation and the pollution-intensity of its industrial activity may change following trade liberalization. For instance, if environmental quality is a normal good, then as trade increases income, the public's demand for more stringent pollution controls will increase. Foreign firms opening facilities in less developed countries may also bring with them better pollution abatement technologies.

The empirical question is whether the technique and composition effects outweigh the

[2] A more formal theoretical treatment appears in Antweiler *et al*. 2001.

composition and scale effects, recognizing that the composition effect is itself ambiguous. In their study of the possible effects of NAFTA on Mexico and the United States, Grossman & Krueger 1993 find that Mexico at the time was exactly at a level of per capita income where further increases in income would likely lead to increased demand for environmental protection. In addition, they find that freer trade would likely result in Mexico further specializing in industries employing low-skilled workers (its comparative advantage), which tend to be less pollution-intensive. On net, therefore, they concluded that NAFTA might well improve the Mexican environment, counter to the concerns of environmental groups at the time.[3] Antweiler *et al.* 2001 model and estimate the scale, composition, and technique effects of international trade on SO_2 concentrations and find that the composition effect is negative (but small) for the average country, and the scale and technique effects are (together) negative. Their findings suggest that free trade is indeed good for the environment. Looking at seven different pollutants / environmental outcomes, Frankel & Rose 2005 find that trade is beneficial to the environment on a few measures, has no effect on others, and potentially has a detrimental effect on one (carbon dioxide).

Embedded within this larger scale/composition/technique structure are two separate notions that have received significant attention and debate. One, taken together, the scale and technique effects trace out what is now called the *environmental Kuznets curve* (EKC), an inverse-U relating per capita income and pollution. Launched by Grossman & Krueger 1993, there is a large and growing number of papers estimating this relationship (and the top of the hump) for a varying set of pollutants, geographic regions, and time periods. The second set of literature deals with the ambiguous composition effect, and in particular, which countries attract polluting

[3] However, if Mexico were also to become more capital-abundant – for example, from more foreign direct investment – then the impact is more ambiguous.

industries when trade is liberalized. For the purposes of this paper, we are most interested in this second notion.

On this issue, the literature has identified three main hypotheses. One, dubbed the *pollution haven effect* (PHE) by Copeland & Taylor 2004 in their survey of the subject, states that an increase in a country's regulatory stringency will, at the margin, result in a relocation of pollution-intensive industrial activity and a related impact on trade flows.[4] This notion has strong theoretical support, but early empirical studies essentially found no evidence of PHE – that is, that environmental regulation affects the (domestic or international) location of industrial activity (see Jaffe *et al.* 1995 for a review of this literature). On the specific question of international trade, studies have examined whether, all else equal, a country's net exports (or imports) of an industry's products is dependent on the domestic regulation faced by the industry, often as measured by the industry's relative pollution abatement costs. These studies have generally found no significant relationship (Kalt 1988; Tobey 1990; Grossman & Krueger 1993). However, more recent studies have overcome the empirical issues that plagued the earlier research and do in fact find significant "pollution haven effects". Many of these studies focus on regulatory differences and industrial relocation within the United States (e.g., the county-level focus of Becker & Henderson 2000). Two studies examining foreign trade find the expected impact of domestic regulation of an industry (as proxied by pollution abatement costs) on net imports (Ederington & Minier 2003; Levinson & Taylor 2008). Brunnermeier & Levinson 2004 and Copeland & Taylor 2004 offer reviews and discussions of both waves of this literature.

A second hypothesis related to the composition effect, and a popularly held belief, is the *pollution haven hypothesis* (PHH). It states that trade liberalization will result in a shift of

[4] This is sometimes referred to as the pollution haven hypothesis but, as Copeland & Taylor 2004 do, we draw an important distinction.

pollution-intensive industrial activity from countries with stringent environmental regulations to those with weaker regulations. In a common variant of this hypothesis, the shift is from high-income countries to low-income countries (relying on the notion that environmental quality is a normal good and therefore environmental regulation increases with per capita income). A corollary to this hypothesis is that pollution decreases in high-income countries and increases in low-income countries. Because they are closely related, and the distinction between them is often blurred, it is worth noting that the PHE is necessary (but not sufficient) for the PHH to be true.

The third hypothesis, and the chief alternative to the PHH, is the *factor endowment hypothesis* (FEH). It states that trade liberalization will result in a shift of pollution-intensive industrial activity toward countries relatively abundant in the factors used in such activities. To a large extent, pollution-intensive industries are capital intensive and therefore a shift to capital-abundant countries would be predicted. What is noteworthy is that capital-abundant countries tend to be high-income countries with stricter environmental regulations. Therefore an interesting possibility is that the PHH and the FEH are both valid but they work in opposite directions of each other and the resulting shift in trade patterns would depend on which effect is stronger (Antweiler *et al.* 2001). And if pollution-intensive activity shifts towards more regulated countries, it is possible for global pollution to decrease. Of course, all these effects may differ by industry, by pollutant, and/or by country.

In terms of evidence for the PHH, Low & Yeats 1992 is an oft-cited study. These authors show that the share of pollution-intensive goods exported by developed countries fell between 1966 and 1985, while the share of those goods exported by poor, developing countries increased. Another well-cited study, Hettige *et al.* 1992 similarly find that the toxic intensity of industrial

production grew most quickly in the 1970s and 1980s for lower-income countries. While consistent with the PHH, Copeland & Taylor 2004 describe how these trends might also be consistent with the PHE alone, or with the FEH (e.g., increasing capital abundance in lower-income countries during this period). That most pollution-intensive production still occurs in high-income – and typically heavily regulated – countries clearly suggests that factors besides environmental policy also play a role.

A number of recent studies suggest this as well. Antweiler *et al*. 2001 find support for the FEH, and in particular that high-income, capital-abundant countries have a comparative advantage in pollution-intensive, capital-intensive products. However, the composition effect appears to be small, suggesting that the effect predicted by the PHH is largely negating. Cole & Elliott 2003 also find evidence of both the FEH and the PHH cancelling each other out, for SO_2 emissions and somewhat for CO_2. Similar results are not found with NO_x and BOD however. Frankel & Rose 2005 find no evidence for either the PHH or FEH. Meanwhile, Ederington *et al.* 2004 find that the U.S. manufacturing sector shifted toward less pollution-intensive industries between 1972 and 1994 (as has U.S. imports). They find that this shift is not due to trade liberalization; in fact, tariff reductions may have shifted U.S. industrial production *towards* more pollution-intensive industries. Furthermore, they find no evidence for the PHH, in that tariff reductions had a smaller effect on pollution-intensive imports from non-OECD countries than OECD countries.

3. The Toxics Release Inventory

On December 3, 1984, over 40 tons of methyl isocyanate gas leaked from a Union Carbide

plant in Bhopal, India, killing thousands.[5] In January 1985, the EPA announced that 28 leaks of methyl isocyanate had occurred in the previous five years at a similar Union Carbide plant in Institute, West Virginia, and on August 11, 1985, that same plant experienced a chemical release that hospitalized 135 workers and nearby residents. These events are often cited as being among the primary motivations for the federal Emergency Planning and Community Right-to-Know Act (EPCRA), which was signed into law in October 1986.

EPCRA instituted four new reporting requirements for facilities that use, produce, store, or release certain specified chemicals. Among the four, EPCRA Section 313 requires affected facilities to submit to the EPA and the relevant state office, by July 1 of every year, information on releases into the environment and off-site transfers of certain toxic chemicals.[6] The information collected by "Form R" is compiled and made available to the public in the Toxics Release Inventory (TRI). The TRI program and the chemicals covered by it are our interest in this study. The first TRI data were released in June 1989, for reference year 1987.

Facilities are required by law to report to TRI their toxic releases and transfers if the facility meets certain conditions. First, the facility must have 10 or more full-time equivalent employees. Second, the facility must be classified as a manufacturing facility (SIC 20-39) or be engaged in one of a number of non-manufacturing activities.[7] Executive Order 12865, signed in August 1993, extended reporting requirements to federal facilities, regardless of their SIC

[5] The number of deaths remains uncertain to this day. One commonly cited figure is that at least 3,800 died immediately, and it is commonly believed that subsequent deaths bring the total to a few times that initial amount, with 100,000 or more permanently injured.

[6] Meanwhile, EPCRA Section 302 ("Emergency Planning") requires facilities to notify local officials of the presence of any of the 356 extremely hazardous substances (EHS) if it exceeds the "threshold planning quantity." EPCRA Section 304 ("Emergency Release") requires facilities to notify local officials in the event of a release of one of the specified hazardous chemicals (EHS plus those defined under CERCLA) in excess the "reportable quantity." EPCRA Sections 311-312 requires facilities to notify local officials if it has critical quantities of any hazardous chemicals, as defined by the Occupational Safety and Health Act (OSHA).

[7] Non-manufacturing facilities were exempt until reference year 1998. The non-manufacturing industries currently in scope to the TRI include SIC 10 (except 1011, 1081, and 1094); SIC 12 (except 1241); coal- and/or oil-combusting facilities in SIC 4911, 4931, and 4939; "RCRA facilities" in SIC 4953; SIC 5169; SIC 5171; and solvent recovery facilities in SIC 7389.

industrial classification. Finally, the facility must manufacture, import, process, or otherwise use any of the listed chemicals in amounts greater than the threshold quantities. For most of the chemicals covered by TRI, the critical annual thresholds are 25,000 pounds for the manufacture, import, or processing of a chemical, and 10,000 pounds for the mere use of a chemical.[8] Over the first 20 years, the number of facilities reporting to the TRI has ranged from approximately 22,000 to 25,400 per year.

At TRI's inception, 332 chemicals and chemical categories were subject to reporting. Through the years, chemicals have been added to the list and others deleted from the list. Currently, for reporting year 2007, there are 666 chemical entities subject to TRI reporting. In addition to some basic information about the facility itself, for each of these chemicals meeting any of the above thresholds, the facility is required to report: how the chemical is used at the facility; the maximum amount of the chemical at the facility at any one time during the year; releases (in pounds) of the chemical to the environment during the year, classified by on-site media (air, water bodies, underground, and land); transfers (in pounds) of the chemical to off-site locations during the year (e.g., disposal facilities, or treatment & recycling facilities); on-site waste treatment methods related to the chemical and their efficiency; source reduction and recycling activities related to the chemical. In the most recent available year (2007), 21,996 facilities submitted approximately 84,900 chemical-level reports.

The facility-level data collected by the TRI program (and tabulations thereof) are made available to the public through a variety of means and by a variety of entities. Previously this meant paper publications and CD-ROMs. These days, the internet lends itself particularly well to this sort of data dissemination. The chief source for this information is EPA's TRI website

[8] Effective reporting year 2000, the thresholds for certain chemicals were lowered to 100 pounds per year, and for others that are particularly persistent in the environment and highly bioaccumulative, the threshold was set at 10 pounds per year. For dioxin and dioxin-like compounds, thresholds were set at 0.1 grams per year.

(http://www.epa.gov/tri/), but alternative interfaces to search and compile the same data have been created, such as the National Institutes of Health's National Library of Medicine's TOXNET and TOXMAP, OMBWatch's Right-to-Know Network, Environmental Defense's Scorecard, and MapEcos (supported by Duke, Harvard, and Dartmouth). By far, the most widely used and cited items from the TRI are the total on-site releases, total off-site transfers, and the sum of the two, classified by facility, chemical, industry, and/or geography.

The basic premise behind TRI is that making this information publicly available creates incentives for companies to improve their chemical management and reduce toxic releases. The mechanism that is chiefly cited here is community pressure on local facilities; however, consumers and investors can obviously influence companies through market signals. Meanwhile, environmental groups (and journalists) play a role in amplifying the information released by TRI to get companies, local communities, consumers, investors, legislators, and regulators to take action. In any event, TRI is often held up as a successful market-based solution and alternative to the usual command-and-control regulation: Between 1988 and 2007, pounds of on-site toxic releases into the environment have decreased 73%, while the sum of on-site releases and off-site transfers has decreased 61% (implying a 24% increase in off-site transfers).[9]

Whether these declines are entirely due to TRI's market-based approach is subject to some debate. A number of studies have found that facilities under-report their toxic releases (e.g., Koehler & Spengler 2007, which also provides a nice summary of other such studies). Facilities may also be engaged in "threshold regarding" which would exempt them from reporting their

[9] These calculation are based on the 296 chemicals (of the original 332 and current 666) that remained on the TRI list throughout this time period, but does not adjust for the relatively toxicity of a pound of each of these chemicals. It is also worth noting that data for 1987 (the first year of TRI) is routinely dismissed as unreliable. From early on, EPA measured changes using 1988 as the base year.

releases (Bennear 2005). Other studies have suggested that declines might be due to regulation of some of these chemicals under other federal and state programs and/or might be a side-benefit of the regulation and abatement of (non-toxic) pollutants such as those covered under the Clean Air Act (Koehler & Spengler 2007, Bui 2005).

While some studies have suggested that the benefits of TRI have been overstated, others suggest that it has in fact had an impact. The economics literature has focused on the role of investors, with various event studies. Hamilton 1995 finds that publicly-traded firms reporting to TRI experienced statistically significant abnormal negative stock returns on the day following the release of the very first TRI data in June 1989. The effect was more pronounced for companies reporting a greater number of TRI chemicals, and less pronounced for those with known Superfund sites. The study also examines the characteristics of companies that significantly impacted whether they received print media coverage in 1989 regarding their TRI emissions. Konar & Cohen 1997 find that, on average, a publicly-traded firm reporting to TRI experienced a statistically significant abnormal negative stock return on the day following the first print media mention of the company's TRI emissions in 1989. Those companies with the largest drop in stock price then experienced greater declines in their TRI emissions than their industry peers, suggesting the presence of market incentives. Khanna *et al.* 1998 finds negative stock market returns for chemical companies in the days following the release of new TRI data, over a series of years. In turn, their stock market losses resulted in reductions in on-site toxic releases, but no change in total toxic waste generated (i.e., on-site releases plus off-site transfers). However, this too suggests the presence of market incentives, as off-site transfers is likely to be more socially responsible than on-site releases into the environment.

Investors may be reacting to various possibilities. TRI emissions may suggest future

liability, future regulation, and future pollution abatement costs. Relatively high TRI emissions might also indicate inefficiencies in the production process, a general lack of innovation, and/or poor management. Adverse publicity may affect consumer behavior (e.g., boycotts). And TRI data are often considered by investors and mutual funds interested in Socially Responsible Investing (SRI). In turn, firms may be motivated by declines in share price because it may impact the future cost of capital, managers' own stakes in the company (and potentially their jobs), takeover threats, and simple corporate pride.

4. Research Questions

In this paper, we begin to explore two basic questions. First, we look for evidence of whether the TRI program has caused a pollution haven effect. The intent behind TRI is to create incentives for companies to improve their chemical management and reduce toxic releases. Some of the evidence presented in the previous section suggests that the TRI program has had its intended effect: It appears that there are indeed costs associated with producing, using, and processing these particular chemicals, and reported toxic emissions have decreased over time. International trade may potentially play a role here. For example, for a particular chemical, if domestic use remains the same, domestic production can be replaced by an increase in (net) imports. This would be potential evidence of industrial relocation and, hence, a pollution haven effect.[10]

Second, we look for evidence that may support the pollution haven hypothesis. In particular, we examine the share of imports of HCFC-22 originating in OECD and non-OECD countries – the division often used in the literature to distinguish high- and low-income

[10] We might also expect this effect to be stronger for chemicals that are more toxic and/or are released into the environment in greater quantities (and therefore are more noticeable to the public). In future work, we will examine this possibility by considering multiple TRI chemicals.

countries, respectively, and countries with more- and less-stringent environmental policies. In subsequent work, we will further explore the factors that explain the pattern of trade in this and other TRI chemicals. For example, we may expect fewer imports of toxic chemicals from countries that have TRI-like pollution release & transfer registers (PRTRs), particularly if they cover the same chemical.

In this paper, we focus on one particular chemical – chlorodifluoromethane (HCFC-22) – that was *added* to the TRI list after 1992 (the start of the trade data we have). This allows us to better explore the "treatment effect" of TRI listing/regulation, through examination of differences in before and after trends. In future work, we will consider a fuller set of chemical products, including others that were added to the TRI list, ones that were among the original TRI chemicals, and those that have been removed from the TRI list.

5. Data

The primary source of data used in this study comes from U.S. Customs and Border Protection administrative records, which are processed by the Foreign Trade Division (FTD) of the U.S. Census Bureau. These transaction-level records include all merchandise exports and imports between the United States[11] and its foreign trading partners over the period 1992 to 2005, comprising nearly 700 million unique commodity shipments. These records do not include low value transactions (for exports, less than $2,501; for imports, less than $2,001), which are estimated using historical values per commodity per country.

In this paper, we use only the import transaction data. Most of these import data are collected via the U.S. Customs' Automated Commercial System, with the remainder from import

[11] The United States customs area includes all 50 states, the District of Columbia, and US possessions (e.g., Puerto Rico, Virgin Islands).

entry summary forms, warehouse withdrawal forms, and Foreign Trade Zone forms. Variables here include information about the commodity, its transaction date, origin and destination, mode of transport, and processing. Among the characteristics describing the commodity are its Harmonized System (HS) classification code, dollar value, quantities and units of measure, shipping weight, charges for tariff (in dollars), and transportation costs.[12] There are also derivative variables indicating whether it is high value or subject to a special tariff or trade program. Each transaction records the dates of entry into the US, the merchandise's country of origin, and domestic and foreign ports of entry and exit.[13] Also noted is how the merchandise is shipped (i.e., land, sea, or air), whether it was containerized, vessel manifest and visa numbers, and shipper identifiers. Furthermore, there are indicators for automated record processing, related party transactions, and use of imputed values.

To identify imported HS commodities that are TRI chemicals, we mapped the list of chemicals that were added to the TRI by their names. Of the 666 TRI chemicals, over 200 were added between 1992 and 2005, and we found exact name matches for nine of these chemicals.[14] This number is limited primarily because most HS classifications encompass multiple chemicals with at least one not on the TRI. In addition, the HS schedule has changed over the years, which we account for in matching the codes.

Of the nine chemicals that were added to TRI during the period under study and had an exact counterpart in the HS schedule, we restrict our attention to the one that is most widely used in the United States and had the most pounds of emissions in the years immediately following its

[12] Imports to the U.S. are classified at the 10-digit level according to the Harmonized Tariff Schedule of the United States Annotated for Statistical Reporting Purposes (HTSUSA), and are valued at their CIF (cost, insurance, and freight) value, which includes all costs incurred prior to arrival in the first American port of entry.
[13] Canadian and Mexican transactions may also indicate foreign province in addition to port and country identifiers.
[14] These chemicals are: chlorodifluoromethane (or HCFC-22), dicyclopentadiene, TBBPA (2,2`,6,6`-tetrabromobisphenol A), 3,3` dichlorobenzidene dihydrochloride, formic acid, vanadium compounds, MCPA (2-methyl-4-chlorophenoxyacetic acid), bromine, and fluorine. For a full list of changes to the TRI list of toxic chemicals, see http://www.epa.gov/tri/chemical/list%20changes/ChemListChanges05.pdf.

TRI listing: Chlorodifluoromethane (CAS Register No. 75-45-6), also known as HCFC-22, is a water-soluble, colorless gas with a faint ether-like odor. It is commonly used as a refrigerant but also has industrial and commercial uses as a solvent, a propellant in aerosol sprays, in foam production, among others.[15] HCFC-22 replaced chlorofluorcarbons (CFCs) that were banned because of their detrimental impacts on the stratospheric ozone layer.[16] Hydrochlorofluorocarbons such as HCFC-22 are set to be phased out as well in the near future because of their ozone depletion potential (of about 1/20th of the CFCs they replaced). HCFC-22 is also a greenhouse gas, with a global-warming potential 1,700 times that of carbon dioxide.

HCFC-22 was added to the TRI list of chemicals in 1994. At the time, the basis used for its inclusion was its neurological effects, miscellaneous chronic (non-cancer) effects, cancer effects, and environmental effects.[17] The last comprehensive review by EPA scientists of toxicological studies involving HCFC-22, conducted in 2003, yielded consensus on increased kidney, adrenal, and pituitary weights, as well as reduced maternal weight gain.[18] In one commonly used toxicity index, one pound of airborne HCFC-22 is the toxic equivalent of 1.4 pounds of toluene (the reference compound), in terms of its non-cancer health effects, and is ranked 266th out of the 319 toxic chemicals with index scores.[19]

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[15] We will note that the using industries most represented in the 1995 TRI are: Refrigeration & heating equipment (SIC 3585), Plastic foam products (SIC 3086), Agricultural chemicals n.e.c. (SIC 2879), Plastic materials & resins (SIC 2821), Truck trailers (SIC 3715), and Household refrigerators & freezers (SIC 3632). The using industries most represented in the 2005 TRI are: Air-conditioning and warm air heating equipment and commercial and industrial refrigeration equipment manufacturing (NAICS 333415), Plastics material and resin manufacturing (NAICS 325211), All other motor vehicle parts manufacturing (NAICS 336399), Metal window and door manufacturing (NAICS 332321), and Household refrigerator and home freezer manufacturing (NAICS 335222).

[16] Phase-out of CFCs began in 1987 as part of the international agreement known as the Montreal Protocol, with the complete ban of their use in January 1996.

[17] For summary hazard information for the 286 chemicals added to the TRI in 1994, see http://www.epa.gov/tri/chemical/hazardinfo/hazard_cx.htm.

[18] See http://www.epa.gov/IRIS/subst/0657.htm.

[19] See http://www.scorecard.org/env-releases/def/tep_gen.html.

6. Findings

Table 1 summarizes some of our findings. First, total on-site releases of HCFC-22 into the environment, as reported by manufacturers in TRI, fell by 48% since 1995 (the second year of HCFC-22 in TRI), to a level of 6,610,326 pounds in 2006.[20] A similar decline occurred in the sum of on-site releases and off-site transfers. These declines suggest that TRI is having its intended regulatory effect, of providing facilities with incentives to reduce their toxic releases.

Next, we use facility-level data from the TRI to examine trends in the number of facilities producing, using, and importing HCFC-22.[21] Because of TRI's reporting thresholds (discussed above), each of these facility counts must be viewed as a lower bound. This is also true to the extent that some facilities may neglect to fill out a Form R for a chemical, despite meeting the reporting threshold. If the incidence of filing negligence is constant across time, and if facilities do not increasingly engage in "threshold regarding" (though users may have special incentive to do so), then the rates and directions of change seen here may be informative, even if the actual levels are not.

With these caveats in mind, the pattern of changes we observe here is entirely consistent with a pollution haven effect: We find that, between 1995 and 2006, the number of facilities producing HCFC-22 declined 50% (from 6 to 3), the number of manufacturing facilities using or processing HCFC-22 declined 18% (from 229 to 187), and the number of manufacturing

[20] We use the second year of data here because data from the first year may be unreliable. Nevertheless, reported on-site emissions fell 23% between 1994 and 2006.

[21] We employ the following definitions. Facilities engaged in production are those that identified themselves on Form R as "producing" HCFC-22 for either "on-site use/processing" or "sale/distribution", except those that also claimed to import HCFC-22. Any facilities that produced the chemical as a byproduct (that is not sold) or as an impurity (that is contained in some other final product) are not counted as producers. Facilities engaged in use or processing are those that identified themselves as producing and/or importing HCFC-22 for on-site use, plus those that claimed to "process" HCFC-22 as a reactant, as a formulation compound, as an article component, or repackaging, plus those that claimed to "otherwise use" HCFC-22 as a chemical processing aid, as a manufacturing aid, or ancillary use. Facilities engaged in importation are simply those that identified themselves as importing HCFC-22. According to these definitions, producers can be users, but they cannot be importers. Users can be producers, importers, or neither. Importers can be producers, users, or neither.

facilities claiming to import HCFC-22 grew 113% (from 8 to 17). If having to report emissions of HCFC-22 to TRI is costly for firms, we may indeed expect to see fewer facilities engaged in its production and fewer facilities using it. And if domestic use drops less than domestic production – and there might certainly be reasons to expect such asymmetry – then imports must increase. Here we find that the share of HCFC-22 users that imported the chemical increased from 2.6% to 8.0%.

Turning to the trade data, we compute that the import of HCFC-22 has indeed increased over this period. In particular, we find that between 1994 and 2005 the total pounds imported increased 307% (to nearly 89 million pounds annually) and the total value of these imports increased 465%. During this period, the increase in the dollar value of HCFC-22 imports outpaced the increase in U.S. imports of all non-TRI listed chemicals by 25%.[22] We find that imports of HCFC-22 also outpaced that of all non-TRI chemicals *prior* to its listing in 1994, but its relative pace of increase increased after its listing. The difference-in-difference estimate is 2.15, where 1 suggests equal relative increases before and after TRI listing.[23] The increase in imports, the higher pace relative to other chemical imports, and the increase in the relative pace after listing, are all suggestive of the pollution haven effect.

Increased imports may suggest that domestic supply is decreasing faster than domestic use, or that domestic use is increasing faster than domestic supply. Unfortunately, there exists no good official data on either domestic production or domestic use of HCFC-22. Under its Inventory Update Reporting (IUR) program, the EPA does produce estimates every four years of

[22] The appropriate counterfactual is certainly debatable.

[23] That is, $\dfrac{(HCFC_{2005} - HCFC_{1994}) / HCFC_{1994} \big/ (ALL_{2005} - ALL_{1994}) / ALL_{1994}}{(HCFC_{1994} - HCFC_{1992}) / HCFC_{1992} \big/ (ALL_{1994} - ALL_{1992}) / ALL_{1992}} = 2.15$, where *HCFC* is the dollar value of HCFC-22 imports and *ALL* is the dollar value of U.S. imports of all non-TRI listed chemicals.

the total volume of HCFC-22 produced domestically or imported.[24] These might be viewed as a crude proxy for domestic use (the difference being U.S. exports of HCFC-22). However, the EPA only publishes these data in wide ranges. Table 1 shows that, since reporting began in 1986, the total volume of HCFC-22 produced domestically or imported has remained "constant" – in the range of 100-500 million pounds annually. This range is wide enough to mask significant shifts in use, production, and imports.

Having found suggestive evidence of a pollution haven effect related to the TRI listing of HCFC-22 in 1994, we turn to our second main research question. Figure 1 plots the total volume of HCFC-22 imports originating in OECD and non-OECD countries, and Table 2 lists the relative shares. One fact immediately worth noting is that the vast majority of U.S. imports of HCFC-22 come from OECD countries. That high-income – and typically heavily regulated – countries are our chief suppliers clearly suggests that factors besides environmental policy play a role in determining this trade. It is interesting, however, that the share of HCFC-22 imports from non-OECD has increased five-fold since its listing in TRI. Furthermore, the share of OECD imports peaked in the year 1994, when the chemical was added to the TRI list, while non-OECD imports showed their highest share in the most recent year of data. At a minimum, this trend suggests that the pollution haven hypothesis cannot be easily dismissed.

7. Conclusions

Declines in reported emissions of HCFC-22 in the years following TRI listing suggest that TRI is having its intended regulatory effect. Furthermore, the facility-level data from the TRI suggest a decline in the number of domestic producers of HCFC-22, a decline in the number of

[24] Estimates are based on filings of Form U, as required by the Toxic Substances Control Act. Like TRI, only facilities meeting certain thresholds are required to report. For more information, see http://www.epa.gov/oppt/iur/index.htm.

manufacturing facilities using HCFC-22, and an increase in the number (and share) of facilities claiming to import HCFC-22. This pattern is consistent with a pollution haven effect, and the trade data lend further support. In particular, we find that pounds and value of HCFC-22 imports have increased since its TRI listing, have increased faster than that of all non-TRI listed chemicals, and that these increases have outpaced the increase in all other chemicals at a greater rate following HCFC-22's listing than before. In terms of these imports' countries of origin, we find that the vast majority of U.S. imports of HCFC-22 come from OECD countries. This suggests that factors other than environmental policy play a role in determining this trade. However, the dramatic increase in the share of HCFC-22 imports from non-OECD countries since the chemical's listing on TRI relative to those of OECD trade partners suggests a shift of production to countries with more lax environmental standards.

We therefore find suggestive evidence of a pollution haven effect and are unable to reject the pollution haven hypothesis out of hand. However, more rigorous testing of both is needed, to rule out other possible explanations. In future work, we hope to consider a fuller set of chemical products, including others that were added to the TRI list, ones that were among the original TRI chemicals, and those that have been removed from the TRI list. We might expect hypothesized effects to be stronger for chemicals that are more toxic and/or are released into the environment in greater quantities (and therefore are more noticeable to the public). And in terms of the countries of origins of these toxic imports, the effects of economic development and growing capital accumulation in the non-OECD world will have to be disentangled from any regulatory effects. One interesting question is whether, all else being equal, the United States has received fewer imports of toxic chemicals from countries that have instituted TRI-like pollution release & transfer registers (PRTRs), especially if they cover the same chemical.

References

Antweiler, Werner, Brian R. Copeland, and M. Scott Taylor, "Is Free Trade Good for the Environment?" *American Economic Review*, 91 (September 2001), 877-908.

Becker, Randy and Vernon Henderson, "Effects of Air Quality Regulations on Polluting Industries," *Journal of Political Economy*, 108 (April 2000), 379-421.

Bennear, Lori Snyder, "Strategic Response to Regulatory Thresholds: Evidence from the Massachusetts Toxics Use Reduction Act," mimeo, Duke University, June 2005.

Brunnermeier, Smita B. and Arik Levinson, "Examining the Evidence on Environmental Regulations and Industry Location," *Journal of Environment & Development*, 13 (March 2004), 6-41.

Bui, Linda, "Public Disclosure of Private Information as a Tool for Regulating Environmental Emissions: Firm-Level Responses by Petroleum Refineries to the Toxics Release Inventory," *Center for Economic Studies Discussion Paper*, 05-13, October 2005.

Cole, Matthew A. and Robert J. R. Elliott, "Determining the Trade-Environment Composition Effect: The Role of Capital, Labor, and Environmental Regulation," *Journal of Environmental Economics and Management*, 46 (November 2003), 363-383.

Copeland, Brian R. and M. Scott Taylor, "Trade, Growth, and the Environment," *Journal of Economic Literature*, 42 (March 2004), 7-71.

Ederington, Josh and Jenny Minier, "Is Environmental Policy a Secondary Trade Barrier? An Empirical Analysis," *Canadian Journal of Economics*, 36 (February 2003), 137-154.

Ederington, Josh, Arik Levinson, and Jenny Minier, "Trade Liberalization and Pollution Havens," *Advances in Economic Analysis & Policy*, 4(2), 2004, 1-22. Reprinted in *The Economics of Pollution Havens*, Don Fullerton (ed.), Edward Elgar Publishing, 2006.

Frankel, Jeffrey A. and Andrew K. Rose, "Is Trade Good or Bad for the Environment? Sorting Out the Causality," *Review of Economics and Statistics*, 87 (February 2005), 85-91.

Grossman, Gene M. and Alan B. Krueger, "Environmental Impacts of a North American Free Trade Agreement," in *The Mexico-U.S. Free Trade Agreement* (ed. Peter M. Garber), Cambridge, MA: MIT Press, 1993.

Hamilton, James T. "Pollution as News: Media and Stock Market Reactions to the Toxics Release Inventory Data," *Journal of Environmental Economics and Management*, 28 (January 1995), 98-113.

Hettige, Hemamala, Robert E. B. Lucas, and David Wheeler, "The Toxic Intensity of Industrial Production: Global Patterns, Trends, and Trade Policy," *American Economic Review*, 82 (May 1992), 478-81.

Jaffe, Adam B., Steven R. Peterson, Paul R. Portney, and Robert N. Stavins, "Environmental Regulation and the Competitiveness of U.S. Manufacturing: What Does the Evidence Tell Us?" *Journal of Economic Literature*, 33 (March 1995), 132-163.

Kalt, Joseph P. "The Impact of Domestic Environmental Regulatory Policies on U.S. International Competitiveness, " in *International Competitiveness* (eds. A. Michael Spence and Heather A. Hazard), Cambridge, MA: Ballinger Publishing, 1988.

Khanna, Madhu, Wilma Rose H. Quimio, and Dora Bojilova, "Toxics Release Information: A Policy Tool for Environmental Protection," *Journal of Environmental Economics and Management*, 36 (November 1998), 243-266.

Koehler, Dinah A. and John D. Spengler, "The Toxic Release Inventory: Fact or Fiction? A Case Study of the Primary Aluminum Industry," *Journal of Environmental Management*, 85 (October 2007), 296-307.

Konar, Shameek, and Mark A. Cohen, "Information as Regulation: The Effect of Community Right to Know Laws on Toxic Emissions," *Journal of Environmental Economics and Management*, 232 (January 1997), 109-124.

Levinson, Arik and M. Scot Taylor, "Unmasking the Pollution Haven Effect," *International Economic Review*, 49 (February 2008), 223-254.

Low, Patrick and Alexander Yeats, "Do 'Dirty' Industries Migrate?" in *International Trade and the Environment* (ed. Patrick Low), Washington, DC: The World Bank, 1992.

Taylor, M. Scott, "Unbundling the Pollution Haven Hypothesis," *Advances in Economic Analysis & Policy*, 4(2), 2004, 1-26. Reprinted in *The Economics of Pollution Havens*, Don Fullerton (ed.), Edward Elgar Publishing, 2006.

Tobey, James A. "The Effects of Domestic Environmental Policies on Patterns of World Trade: An Empirical Test," *Kyklos*, 43 (1990), 191-209.

TABLE 1
U.S. Emissions, Production, Use, and Importation of HCFC-22

Total on-site releases into the environment by manufacturers (EPA-TRI)	
1995	12,628,068 lbs.
2006	6,610,326 lbs.
Percent change (1995-2006)	-48%
Number of manufacturing facilities producing HCFC-22 (EPA-TRI)	
1995	6
2006	3
Percent change (1995-2006)	-50%
Number of manufacturing facilities using or processing HCFC-22 (EPA-TRI)	
1995	229
2006	187
Percent change (1995-2006)	-18%
Number of manufacturing facilities importing HCFC-22 (EPA-TRI)	
1995	8
2006	17
Percent change (1995-2006)	+113%
Number (and share) of using/processing facilities that imported HCFC-22	
1995	6 (2.6%)
2006	15 (8.0%)
Total volume imported (Becker & Tang)	
1994	21,820,096 lbs.
2005	88,877,112 lbs.
Percent change (1994-2005)	+307%
Total value imported (Becker & Tang)	
Percent change (1994-2005)	+465%
Percent change relative to percent change in value of all chemical imports (1994-2005)	1.25
Difference-in-difference: Percent change relative to percent change in all chemicals (1994-2005) relative to same (1992-1994)	2.15
Total volume produced domestically or imported (EPA-IUR)	
1986	100,000,000 – 500,000,000 lbs.
1990	100,000,000 – 500,000,000 lbs.
1994	100,000,000 – 500,000,000 lbs.
1998	100,000,000 – 500,000,000 lbs.
2002	100,000,000 – 500,000,000 lbs.
2006	100,000,000 – 500,000,000 lbs.

TABLE 2
Shares of HCFC-22 Imports Originating in OECD and Non-OECD Countries

	OECD	Non-OECD
1992	90.5%	9.5%
1993	86.2%	13.8%
1994	94.7%	5.3%
1995	93.1%	6.9%
1996	77.7%	22.3%
1997	85.0%	15.0%
1998	93.6%	6.4%
1999	77.4%	22.6%
2000	80.7%	19.3%
2001	81.8%	18.2%
2002	85.6%	14.4%
2003	82.6%	17.4%
2004	80.2%	19.8%
2005	71.6%	28.4%
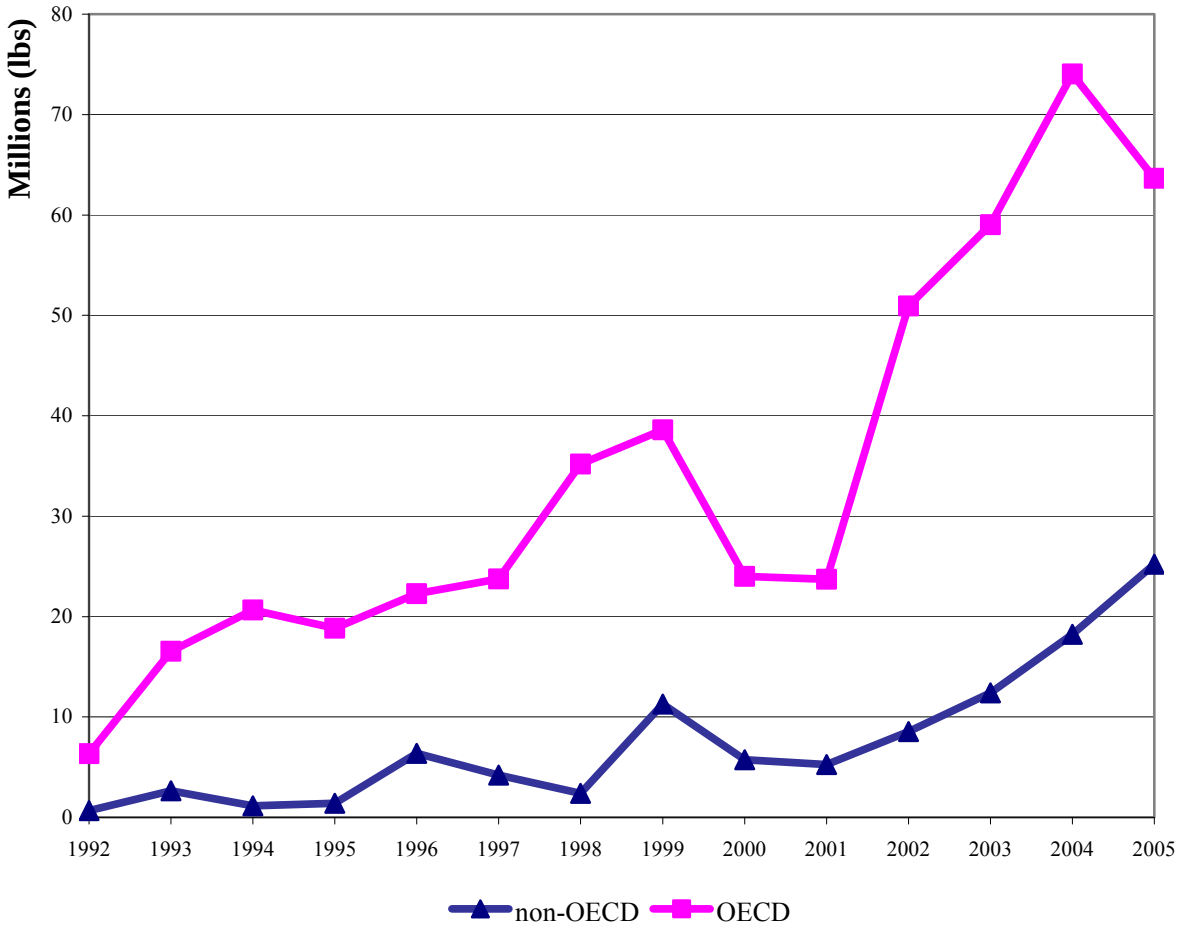
Figure 1
Pounds of HCFC-22 Imports from OECD and Non-OECD Countries