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Private Regulation on the Environment:
Bilateral Voluntary Agreements in U.S. Toxic Chemical Policy

Lily Hsueh

A dissertation
submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington

2012

Reading Committee:

David Layton, Chair

Leigh Anderson

Aseem Prakash

Craig Thomas

Eric Zivot

Program Authorized to Offer Degree:

Evans School of Public Affairs

ABSTRACT

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by

Lily Hsueh

Doctor of Philosophy in Public Policy and Management

University of Washington, 2012

Professor David Layton, Chair

In recent decades, in the backdrop of highly constrained government and public sector finances worldwide, private forms of regulation in natural resource and environmental policy have gained political and public salience: there is an increased interest in governance *with* government rather than governance *by* government. This dissertation, consisting of three essays, investigates the policy impact of bilateral voluntary agreements, one form of voluntary environmental programs, and the compliance-related decision-making processes involving regulators, corporate actors, and NGO activists that have led to them. The first essay of the dissertation examines the effectiveness of a bilateral voluntary agreement negotiated between the U.S. EPA and the pressure-treated wood industry to ban the use of a poisonous arsenic compound. Unlike earlier studies on voluntary programs, results from dynamic panel estimation and advanced time series techniques show that the voluntary agreement has lowered arsenic use in the U.S. to levels not seen since the 1920s. Moreover, a government-driven information disclosure policy—namely the EPA’s Toxic Release Inventory—was effective in decreasing

arsenic use, albeit to a lesser magnitude than the industry voluntary ban. Prioritizing environmental protection through financial resources, as measured by Congress-allocated dollars to the EPA, has also reaped environmental benefits. Systematic surveys of key stakeholders provide institutional, political, and economic insights into the impact estimates of the bilateral voluntary agreement on arsenic use.

Policy process tracing based on the survey data shows that the pressure-treated wood industry was compelled to engage in beyond-compliance action given the existence of a poison-free substitute, market competitive pressures, and the threat of future regulation. The EPA regulators casted a shadow of public law with the credible threat of future regulation by “steering” or encouraging voluntary action and sanctioning noncompliance once the voluntary beyond compliance action had occurred. Moreover, third-party stakeholders, such as NGO activists, played an important “accountability” role by pressuring for and certifying firms' beyond compliance environmental stewardship.

In the second essay, I develop a theoretical framework by building on the multiple streams framework (Kingdon, 1984) to explain the compliance-related decision-making processes and apply it to two cases of “successful” bilateral voluntary agreements in mercury and arsenic use, respectively. Specifically, to the problem, policy, and politics streams of the multiple streams framework I add an economy stream and delineate its key variables. I argue that the economy stream demarcates the roles that *product substitutes*, *market competition*, *corporate social responsibility*, the *market changer*, and the *global economy* play in creating incentives for businesses to partake in industry self-regulation. The market changer is a maverick business that engages in an action or a set of actions that completely transforms the modus operandi of the industry in which the market changer operates. While both bilateral

voluntary agreements achieved the negotiated chemical reduction objectives, the push and pull of politics, economics, as well as institutional factors led to two distinctive bilateral voluntary agreements: one was an outcome of industry voluntary stewardship and the other was a result of activist campaigns.

The final essay employ recently developed, state-of-the-art structural change and unit root tests, as well as cointegration analyses to investigate whether federal regulations since the 1970s have had an effect on toxic chemical use and what the time series properties of the data reveal about policy efficacy over the long-run. I examine whether there is a long-run equilibrium relationship among chemicals that are regulated under the same laws and whether there are clusters of chemicals (e.g., end-use sectors that use the same chemicals) that share a common trend, which could suggest common economic and institutional drivers. Results indicate that while some toxic chemicals have been successfully reduced or phased-out by regulatory efforts, a majority of the toxic chemicals used in commercial products are largely driven by changes in U.S. GDP, industrial production, and private investments in research and development, rather than by common political, economic, and institutional factors, such as government regulations.

ACKNOWLEDGEMENTS

I am honored and indebted to so many kind, intelligent, and wise individuals who have taken an interest in my intellectual development. This dissertation stands on these “shoulders of giants.” I first thank the members of my supervisory committee: David Layton (Chair; Public Affairs), Leigh Anderson (Public Affairs), Aseem Prakash (Political Science), Craig Thomas (Public Affairs), and Eric Zivot (Economics). Their guidance, advice, and support have been invaluable and replaceable. I have learned from these teachers, advisers, and scholars how to ask the right questions, collect and analyze data, research, and write with both rigor and humility.

I have also benefited from the advice and expertise of Tim Bruckner, Joseph Cook, Laura Evans, Susan Gunn, Kirsten Foot, Crystal Hall, Roselyn Hsueh, Raul Lejano, Maureen Pirog, and Bill Zumeta, as well as participants at seminars and conferences at various stages of the dissertation process. I thank my fellow graduate school cohorts at the Evans School and the University of Washington for pacing me and rooting for me on this PhD marathon. The Evans School staff has been phenomenal in providing logistical, technical, and at times moral support. Generous financial support came from several sources at the University of Washington.

Moreover, I acknowledge and thank the government officials—administrators, analysts, and regulators—as well as managers and staff at corporations and environmental NGOs for sharing their expertise and insights with me. Without access to the substantive knowledge of these informants and the data to which they granted me access my research would not have been possible.

Finally, I thank Joseph Huang, my husband and co-parent of our twin toddlers, Hope and Faith, for his unwavering confidence and support in my abilities and endeavors. This dissertation would not have come to fruition without him.

DEDICATION

I dedicate this dissertation to my father, Tse-Huang Hsueh, who has instilled in me a fondness and respect for the environment and a conviction for environmental protection and stewardship.

I also dedicate this research to my mother, Pauline Lee Hsueh, who has taught me the importance of synthesizing seemingly diverse ideas and ideals for understanding and solving multi-faceted problems confronting our society today.

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CHAPTER 1. INTRODUCTION AND OVERVIEW

Experimentation with alternative, incentive-based governance approaches that devolved regulation to the states and the private sector began with President Regan's "Environmental Federalism," and have continued into subsequent presidential administrations. In recent decades, in the backdrop of highly constrained government and public sector finances worldwide, private forms of regulation in natural resource and environmental policy have gained political and public salience: there is an increased interest in governance *with* government rather than governance *by* government. Private regulations employ private, nongovernment, or market-based regulatory frameworks to govern multinational firms and global supply networks (Vogel, 2010). A defining feature of private regulations is that their legitimacy, governance, and implementation are not necessarily rooted in government authority, although government continues to play an important role, notably in incentivizing businesses to undertake costly, beyond compliance actions without the force of law.

Industrial toxic chemicals are a policy issue area that has seen much experimentation with private forms of regulation (Morgenstern & Pizer, 2007). A chief challenge facing toxic chemical regulation is the rapid speed of technological development in toxic chemical-using sectors. It has been challenging for regulators to understand the toxicology of currently available toxic chemicals before the next new chemical is on the market, and their impact on human health and the environment (GAO, 2007). Thus the U.S. EPA, the chief regulator of industrial chemical use and emissions, has increasingly worked with the private sector to curb toxic chemical use through voluntary environmental programs, such as voluntary programs initiated by the

government or the private sector and bilateral voluntary agreements negotiated between regulators and the private sector. The latter of which is the subject of this dissertation.¹

This dissertation—consisting of three essays—takes a multi-disciplinary and multi-methods approach, drawing from economics, political science, and public policy to investigate the policy impact of bilateral voluntary agreements, one form of voluntary environmental programs, and the compliance related decision-making processes involving regulators, corporate actors, and non-governmental organization (NGO) activists that have led to them. In particular, I examine how the interactions of key stakeholders and the incentive structures of the marketplace and regulatory regimes induce the private sector to voluntarily phase out the industrial use of poisonous chemicals that are also key inputs in the manufacturing of commercially important products.

While private forms of regulation, particularly voluntary environment programs, have gained political and public salience, evidence has been mixed about the effectiveness of these alternative governance approaches. A majority of the literature points to modest or negligible impact on the effectiveness of voluntary programs on the environment.

A central obstacle to the efficacy of voluntary environmental programs is the free-rider problem. The free-rider's problem is this: Instrumental actors may want to establish a reputation for environmental stewardship without having to incur the costs of taking on new obligations, such as adopting new technology or curtailing toxic chemical use. They might hope that the

¹ Voluntary environmental programs is one form of private regulation that is based on the exchange between government and business on the design of a framework of incentives in a context of cooperation (Crocì, 2005). Voluntary programs impose obligations on firms that are beyond the legal requirements (or where the law is silent) to induce them to voluntarily reduce pollution and adopt pollution abatement technologies. These programs are sponsored by the government, firms, industry associations, or NGOs.

goodwill created by environmentally responsible firms will spill over to them. Thus, the free-rider's problem leads to shirking by participants or unwillingness by firms to participate in voluntary environmental programs in the first place. This opportunistic behavior on the part of individual firms leads to "adverse selection" and "moral hazard" and thereby ruin any attempts at coordinated action (Hardin G, 1968; Olson, 1965).²

When variation in voluntary environmental programs is accounted for, however, a more nuanced depiction of program efficacy emerges. Some studies have shown that despite the free-rider problem, third-party or NGO sponsored voluntary programs (e.g., ISO 14000) bilateral voluntary agreements have had more success compared to government-initiated or public voluntary programs or unilateral initiatives by industry to reduce environmental pollution and degradation (T. Arimura, Hibiki, & Katayama, 2008; Darnall & Kim, 2012; Dasgupta, Hettige, & Wheeler, 2000; Glachant & Muizon, 2007; Krarup & Millock, 2007; Morgenstern & Pizer, 2007; Potoski & Prakash, 2005; Wakabayashi & Sugiyama, 2007). Bilateral voluntary agreements are voluntary agreements to reduce pollution in specific industries that are negotiated between the government and the private sector (Borck & Coglianesse, 2009). These negotiated agreements often lead to legal binding contracts.

Among the different types of voluntary environmental programs, unilateral or industry sponsored voluntary programs are the weakest in their environmental performance (Gamper-

² Potoski and Prakash (2011) characterize the free-rider problem in voluntary environmental programs as "regulatory dilemma," which is an extension of the prisoner's dilemma game. Given interdependence, the outcomes for each player depend on her own and other's choice (cooperation versus evasion or deterrence). The key point is that no matter which approach the government chooses, firms are better off evading and, no matter which approach the firm chooses, the government is better off choosing deterrence. This creates a vicious cycle of opportunism and a series of lose-lose outcomes. The Nash equilibrium is Pareto suboptimal: together government and firms are better off if the government chooses flexible enforcement and the firm chooses to self-police in a cooperative context.

Rabindran & Finger, 2012; King & Lenox, 2000). Evidence of the effectiveness of public voluntary programs or government initiated programs in reducing pollution has also been lackluster (Antweiler & Harrison, 2007; Gamper-Rabindran & Finger, 2012; Gamper-Rabindran, 2006; Glachant & Muizon, 2007; Morgenstern & Pizer, 2007; Takahashi, Nakamura, Kooten, & Vertinsky, 2001; Vidovic & Khanna, 2007a; Welch, Mazur, & Bretschneider, 2000).

Why this might be the case has not been systematically studied. In fact, current research has provided little insights into the mechanisms by which bilateral voluntary agreements and voluntary environmental programs more generally work and the interplay between various motivating and demotivating factors in the political economy for regulators, corporate actors, and other external stakeholders, such as NGO activists. Prakash and Potoski (2012) call for more research that systematically examines conditions under which voluntary environmental programs reduce pollution. Uncovering the compliance-related decision-making process is important for understanding the emergence, diffusion, and efficacy of voluntary environmental programs more generally. Moreover, distinction among different types of voluntary policies or approaches is critical to understanding the mechanisms of corporate responses. This dissertation fills this gap in the literature, as well as places private regulation in the context of the broader history of environmental governance in the U.S. industrial toxic chemical policy domain.

This dissertation also contributes methodologically to public policy research. First, the dissertation's mix of quantitative analyses and systematic qualitative process tracing is a novel methodological contribution to evaluation research that has primarily relied on quantitative analysis. The reality of nonexperimental data in policy efficacy studies warrants the

triangulation between methods.³ Second, this dissertation introduces mainstay tools of researchers in macroeconomic growth and applied finance studies to environmental and resource economics and policy. The benefits are several folds: advanced time series econometrics can aid in optimal regulatory policy as well as developing empirical verification of theories put forth to explain social science and public policy phenomena.

Dissertation Overview

The second chapter of this dissertation, which is the first of the three essays, examines the effectiveness of a bilateral voluntary agreement negotiated between the U.S. EPA and the pressure-treated wood industry to ban the use of arsenic, which is the #1 ranked toxic chemical on the EPA's priority list of hazardous substances. Unlike a majority of earlier studies on voluntary programs, results from dynamic panel estimation and advanced time series techniques show that the voluntary agreement has lowered arsenic use in the U.S. to levels not seen since the 1920s. Moreover, a government-driven information disclosure policy—namely the EPA's Toxic Release Inventory—was effective in decreasing arsenic use, albeit to a lesser magnitude than the industry voluntary ban. Prioritizing environmental protection through financial resources, as measured by Congress-allocated dollars to the EPA, has also reaped environmental benefits.

Policy process tracing based on the systematic surveys of key stakeholders in the voluntary agreement shows that the pressure-treated wood industry was compelled to engage in beyond-compliance action given the existence of a poison-free substitute, market competitive pressures, and the threat of future regulation. The EPA casted a shadow of public law with the

³ The triangulation between methods is a research design that attempts for mutual validation of the same phenomenon through the employment of multiple methods (Brady & Collier, 2010; Jick, 1979; Lieberman, 2005; McFee, 1992).

credible threat of future regulation by “steering” or encouraging voluntary action and sanctioning noncompliance once the voluntary beyond-compliance action had occurred. Furthermore, third-party stakeholders, such as NGO activists, played an important “accountability” role by pressuring for and certifying firms' beyond-compliance environmental stewardship.

In the third chapter (second essay), I develop a theoretical framework building on the multiple streams framework (Kingdon, 1984) to explain the compliance-related decision-making processes involving regulators, corporate actors, and NGO activists in the negotiation of bilateral voluntary agreements to reduce industrial toxic chemicals. Specifically, to the problem, policy, and politics streams of the multiple streams framework I add an economy stream and delineate its key variables.

I argue that the economy stream demarcates the roles that *product substitutes*, *market competition*, *corporate social responsibility*, the *market changer*, and the *global economy* play in creating incentives for businesses to partake in industry self-regulation. Without the existence of product substitutes that perform on par with the original product but generate less toxic impact, businesses have no incentive to go beyond-compliance. Businesses primarily engage in beyond-compliance activities to undercut their competitors. Occasionally, competitors coalesce for their mutual benefit in the face of threat from potentially damaging publicity. Businesses invest in corporate social responsibility in order to supply to the market for “green” products and to deflect threats from public and private politics. The market changer is a maverick business that engages in an action or a set of actions that transforms the modus operandi of the industry in which the market changer operates. Finally, the global supply chains and transnational private standards shape the incentives of firms to engage in environmental protection domestically without legal mandates.

The augmented multiple streams framework is applied to two cases of “successful” bilateral voluntary agreements in mercury and arsenic use. While both bilateral voluntary agreements on mercury and arsenic use achieved the negotiated chemical reduction objectives, the push and pull of politics, economics, and institutional factors led to two distinctive bilateral voluntary agreements: one was an outcome of industry voluntary stewardship (mercury case) and the other was a result of an activist campaign (arsenic case).

The fourth chapter (final essay) employs recently developed, state-of-the-art structural change and unit root tests, as well as cointegration analyses to investigate whether federal regulations since the 1970s have had an effect on toxic chemical use and what the time series properties of the data reveal about policy efficacy in the long-run policy horizon. I examine whether there is a long run equilibrium relationship among chemicals that are regulated under the same laws and whether there are clusters of chemicals (e.g., end-users of the same chemicals) that share a common trend, which could suggest common economic and institutional drivers. Empirical results suggest that structural changes occurred around the time of economic booms and busts, WWII, environmental regulations, and industry developments. The Toxic Release Inventory, which was established in 1986, has had impact on the consumptive use of more poisonous industrial chemicals than command-and-control regulations.

While some toxic chemicals have been successfully reduced or phased-out by regulatory efforts, a majority of the toxic chemicals used in commercial products are largely driven by changes in U.S. GDP, industrial production, and private investments in research and development, rather than by common political economic and institutional factors, such as government regulations. Finally, evidence suggests that government policies aimed at the use of individual toxic chemicals will likely have more restraining effect than policies that target

aggregate chemical use or chemical use by end-use industry sectors because of the stochastic nature of the toxic chemical use data.

In the fifth chapter, I conclude by explicating the dissertation's contributions to the literature and to public policy scholarship more generally. I do so in the context of recognizing this research's limitations, which leads me to delineate an agenda for future research.

CHAPTER 2. BEYOND REGULATIONS: INDUSTRY VOLUNTARY BAN IN ARSENIC USE

Abstract

Firms play a key role in pollution abatement and control by engaging in beyond-compliance actions without the force of law in voluntary environmental programs. This study examines the effectiveness of a bilateral voluntary agreement, one type of voluntary environmental programs, negotiated between the U.S. Environmental Protection Agency (EPA) and the pressure-treated wood industry to phase-out the use of chromated copper arsenate (CCA), a poisonous arsenic compound in residential uses. Arsenic is ranked number one on the EPA's priority list of hazardous substances. Unlike a majority of earlier studies on voluntary programs, results show that the CCA voluntary agreement has lowered arsenic use in the U.S. to levels not seen since the 1920s. Moreover, a government-driven policy, namely the EPA's Toxic Release Inventory, was effective in decreasing arsenic use, albeit to a lesser magnitude than the industry voluntary ban. Prioritizing environmental protection through financial resources, as measured by Congress-allocated dollars to the EPA, has also reaped environmental benefits in the form of reduced arsenic use. Finally, systematic surveys of key stakeholders provide institutional, political, and economic insights into the impact estimates of the CCA voluntary agreement on arsenic use.

Key Words: Voluntary environmental programs, voluntary compliance, industry self-regulation, environmental policy

1. INTRODUCTION

Since the 1980s, President Ronald Reagan's "Environmental Federalism" has increased state and private sector involvement in environmental policy (Council of Economic Advisors, 1982, p. 44). Experimentation with alternative policy instruments that devolved regulation from the federal government was continued by the administrations of Presidents Bush Sr., Clinton, Bush Jr., and Obama. New governance approaches include information-based regulations (e.g., EPA's Toxic Release Inventory), collaborative partnerships (e.g., regional watershed partnerships), market-based approaches (e.g., SO₂ trading), and voluntary environmental programs (e.g., EPA's 33/50 program, the Chemical Industry's Responsible Care).

Firms play a key role in pollution abatement and control by engaging in beyond-compliance actions without the force of law in voluntary environmental programs. A majority of the literature points to modest or negligible impact on the effectiveness of such voluntary programs. That being said, when variation in voluntary environmental programs is accounted for a more nuanced depiction of program efficacy emerges. Prior research has shown that among the different types of voluntary environmental programs, unilateral or industry sponsored voluntary programs are the weakest in their environmental performance (Gamper-Rabindran & Finger, 2012; King & Lenox, 2000). Evidence of the effectiveness of public voluntary programs or government initiated programs in reducing pollution has also been lackluster (Antweiler & Harrison, 2007; Gamper-Rabindran & Finger, 2012; Gamper-Rabindran, 2006; Glachant & Muizon, 2007; Morgenstern & Pizer, 2007; Takahashi et al., 2001; Vidovic & Khanna, 2007a; Welch et al., 2000). By contrast, third-party or non-governmental organization (NGO) sponsored voluntary programs (e.g., ISO 14001) and bilateral voluntary agreements (which is the subject of this paper) have fared considerably better in their efficacy (T. Arimura et al., 2008;

Darnall & Kim, 2012; Dasgupta et al., 2000; Glachant & Muizon, 2007; Krarup & Millock, 2007; Morgenstern & Pizer, 2007; Potoski & Prakash, 2005; Wakabayashi & Sugiyama, 2007).

Bilateral voluntary agreements are voluntary agreements to reduce pollution in specific industries that are negotiated between the government and the private sector (Borck & Coglianesi, 2009). These negotiated agreements often lead to legal binding contracts.

Compared to the other types of voluntary environmental programs, there have been fewer studies on the efficacy of bilateral voluntary agreements. The few existing studies on bilateral voluntary agreements suggest that the negotiated agreements between regulators and the corporate actors have the potential to reduce pollution by a substantial amount. Three studies of bilateral voluntary agreements to reduce CO₂ emissions in Japan, Denmark, and the United Kingdom (UK), respectively are featured in Morgenstern and Pizer (2007). They report that in each case negotiated targets were met within the first few years of inception (Glachant & Muizon, 2007; Krarup & Millock, 2007; Wakabayashi & Sugiyama, 2007). For example, in four years, participants of the 2001 Climate Change Agreements in the UK surpassed their 2010 targets (Glachant & Muizon, 2007). Similarly, participants of Japan's 1997 Keidanren Voluntary Plan achieved emissions below 1990 levels within the first 5 years of the program's 10 year CO₂ reduction goal (Wakabayashi & Sugiyama, 2007).

This paper examines the effectiveness of a bilateral voluntary agreement negotiated between the U.S. Environmental Protection Agency (EPA) and the largest industrial user of arsenic: the pressure-treated wood industry. The agreement, concluded at the end of 2003, delineated the terms of a voluntary phase-out of the use of chromated copper arsenate (CCA). This is an important study because CCA is an arsenic compound, and arsenic is a poisonous chemical that continues to be ranked number one on the EPA's priority list of hazardous

substances.⁴ Like the abovementioned bilateral voluntary agreements in Japan, Denmark, and the UK, the CCA voluntary agreement was lauded as a success by the major stakeholders involved in the negotiated agreement. In fact, this paper's estimated models show that the CCA voluntary agreement led to a substantial reduction in arsenic use: aggregate arsenic use has been lowered to levels not seen since the 1920s.

The impact of the CCA voluntary agreement on the industrial use of arsenic in the U.S. is rigorously estimated using a unique U.S. Geological Survey (USGS) dataset spanning all industry sectors between 1975 and 2009. Dynamic panel estimators are employed to estimate the impact models and uniquely, impulse response functions and structural break analysis are used in the sensitivity analyses. Importantly, and unlike prior research in this area, the impact models control for federal government command-and-control regulations that have preceded the bilateral voluntary agreement. Furthermore, key stakeholders were systematically surveyed to elucidate compliance-related decision-making processes that led to voluntary compliance with the CCA agreement. These surveys provide key insights into the impact estimates of the CCA voluntary agreement on arsenic use.

Results from the quantitative study as well as the systematic surveys of key stakeholders show that factors *beyond* regulation are important drivers of arsenic use. While a technological innovation in semiconductor manufacturing increased industrial use, an industry voluntary ban has *dwarfed* government regulations in reducing arsenic use. With that said, the government continues to play a critical role in pollution control. There is evidence to suggest that government-driven policies—namely, a mandatory information disclosure rule (i.e., the Toxic Release Inventory)—were effective in decreasing arsenic use, albeit to a lesser magnitude than

⁴ Source: <http://www.atsdr.cdc.gov/SPL/resources/index.html> (Retrieved March 2, 2012)

the CCA voluntary agreement. Furthermore, the estimated models show that prioritizing environmental protection through financial resources, as measured by Congress-allocated dollars to the EPA, has reaped environmental benefits in the form of curtailed arsenic use.

What institutional, political, and economic conditions led to the successful negotiation of the CCA voluntary agreement by regulators and the pressure-treated wood industry? Systematic surveys with policymakers, managers, and staff of businesses and NGOs reveal that a coalition of environmental groups devoted to promoting “green” building materials reframed a routine pesticide reregistration into an environmental crisis concerning the toxic exposure of children to CCA on the playground. The green buildings network promoted their cause in multiple institutional venues, built a coalition of supporters in and outside of government, and engaged in public naming and shaming via the media. The government played important facilitating roles of “steering” and “commanding”, particularly in casting a shadow of public law with the credible threat of future regulation. In the face of the media maelstrom, the pressure-treated wood industry was compelled to engage in beyond-compliance actions given the existence of a poison-free substitute, market competitive pressures, and the threat of future regulation.

This paper contributes to the literature in several ways. First, the paper presents a U.S. case of a bilateral voluntary agreement—which is distinct from the three experiences of negotiated agreements in Japan, the UK, and Denmark that have been documented in the literature—to present new evidence that under certain conditions bilateral voluntary agreements have the potential to reduce pollution by a considerable amount. Second, my paper answers the call by Prakash and Potoski (2012) in a recent symposium paper for the *Journal of Policy Analysis and Management* for more research that systematically examines the institutional, political, and economic conditions under which voluntary environmental programs reduce

pollution. Uncovering the compliance-related decision-making process is important for understanding the emergence, diffusion, and efficacy of voluntary environmental programs more generally.

Third, the paper's empirical analysis highlights the importance of considering the role of environmental groups and other stakeholders, as well as the government's role in encouraging and at times pressuring for beyond-compliance activities by businesses. Prior empirical literature on voluntary environmental programs has placed less emphasis on the role of third-party stakeholders with the exception of Takahashi et al. (2001) in which the authors posit that media and community pressures are significant in explaining the emission reduction potential of the Canada's Voluntary Challenge Registry program.⁵ Moreover, this research is consistent with prior work that show that voluntary environmental programs are often developed and adopted in the shadow of public law or the threat of the government's imposition of more stringent rules (Buthe, 2010a; Cashore, Auld, & Renckens, 2011; Mayer & Gereffi, 2010; Potoski & Prakash, 2005). The key roles played by the government and third-party stakeholders in the CCA voluntary agreement lead to a natural question: how "voluntary" are voluntary environmental programs? This question will be explored in the concluding section of this paper.

Finally, this paper's mix of quantitative analysis and systematic qualitative process tracing is a novel methodological contribution to evaluation research that has primarily relied on

⁵ By contrast, there have been many empirical examples of the prominent roles that NGOs play in the larger literature on private governance, across multiple issue areas, not just in environmental policy. Examples include the role of NGOs in sustainable forestry, Fair Trade coffee, "sweatshop free" apparel, and responsible recycling of e-wastes (Cashore, Auld, & Newsom, Deanna, 2004; Cashore, Auld, & Renckens, 2011; Fung & O'rourke, 2000; Fung, O'Rourke, & Sabel, 2001; Mayer & Gereffi, 2010; O'Rourke, 2003). In some cases NGOs were perpetrators of activist campaigns and in other cases NGOs were disinterested third-party monitors and auditors of firm and industry compliance with voluntary standards.

quantitative analysis. The reality of nonexperimental data in policy efficacy studies, including research on voluntary program efficacy, warrants the triangulation between methods. The triangulation between methods is a research design that attempts for mutual validation of the same phenomenon through the employment of multiple methods (Brady & Collier, 2010; Jick, 1979; Lieberman, 2005; McFee, 1992).

With respect to quantitative methods, I employ dynamic panel estimation and time series analyses that are mainstays in applied macroeconomic and finance research but seldom used in policy evaluation studies in order to better disentangle the causal effects of the CCA voluntary agreement. The three separate analyses are based on different underlying models of the data. The Arellano-Bond dynamic panel estimator exploits the time dimension of the industry-level arsenic use data to resolve omitted variable bias. The structural break analysis is a test of the endogenous or actual change points in the data, eliminating the need, as in standard statistical analyses, to impose and then “test” for the significance of exogenously determined factors. Additionally, the impulse response functions (IRFs) employ a vector autoregressive system, which models each explanatory variable separately to capture their linear interdependencies through time. The hypothesis is that if the estimated structural breaks and the IRFs are qualitatively similar to the regression results of the Arellano-Bond estimator then the validity of the regression results is corroborated. Together, these separate methods move us closer toward the causal inference of the experimental ideal.

The paper’s process tracing, which is made possible by the systematic surveys of major stakeholders, documents the causal mechanisms of the multiple interactions of political, economic, and institutional factors that have led to the CCA voluntary agreement formation. While the systematic qualitative analysis is not meant to give quantitative measures of causal

effects, it does help build an argument for the significance of the CCA voluntary agreement in controlling the industrial use of arsenic, which is the number one ranked toxic chemical on the EPA's priority list of hazardous substances. Importantly, process tracing of the compliance-related decision-making processes uncover factors under which the CCA voluntary agreement and bilateral voluntary agreements more generally are effective for reducing pollution.

2. BACKGROUND

Voluntary environmental programs have proliferated across issue areas (Coglianese, 2001; Hsueh & Prakash, 2012a; Potoski & Prakash, 2009; Ronit, 2012; Vogel, 2005) and across the globe (D. J. Fiorino, 2006; D. Fiorino, 1999; Morgenstern & Pizer, 2007). For example, voluntary programs for increasing energy efficiency and curbing toxic chemical use have been established in the U.S., Canada, France, Germany, Japan, and the UK, among other industrialized countries (T. Arimura et al., 2008; Dietz & Stern, 2002; Morgenstern & Pizer, 2007; Price, 2005). These programs are sponsored by supra-national structures such as the European Commission, national and state governments, NGOs, and trade associations. The EPA has sponsored close to 100 programs while there were over 300 programs reported by the European Environmental Agency, and 30,000 voluntary programs in Japan (Morgenstern & Pizer, 2007). The underlying characteristic of voluntary programs that differs from command-and-control regulations is that they are non-mandatory. Firms agree to modify the way they manage pollution without the force of law (Borck & Coglianese, 2009). Notwithstanding, research shows that voluntary environmental programs and other forms of private regulation are developed and adopted in the shadow of public law (Buthe, 2010a; Cashore et al., 2011; Mayer & Gereffi, 2010; Potoski & Prakash, 2005).

Industrial toxic chemicals are an issue area that has seen much experimentation with voluntary programs (Morgenstern & Pizer, 2007). Examples include the EPA's 33/50 program, a public voluntary program, and the Chemical Industry's Responsible Care program, a unilateral or industry sponsored voluntary program. A chief challenge facing toxic chemical regulation is the rapid speed of technological development in toxic chemical-using sectors. It has been challenging for regulators to understand the toxicology of currently available toxic chemicals and their impact on human health and the environment before the next new chemical is on the market (GAO, 2007). Thus, the EPA, the chief regulator of industrial chemical use and emissions, has increasingly worked with the private sector to curb toxic chemical use through voluntary environmental programs, notably public voluntary programs and bilateral voluntary agreements. With respect to the latter, government regulators have on occasions negotiated with industry to reduce toxic chemical use, as in the case of the CCA voluntary agreement, which is the subject of this paper.

Bilateral voluntary agreements are unique in that they are a type of "cooperative regulation" (Harrison, 1998) in which government attempts to "exhort" or persuade organizations to alter their behavior. Specifically, the government preserves a significant threat of punishment (i.e., legal sanctions) in the case of voluntary failure. Moreover, the government can indirectly induce behavioral change by proactively inviting or at least allowing multiple stakeholder participation. This creates multiple social-political and economic pressure points for encouraging behavioral change by the private sector. At the same time, the private sector retains varying flexibility in the negotiation process. In many cases, as with the CCA voluntary agreement, the private sector is free to determine the level of detail and extent of commitment in the agreement, as long as regulators acquiesce.

At the center of the CCA voluntary agreement is the controversy over the pressure-treated wood industry's use of CCA, an arsenic compound, as a wood preservative in residential products, such as residential decks, picnic tables, and playground equipment. The contention was about the exposure of children who play on CCA-treated wooden playsets to arsenic, a poisonous chemical.⁶ In early 2002, the EPA announced that the manufacturers of CCA had requested that the registrations of CCA be cancelled for residential uses, including playground equipment, effective December 31, 2003.⁷ According to the terms of the agreement, CCA-treated residential wood products prior to year-end 2003 remained in circulation. Furthermore, the EPA accepted the pressure-treated wood industry's claim that children's exposure to CCA-treated wood used for nonresidential purposes (e.g., highway utility poles) was relatively negligible, thus CCA registration was permitted for nonresidential uses.⁸ The political economy narrative behind this landmark decision is explored in a subsequent section of this paper.

At critical dosages, arsenic causes a variety of cancers, including cancer of the lung, bladder, skin, and liver.⁹ In addition to ranking first on the EPA's priority list of hazardous substances, arsenic ranks among the top 10 most toxic substances according to the CRA

⁶ A Consumer Product and Safety Commission study (CPSC, 2003) found that the principle exposure to arsenic from CCA-treated wood in playground equipment occurs through the transfer of wood surface residues to a child's hands and subsequent hand-to-mouth transfer that can occur when children put their hands or fingers in their mouths.

⁷ The CCA voluntary agreement was different from a standard product recall by the CPSC because CCA itself is not a consumer product. Rather, CCA is a pesticide, which according to rules promulgated by the EPA, can only be used by certified pesticide applicators. As such, the CPSC does not have direct regulatory oversight over CCA's use as a pesticide. Before the EPA had a chance to promulgate any regulatory action, such as a pesticide recall, the pressure-treated industry pre-empted any such actions with a voluntary cancellation of CCA in residential uses.

⁸ Source: <https://www.federalregister.gov/articles/2003/04/09/03-8372/response-to-requests-to-cancel-certain-chromated-copper-arsenate-cca-wood-preservative-products-and> (Retrieved August 14, 2012)

⁹ Source: <http://www.atsdr.cdc.gov/substances/toxsubstance.asp?toxid=3> (Retrieved March 19, 2012)

Handbook of Chemistry and Physics, a key reference book for chemists and physicists. Finally, arsenic is a “controlled” substance under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.¹⁰

Notwithstanding, arsenic is a key ingredient in the manufacturing of wood preservatives, as well as agriculture pesticides, glass, and electronics. For the past three decades, wood preservative uses had surpassed any other applications. Between 1975 and 2004, close to 90 percent of all arsenic used in the U.S. was consumed by manufacturers who treated wood with CCA to prevent the wood from decay. The electronics, glass, and agriculture industries together make up the other 10 percent of total arsenic use.

3. DID THE CCA VOLUNTARY AGREEMENT LOWER ARSENIC USE?

The CCA voluntary agreement was lauded as a success by regulators, industry representatives, and environmental NGO activists involved in its development. It was considered a landmark decision by all major stakeholders because the largest arsenic-using industry’s voluntary compliance ensured that the industrial use of arsenic, a poisonous chemical that is ranked number one on the EPA’s priority list of hazardous substances, would be lowered.¹¹ By how much did the CCA voluntary agreement reduce arsenic use in the U.S.? In this section, I present a rigorous empirical analysis of the CCA voluntary agreement’s impact on arsenic use in the U.S.

3.1 Data and Measures

¹⁰ Source: <http://www.basel.int/Portals/4/Basel%20Convention/docs/text/BaselConventionText-e.pdf> (Retrieved October 21, 2012)

¹¹ In a July 20, 2011 interview, the coordinator of the NGO activist campaign expressed some regret that the CCA voluntary agreement did not cover arsenic use in nonresidential applications, such as utility poles. With that said, environmental NGO stakeholders were overall pleased with the outcome of the CCA voluntary agreement.

This paper quantifies the effect of the CCA voluntary agreement on the industrial use of arsenic using a unique dataset on arsenic use across all arsenic-using industry sectors from the mineral statistics publication of the U.S. Bureau of the Mines and the U.S. Geological Survey (USGS). Arsenic use data are a combination of published and calculated industrial use data.¹² Arsenic use is estimated by the USGS using the following equation for most years: Chemical Use = Production + Imports – Exports ± Stock Changes. Data for the other years come from published data from the USGS Mineral Facts and Problems and the Mineral Yearbook. Aggregate arsenic use data are available through 2009.

Data between 1975 and 2003 are available for the following arsenic end-use sectors: agricultural chemicals, glass, nonferrous alloys and electronics, and other commercial uses. Data are available through 2004 for the pressure-treated wood industry. The USGS estimates end-use distributions based on apparent demand information collected from industry contacts and Internet sources.¹³ End-use figures sum up to total use figures.

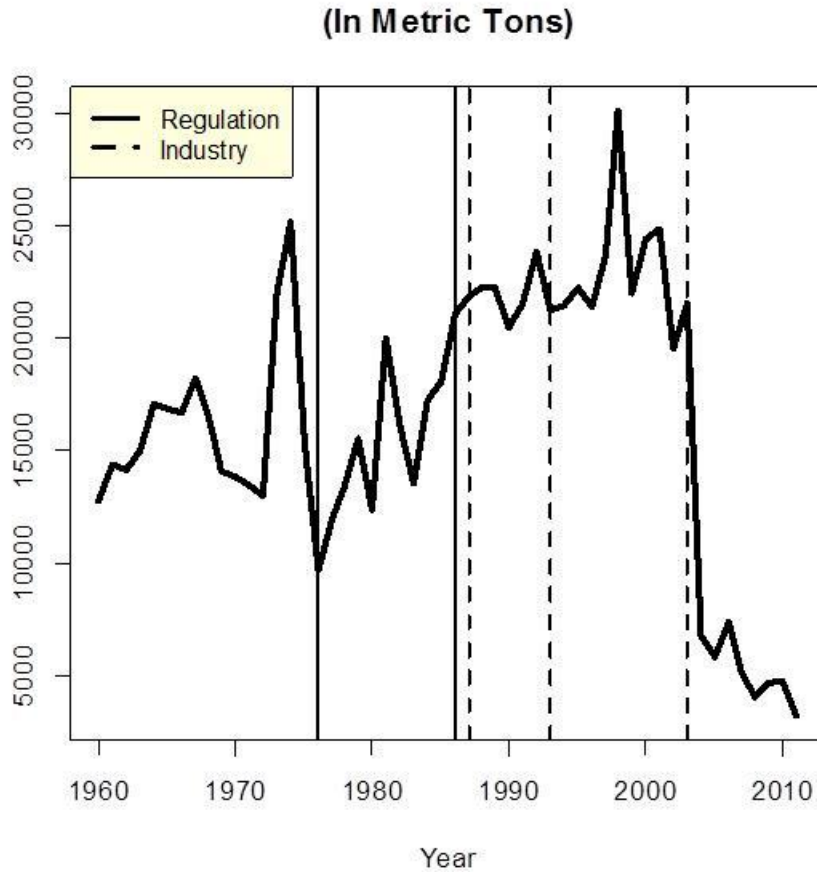
Figure 1 shows aggregate arsenic use between 1960 and 2009. The solid vertical lines represent the federal regulations that pertain to arsenic use: the Toxic Substances Control Act (TSCA) of 1976, and the Comprehensive Environmental Response, Compensation, the Emergency Planning and the Community Right-to-Know Act (EPCRA) of 1986 (which established the Toxics Release Inventory). The dotted vertical lines represent the discovery of gallium arsenide, a key arsenic compound in the manufacturing of semiconductors, in 1987; a

¹² To my knowledge, there is no other source of comprehensive industrial use data. Data are publically available on the USGS website (<http://minerals.usgs.gov/ds/2005/140/>). The USGS houses data on the production, trade, and commercial use of over 80 mineral commodities (many of which are elemental chemicals) in the U.S., including arsenic dating back to 1900, albeit the current analysis is concerned only with industrial chemical use during the post-1960 environmental regulatory era.

¹³ This information is provided in an email exchange on May 11, 2009 by Dr. William E. Brooks, the commodity specialist at the USGS for Silver, Mercury, and Arsenic.

voluntary ban on arsenic acid by agriculture users in 1993; and the CCA voluntary agreement in 2003.

Figure 1
Arsenic Use in the U.S., 1960-2009



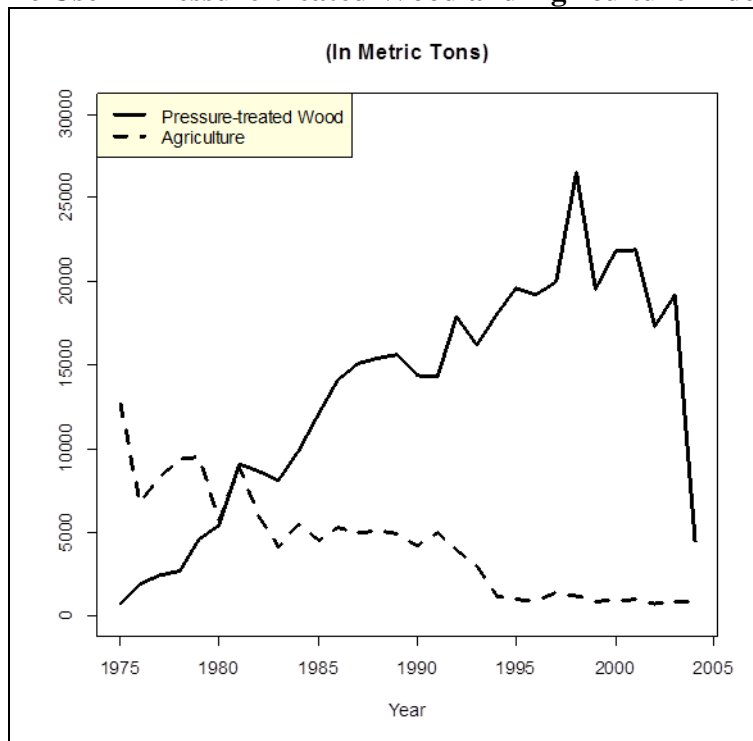
Source: USGS.

Figure 2 Panels A and B present arsenic use by major industrial users. Figure 2 Panel A plots arsenic use by the pressure-treated wood and the agriculture industries from 1975-2004, respectively. In 1975, the agricultural sector was the leading user of arsenic; arsenic is used as a pesticide and cotton desiccant (Loebenstein, 1994). By the early 1980s, the pressure-treated wood industry exceeded the agriculture sector in arsenic use. This rise coincided with the

expansion of CCA as a major ingredient in wood preservatives. By contrast, arsenic use in the agriculture sector has been on a decline since the 1975 and hastened in the 1990s.

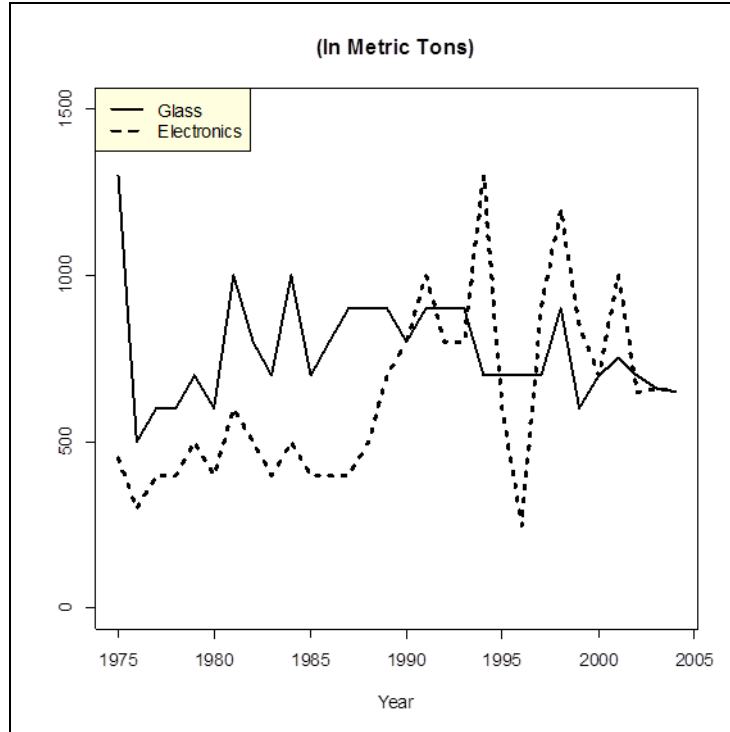
Arsenic use by the glass and the electronics industries since 1975 are plotted in Figure 2 Panel B. The two sectors have been relatively small but consistent users of arsenic. Arsenic is used in the compound form of gallium arsenide in semiconductor manufacturing and as a key ingredient in glass purification.

Figure 2 Panel A
Arsenic Use in Pressure-treated Wood and Agriculture Industries



Source: USGS.

Figure 2 Panel B
Arsenic Use in Electronics and Glass Industries



Source: USGS.

My empirical objective is to illustrate how a voluntary action to reduce the use of a poisonous chemical by the largest industrial user could have had a dramatic effect on the total use of a toxic input in the U.S., while at the same time radically reducing the use of the said chemical in that sector. As such, I pool data across the four industry sectors in the dynamic panel regression analysis. It is the interest of public policy to be concerned about how regulatory or voluntary actions in specific sectors impact aggregate environmental performance. As such, the success of the CCA voluntary agreement is assessed by whether or not it generates discernible impact for aggregate arsenic use.

While there is currently no available data to corroborate this, it is possible that the CCA voluntary agreement has spillover effects into other arsenic-using sectors. In King and Lenox's (2000) study of pre-2002 Responsible Care program sponsored by the chemical industry, the

authors find that participation in the industry sponsored voluntary program had positive spillover effects onto nonmembers' environmental performance. Moreover, Arimura et al. (2011) find that the adoption of ISO 14001 by participants increases the likelihood of facilities to engage in a more advanced form of beyond-compliance actions, namely the adoption of green supply chain management.

In the following regression analysis, the dependent variable or outcome variable of interest is the natural log-transformed arsenic use. The log transformation of arsenic use retains the structure of the data but reduces fluctuations and facilitates the interpretation of results without changing the results. To elaborate on the first point, the logarithm function squeezes the outliers of high values by pulling the outliers back in closer to the rest of the data; in essence the log transformation stabilizes the variance of the data. Moreover, the log transformation allows for easier data interpretation. Specifically, the application of natural logs allows the analyst to interpret the policy impacts of the regulations and voluntary programs in percentage terms without altering the base coefficient estimates.

The key independent or explanatory variable is *CCAvoluntaryban03* (CCA voluntary agreement), which is hypothesized to exhibit a statistically significant negative relationship with arsenic use, i.e., CCA voluntary agreement should reduce arsenic use. *CCAvoluntaryban03* is constructed as an indicator variable that equals 0 between years 1975 and 2002 and 1 in years 2003 and 2004 (the end of the data series).

The choice of the control variables is guided by the need to account for factors in the political economy that could potentially "cause" or at least "correlate" with an increase or decrease in arsenic use, which are not directly related to the CCA voluntary agreement. A

parsimonious set of variables that include relevant federal regulations, economic factors, industry developments, and political factors, along with time fixed effects serve as controls.

Two umbrella government regulations address arsenic use by U.S. manufacturers.¹⁴ The Toxic Substances Control Act (TSCA) of 1976 is a command-and-control regulation that authorizes the EPA to regulate the manufacture and use of toxic chemicals, including arsenic and arsenic compounds that pose an unreasonable risk to human health or the environment. To implement the TSCA, the EPA reviews information it obtains from companies and other sources on a chemical's potential exposure levels and its potential adverse effects on human health or the environment. If the EPA concludes that a chemical presents an unreasonable risk, the agency has the authority to promulgate a rule to ban or restrict the chemical's production, processing, distribution, use, or disposal, or to require that warning labels be placed on the chemical.

While arsenic compounds used in the manufacturing of electronics and glass fall under the authority of TSCA, CCA and arsenic acid, which are pesticides for preserving wood and treating cotton, respectively, are excluded from the TSCA. Instead, CCA and arsenic acid are regulated under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), which has been amended multiple times since its enactment in 1910.¹⁵ The most extensive of the revisions

¹⁴ Since the 1970s, the federal government has played an increasingly active role in environmental regulation (R. Revesz, 2001; Stavins, 2004a). From 1970 through 1990, eight major federal statutes pertaining to toxic substances were passed. These federal statutes are the Occupational Health and Safety Act of 1970, the Clean Water Act of 1972, the Safe Drinking Water Act of 1974, the Resource Conservation and Recovery Act of 1976, the Toxic Substances Control Act of 1976, the Comprehensive Environmental Response, Compensation, and Liability Act of 1980, the Emergency Planning and Community Right-to-Know Act of 1986 (which established the Toxics Release Inventory), and the Clean Air Act of 1990. While arsenic is listed as a priority chemical by all these federal rules, only two rules regulate arsenic use and production. These two umbrella rules are the concern of this paper.

¹⁵ Under FIFRA, before a pesticide could be registered for use, the applicant must show that using the pesticide according to specifications "will not generally cause unreasonable adverse effects on the environment." Pesticides that have already been registered must undergo a

was in 1972, which occurred before the start of the data series. As such, the regression analysis does not explicitly control for it. Other legislative changes to the FIFRA that occurred in 1988 and 1996, respectively, are accounted for in the estimated models by time fixed effects (see below for more details).

In 1986, Congress passed the Emergency Planning and Community Right-to-Know Act (EPCRA), which created the Toxics Release Inventory (TRI). Henceforth, the EPCRA will be referred to as the TRI. The TRI is not a traditional command-and-control regulation. Rather, the TRI is an information disclosure rule that stipulates mandatory reporting of toxic emissions and transfers by manufacturers in specific industries.¹⁶ For industrial users of arsenic this means that they must report to the EPA whatever arsenic is not absorbed by the manufacturing process and is released into the environment, recycled, or transferred to another facility.

The idea is that mandatory accounting and reporting of emissions will induce manufacturers to seek ways to reduce toxic chemical use and emissions through pollution prevention and abatement measures, in part because of public pressures resulting from the increased transparency (Fung & O'Rourke, 2000; Khanna, Quimio, & Bojilova, 1998; Konar & Cohen, 1997).

periodic reregistration review process whereby a formal risk assessment with new information is conducted. Source: <http://www.epa.gov/oecaagct/lfra.html> (Retrieved August 10, 2012)

¹⁶ The TRI covers 682 toxic chemicals used by facilities across a wide range of industries (including electric utilities, chemical, mining, paper, oil and gas, hazardous waste management industries) that produce more than 25,000 pounds or handle more than 10,000 pounds of these listed chemicals. Unlike the TSCA, there are no exemptions for pesticides. Manufacturers must report the emissions and transfers of these listed chemicals once the established thresholds have been reached.

In the regression analysis, the two government regulations are quantified by indicator variables (*reg_TSCA76*, *reg_TRI86*, respectively) that equal 1 starting in the year the respective federal rules were promulgated and thereon after, and 0 otherwise.

An indicator variable is used to represent the 1987 discovery of gallium arsenide (*GaAs87*) in semiconductor manufacturing. There has been rapid adoption of gallium arsenide (GaAs) by electronic manufacturers because GaAs's higher saturated electron velocity and higher electron mobility relative to silicon have allowed transistors made from it to function at high frequencies. Moreover, unlike silicon, GaAs devices are relatively insensitive to heat and tend to have less noise than silicon devices especially at high frequencies. Thus, the advent of GaAs should be positively correlated with arsenic use since the demand for arsenic necessarily increases given that GaAs has become a key ingredient in electronic production.

Another industry development is the 1993 voluntary cancellation of inorganic arsenic acid in agriculture for treating cotton by two major agricultural pesticide manufacturers. Before the 1993 voluntary ban (*AsAcidvoluntaryban93*), cotton growers in the U.S. used arsenic acid to dry out the bolls of their cotton plants prior to harvesting them.¹⁷

Like the CCA voluntary agreement, the arsenic acid ban is referred to as an industry-led “voluntary” ban by policymakers and industry as opposed to a government directive.¹⁸ That being said, one major difference between the two voluntary bans is that for arsenic acid the threat of a government-driven directive was notably greater on the eve of the voluntary ban: the EPA

¹⁷ Organic forms of arsenic acid continued to be used as a key ingredient in agricultural pesticides. In 2009, however, the EPA issued a cancellation order to eliminate and phase out the use of organic arsenical pesticides by 2013. Source: http://www.epa.gov/oppsrrd1/reregistration/organic_arsenicals_fs.html#voluntary (Retrieved August 6, 2012)

¹⁸ Source: <http://pmep.cce.cornell.edu/profiles/miscpesticides/alphaalkyl-metaldehyde/arsenic-acid/ars-acid-canc-dess.html> (Retrieved August 9, 2012)

had formally issued a “Notice of Preliminary Determination to Cancel Registration” a year prior to the manufacturers’ voluntary cancellation, which made provisions for the distribution, sale, or use of existing arsenic acid stocks. By contrast, the EPA had not taken any formal action against CCA at the time of the CCA voluntary agreement. I hypothesize that the 1993 voluntary ban is negatively correlated with arsenic use.

The ebb and flow of the business cycle and the economy is measured by each industry’s gross output (*sectorGDP*), as appraised by each industry’s value added, respectively. The sector GDP data are obtained from the U.S. Bureau of Economic Analysis. Sector GDP is expected to be positively correlated with arsenic use: a rise in industrial development necessitates increases in productive inputs, all else equal.

The regression analysis also includes a proxy measure for the extent to which Congress prioritizes environmental policymaking: the EPA’s annual enacted budget (*EPABudget*). The rationale for controlling for Congress’s political priority on the environment is that it is possible the rise and fall of arsenic use is correlated with the importance Congress places on the environment, as indicated by the size of funding it allocates to the EPA, the nation’s chief environmental regulator. Increased funds could be spent on a range of EPA activities, including improving compliance, such as greater rule enforcement and enhanced engagement with stakeholders. Thus, it is expected that an increase in the agency’s budget means that more effort is spent on the implementation and enforcement of existing environmental regulations, which leads to reductions in arsenic use.

Moreover, the extent to which the public is aware of arsenic’s harm to human health and the environment could shape consumer demand for products containing arsenic. I measure the change in public awareness over time regarding the adverse human health and environmental

effects of arsenic use by a count of the number of media reports published by the *New York Times* (*mediaNYT*). An increase in media attention about arsenic's harm to human health and environment should reduce arsenic use.

Finally, time indicator variables for every year between 1975 and 2004 are included to control for contemporaneous macroeconomic, macro-political, as well as institutional characteristics that could affect arsenic use across all industry sectors. The inclusion of the time fixed effects in the model is based on a theoretical conjecture that in each passing year, there are contemporaneous events in the political economy that affect in some unobserved way all the sectors that use arsenic as an input. These exogenous events include commodity price changes, the oil crisis, changes in presidential administrations, and amendments in existing legislations. For example, it is plausible that a more interventionist administration would support a higher stringency of regulatory enforcement by the EPA, which could impact manufacturers' decisions across all industries about toxic input use.

The standard procedure in the empirical literature of including time dummies allow the analyst to take these important exogenous changes that are not the main explanatory variables of interests, into account without having to specify each of the factors individually. Excluding these time indicator variables puts the models at the risk of omitted variable bias.

Table 1 provides summary statistics for the regression analysis based on the main model (Model 1).

Table 1
Summary Statistics

Summary Statistics					
Variable	Obs	Mean	Std. Dev.	Min	Max
Pressure-treated Wood Industry					
<i>arsenic</i>	30	13198.3	6978.6	700.0	26500.0
<i>lnarsenic</i>	30	9.2	0.9	6.6	10.2
<i>CCAvoluntaryban03</i>	30	0.1	0.3	0	1.0
<i>reg_TSCA76</i>	30	0	0	0	0
<i>reg_TRI86</i>	30	0.6	0.5	0	1.0
<i>AsAcidvoluntaryban93</i>	30	0	0	0	0
<i>GaAs87</i>	30	0	0	0	0
<i>sectorGDP</i>	28	28.5	3.8	18.0	34.6
<i>EPAbudget</i>	30	7.9	2.2	2.1	13.6
<i>mediaNYT</i>	30	35.0	16.2	10.0	104.0
Agriculture Industry					
<i>arsenic</i>	30	4290.3	3205.6	750.0	12700.0
<i>lnarsenic</i>	30	8.0	0.9	6.6	9.4
<i>CCAvoluntaryban03</i>	30	0	0	0	0
<i>reg_TSCA76</i>	30	1.0	0.2	0	1.0
<i>reg_TRI86</i>	30	0.6	0.5	0	1.0
<i>AsAcidvoluntaryban93</i>	30	0.4	0.5	0	1.0
<i>GaAs87</i>	30	0	0	0	0
<i>sectorGDP</i>	28	101.3	15.1	77.9	137.3
<i>EPAbudget</i>	30	7.9	2.2	2.1	13.6
<i>mediaNYT</i>	30	35.0	16.2	10.0	104.0
Semiconductor Industry					
<i>arsenic</i>	30	633.7	262.1	250.0	1300.0
<i>lnarsenic</i>	30	6.4	0.4	5.5	7.2
<i>CCAvoluntaryban03</i>	30	0	0	0	0
<i>reg_TSCA76</i>	30	1.0	0.2	0	1.0
<i>reg_TRI86</i>	30	0.6	0.5	0	1.0
<i>AsAcidvoluntaryban93</i>	30	0	0	0	0
<i>GaAs87</i>	30	0.6	0.5	0	1
<i>sectorGDP</i>	28	134.8	32.5	72.6	194.1
<i>EPAbudget</i>	30	7.9	2.2	2.1	13.6
<i>mediaNYT</i>	30	35.0	16.2	10.0	104.0
Glass Industry					
<i>arsenic</i>	30	775.3	162.6	500.0	1300.0
<i>lnarsenic</i>	30	6.6	0.2	6.2	7.2
<i>CCAvoluntaryban03</i>	30	0	0	0	0
<i>reg_TSCA76</i>	30	1.0	0.2	0	1.0
<i>reg_TRI86</i>	30	0.6	0.5	0	1.0
<i>AsAcidvoluntaryban93</i>	30	0	0	0	0
<i>GaAs87</i>	30	0	0	0	0
<i>sectorGDP</i>	28	39.8	5.2	28.3	50.1
<i>EPAbudget</i>	30	7.9	2.2	2.1	13.6
<i>mediaNYT</i>	30	35.0	16.2	10.0	104.0

3.2 Analytical Method: Arellano-Bond Dynamic Panel Estimator

This paper employs the Arellano-Bond dynamic panel estimator (Arellano & Bond, 1991) to rigorously identify the impact of the CCA voluntary agreement. The Arellano-Bond estimator exploits the time dimension of the industry-level arsenic use data to resolve a potential endogeneity problem, i.e., omitted variable bias, by using lagged values of the dependent variables as instrumental variables. The Arellano-Bond estimator is estimated in the Generalized Methods of Moment (GMM) framework.

The following setup of the Arellano-Bond estimator highlights key features of the estimator. To begin, equation (1) is a conventional panel data model with sector fixed effects and time fixed effects.

$$\ln \text{arsenic}_{it} = x'_{i,t-1} \beta_i + z'_{i,t-1} \gamma_i + \alpha_i + T'_t \theta_i + v_{it} \quad (1)$$

$x_{i,t-1}$ is the CCA voluntary agreement, which is the key explanatory variable of interest. $z_{i,t-1}$ is the vector of controls, namely federal regulations and economic and political covariates, respectively, as described in the previous section. α_i represents a whole host of not readily observed factors that could shape an industry's arsenic use, which are unrelated to government mandates or time varying economic and political factors. Time fixed effects control for contemporaneous shocks such as commodity price changes and changes in any economic, political, or institutional characteristics that affect all arsenic-using sectors. v_{it} is an idiosyncratic disturbance that varies with time and sector. Finally, all controls are lagged by one period in order to link the impacts of the explanatory variables to arsenic use for subsequent years.

Equation (1) is converted to its dynamic form by lagging $\ln \text{arsenic}_{it}$, the dependent variable, by one year and adding it to the right-hand side of equation (1) as another regressor.

The logic is that an industry sector's consumption of arsenic in one period is likely to be correlated with that sector's consumption in the previous period. For example, manufacturers regularly purchase commodity chemical inputs via long-term contracts, and as a result production planning horizons are lengthened. This stickiness in arsenic use is captured by including lagged arsenic use as a regressor.

Estimating this model by OLS gives us inconsistent estimates because the explanatory variables now include a lagged dependent variable. Anderson and Hsiao (1981) suggest taking the first difference of equation (1) and then estimate the resulting transformed model, equation (2), using an instrumental variable approach.

$$\Delta \ln arsenic_{it} = \delta \Delta \ln arsenic_{i,t-1} + \Delta x'_{i,t-1} \beta_i + \Delta z'_{i,t-1} \gamma_i + T'_t \theta_i + \Delta v_{it} \quad (2)$$

The first differenced model remains inconsistent when estimated by OLS because $\ln arsenic_{i,t-1}$ is correlated with $v_{i,t-1}$, so that the regressor $\Delta \ln arsenic_{i,t-1}$ is correlated with the error Δv_{it} .

To remedy this, the second lag of the dependent variable, $\ln arsenic_{i,t-2}$, is employed as an instrument for $\Delta \ln arsenic_{i,t-1}$. $\ln arsenic_{i,t-2}$ is a valid instrument because it is uncorrelated with Δv_{it} but correlated with $\Delta \ln arsenic_{i,t-1}$.¹⁹

In effect, the exogenous dependent variable of two periods ago is used as an instrument for the endogenous dependent variable in the current time period. This allows for the possibility that past shocks to arsenic use, such as government mandates, have feedback effects on current values of the explanatory variables, whether it is the annual enacted budget of the EPA or sector GDP growth.

¹⁹ Cameron and Trivedi (2005) posit that for moderate length T (which is what we have) there may be a maximum lag of the y_{it} , the dependent variable, that is used as an instrument, such as $y_{i,t-4}$. The sargan test indicates that our set of overidentifying instruments is valid, namely that the instruments are uncorrelated with the contemporaneous error term.

Finally, equation (2), along with the instrumental variables, is estimated in the GMM framework, which allows for a more efficient estimator than a standard panel data model.²⁰ The standard errors are adjusted with panel-robust standard errors to correct for heteroskedasticity and serial correlation.

3.3 Results

Table 2 reports the results of the regression analysis.²¹ Model 1 is the main specification of interest and the preferred model. Models 2-4 serve as a direct robustness check to Model 1 (as opposed to the sensitivity analyses in the next section, which are based on different underlying models). Moreover, the alternative specifications supplement Model 1 with additional information about the possible causal pathways of sector GDP, EPA budget, and media attention. Specifically, Models 2-4 are replications of the main model plus variations of the following additional controls: quadratic terms of *sectorGDP*, *EPAbudget*, and *mediaNYT*, and interaction terms involving *sectorGDP*, *EPAbudget*, *CCAvoluntaryban03*, *AsAcidvoluntaryban93* and regulation indicator variables, respectively. All estimated models include time fixed effects.²²

²⁰ Holtz-Eakin et al. (1988) and Arellano and Bond (1991) recommend estimating in the GMM framework particularly when the instrument set is unbalanced, i.e., when there are more instruments than there are endogenous variables. In GMM estimation, sample moment conditions (e.g., the mean, variance, and so on, which are functions of the model parameters and the data) are used to estimate parameters. The GMM method minimizes a certain norm of the sample averages of the moment conditions to obtain parameter estimates.

²¹ Each of the four models is run on 108 observations despite the 120 observations from the original USGS toxic chemicals data (30 observations per industry). The twelve “missing” observations are accounted for as follows: eight observations are dropped from the models by *Stata* because of multicollinearity associated with *reg_TSCA76* and the seven year dummies. The other four observations are differenced out as part of the four lags in the models in accordance to the dynamic panel model structure of the Arellano-Bond estimator.

²² The time fixed effects reduce the degrees of freedom in the estimated models, but the model diagnoses of the goodness of fit across the four models (i.e., Prob > chi2 = 0.0000 in Table 2) suggest that the variances of the estimates are small enough for achieving model precision. When time fixed effects are excluded from the estimated models the main results remain qualitatively and quantitatively similar to the original models—namely, the voluntary agreement

Estimated regression coefficients are presented in terms of log-points. Statistically significant coefficients are converted into percentages for the ease of interpretation (Table 2 Columns 4, 7, 10, and 13).

Across all model specifications, the key result is that, as hypothesized, the pressure-treated wood industry's voluntary agreement to phase-out CCA in residential uses yields a statistically significant negative impact on arsenic use. In the main model (Table 2, 'Model 1'), the CCA voluntary agreement reduces arsenic use by close to 75 percent. This significant decline brings arsenic use in the U.S. back to levels not seen since the early 1920s.

The CCA voluntary agreement's enormous estimated effect is not matched by the regulation indicator variables in the regression. The TRI indicator variable, *reg_TRI86*, is estimated to have reduced arsenic use by 28 percent since the legislation's enactment.²³ The statistical significance of the TRI is interesting because while it is a government-driven rule, the TRI is not a traditional command-and-control regulation. The EPA does not set standards related to toxic use nor abatement technologies in the TRI. In so far as compliance with TRI by firms induces firms to engage in pollution prevention and abatement activities—that part is voluntary. As such, the 1986 TRI is closer to the CCA voluntary agreement than traditional command-and-

by the pressure-treated wood industry to reduce CCA in residential uses retain statistically significant negative impact on arsenic use of about the same magnitude. This is also true for the 1993 voluntary ban on arsenic acid. However, in Models 1 and 2, the coefficient on the indicator variable for the TRI contradicts the results from the time fixed effects models. These results are not compelling, however, because of the possibility of omitted variable bias, stemming from unobserved macroeconomic, macro-political, as well as institutional factors that could affect arsenic use across all sectors.

²³ As a reviewer points out, the TRI and/or the TSCA could yield statistical significant larger "effect" on reducing aggregate toxic substances as opposed to reducing any one substance in a specific sector. While it is beyond the goal of the paper, this paper does not preclude the regulations' broader effect on toxic pollution more generally.

control regulation even though it is government-driven with built-in legal sanctions for noncompliance.

Table 2
Arsenic Use Regression Results

Arsenic Use Regressions												
	Model 1			Model 2*			Model 3*			Model 4*		
	Coefficient	Robust Standard Error	Impact (%)	Coefficient	Robust Standard Error	Impact (%)	Coefficient	Robust Standard Error	Impact (%)	Coefficient	Robust Standard Error	Impact (%)
Industry Voluntary Agreement												
2003 Pressure-treated Wood	-1.399 **	0.070	-75%	-1.399 **	0.070	-75%	-1.545 ***	0.072	-79%	-1.522 ***	0.070	-78%
CCA Voluntary Agreement												
Control Variables												
<i>Umbrella regulation</i>												
1976 TSCA												
1986 TRI	-0.328 ***	0.108	-28%	0.062	0.110							
<i>Other controls</i>												
1987 Discovery of GaAs	0.199 ***	0.199	22%	0.203 ***	0.203	23%	0.463 ***	0.066	59%	0.485 ***	0.095	62%
1993 Arsenic Acid Voluntary Ban	-0.443 ***	0.139	-36%	-0.441 ***	0.138	-36%	-0.352 ***	0.097	-30%	-0.388 ***	0.126	-32%
Sector GDP (Bil. 2005 \$)	-0.001	0.002		0.000	0.004		0.011	0.018		0.008	0.018	
EPA Annual Budget (Bil. 2005 \$)	-0.049 ***	0.010	-5%				-0.084 ***	0.030	-8%			
Media Attention	0.003	0.002		0.008	0.004		0.003	0.002		-0.006	0.004	
<i>Quadratic and interaction terms</i>												
Sector GDP ^2				0.000	0.000					0.000 ***	0.000	0%
EPA Budget ^2				0.001	0.001					-0.001	0.002	
Media Attention^2				0.000	0.000					0.000 ***	0.000	0%
EPA Budget X 1976 TSCA							0.038	0.037		0.038	0.036	
EPA Budget X 1986 TRI							-0.005	0.015		0.024	0.014	
EPA Budget X 1993 Arsenic Acid Voluntary Ban							-0.071 ***	0.012	-7%	-0.095 ***	0.015	-9%
EPA Budget X 2003 CCA Voluntary Agreement												
Sector GDP X 1976 TSCA							-0.011	0.018		-0.015	0.018	
Sector GDP X 1986 TRI							-0.004 ***	0.001	0%	-0.004 ***	0.001	0%
Sector GDP X 1993 Arsenic Acid Voluntary Ban							0.004 ***	0.001	0%	0.006 ***	0.001	1%
Sector GDP X 2003 CCA Voluntary Agreement							0.005	0.003		0.005	0.003	
Year fixed effects	Yes			Yes			Yes			Yes		
N	108			108			108			108		
Prob > chi2	0.000			0.000			0.000			0.000		

*Model 2: Model 1 + Quadratic Terms; Model 3: Model 1 + Interactive terms; Model 4: Model 1 + Quadratic Terms + Interactive terms

Moreover, the results show that each additional billion dollars enacted by the EPA is associated with a five percent decrease in arsenic use. This result suggests that the higher the political priority placed on the environment, as measured by Congress-allocated dollars, the tighter is regulatory control on arsenic use. The role of government has continued to be quite important in controlling arsenic use despite the significant impact of the CCA voluntary agreement.

On sectoral developments, the 1993 voluntary ban on arsenic acid is associated with a 36 percent decrease in arsenic use in the main model, which is a larger estimated reduction than the estimated decline in arsenic use associated with the TRI. The fact that the voluntary ban on

arsenic acid and the CCA voluntary agreement are both associated with sizeable reductions in arsenic use bode well for the overall effectiveness of U.S. toxic chemical policy. While the EPA has the authority given by the TSCA and the FIFRA to suspend immediately the registration of pesticides and other toxic chemicals on the market, in practice the agency has sought non-coercive means whereby industry is encouraged to voluntarily recall products and reformulate or repair potential hazards when the said pesticide or toxic chemical does not pose “imminent hazard.”²⁴

Furthermore, the main model shows that the discovery of GaAs in 1987 yields statistically significant increases in arsenic use. The industry innovation is associated with a 20 percent increase in arsenic use since its discovery. GaAs is an important ingredient in semiconductors: the arsenic compound has been used to manufacture computers, lasers, and other advanced telecommunication devices. This result suggests an important implication: arsenic use will continue as the private sector discovers more ways to exploit the physical properties of arsenic to create commercial products that benefit consumers.

Models 2, 3, and 4 in Table 2 present the alternative specifications. On balance, the results from Models 2, 3, and 4 mirror the results of the main model: the CCA voluntary agreement, a nongovernment driven beyond-compliance pollution abatement effort, was a major driver of reductions in arsenic use in the U.S. In these alternative specifications, the CCA voluntary agreement is associated with a statistically significant reduction of 75 to 79 percent in arsenic use, similar to the Model 1 results.

²⁴ Source: <http://www.epa.gov/risk/health-risk.htm> (retrieved August 7, 2012)

Model 2 replicates the main model and includes the quadratic terms of *sectorGDP*, *EPAbudget*, and *mediaNYT* as additional controls.²⁵ The rationale for including the quadratic terms is that these variables could enter into the model nonlinearly. For example, industry gross output could be positively correlated with arsenic use to some point. Beyond this point, industry gross output becomes negatively correlated with arsenic use because it becomes economically feasible to use a more expensive but arsenic-free substitute. Model 2 results on the original set of control variables mirror Model 1 except the coefficient of *reg_TRI86* is no longer statistically significant.

By contrast, Model 3 replicates the main model and includes interaction terms between *sectorGDP* and the regulation variables, *CCAvoluntaryban03*, and *AsAcidvoluntaryban93*, as well as interaction terms between *EPAbudget* and the said variables, respectively.²⁶ The logic is that the effect of the CCA voluntary agreement as well as other policy interventions on arsenic use could be mediated by an industry's gross output and/or the amount of funding Congress grants the EPA for carrying out the agency's regulatory mandates. For example, the higher the EPA's enacted budget, the higher the impact of government regulations because there are more resources for implementation and compliance-related activities. Again, results are qualitatively very similar to that of the main model. One quantitative difference is the increase in the associative power between arsenic use and the discovery of gallium arsenide in semiconductors.

²⁵ In Model 2, *EPAbudget* is dropped from the estimation results by *Stata* due to multicollinearity; as more variables are added the more likely the variables are collinear.

²⁶ In Model 3, *reg_TRI86* is dropped from the estimation results by *Stata* due to multicollinearity.

Model 4 is a combination of Model 2 and Model 3: it replicates Model 1 with additional quadratic and interactive terms as controls.²⁷ In addition to *CCAvoluntaryban03*, the other statistically significant variables are the two sector-specific variables: the 1993 voluntary ban on arsenic acid and the 1987 discovery of gallium arsenide. The latter variable is given a greater weight in this specification than in the other models.

When *EPAbudget* is interacted with the regulatory and voluntary ban indicator variables in Models 3 and 4, one of the interaction terms, namely *budgetXAsAcidvoluntaryban93*, is estimated to be negative and statistically significant.²⁸ The interpretation of the result is that each additional billion dollars spent by the EPA facilitates cotton producers' compliance with the 1993 voluntary ban on arsenic acid by a seven to nine percent reduction in arsenic use. This result suggests there is likely to be complementarity between government authority and voluntary approaches in some cases. Additionally, this raises the question of the "privateness" and "voluntariness" of voluntary approaches.

As mentioned, the EPA was already involved in investigating the exposure risks of arsenic acid through what the agency calls a PD or "Preliminary Determination to Cancel Registration". Part of the PD was a public comment period, which upon its closing the two major manufacturers of arsenic acid initiated discussions with the EPA regarding regulatory options for arsenic acid, as well as the option for voluntary cancellation of the pesticide by industry. Thus, the PD process initiated by the EPA appeared to have set in motion the manufacturers' voluntary cancellation of arsenic acid. The political economic factors and

²⁷ In Model 4, *reg_TRI86* and *EPAbudget* are dropped from the estimation results by *Stata* due to multicollinearity.

²⁸ In Models 3 and 4, *budgetXCCAvoluntaryban03* is dropped from the estimation results due to multicollinearity. Moreover, while several of the quadratic and interaction terms are statistically significant the estimated coefficients are too small for meaningful interpretation.

conditions underlying the arsenic acid voluntary ban are beyond the scope of this paper. That being said, further research on the complementarity between government authority and private authority is warranted.

Finally, in Model 4, when *sectorGDP* is interacted with *AcAcidvoluntaryban93* the resulting estimated coefficient is positive and statistically significant. This result suggests that the voluntary ban on arsenic acid's impact on aggregate arsenic use is moderated by a rise in an industry sector's value added. The industrial use of arsenic has increased even as cotton producers have curtailed their use of arsenic acid given growth in industrial output. This result is not surprising for two reasons. First, agricultural uses of arsenic have made up a decreasing share of total arsenic use over the years. Second, a rise in industrial development requires an increase in productive inputs, including toxic chemical use, all else equal.

Overall, the regression results across all models suggest that over the past several decades both government and industry have played critical roles in arsenic use policy specifically and U.S. toxic chemical policy more generally. While a technological discovery is associated with increases in arsenic use, the voluntary agreement by the pressure-treated wood industry to phaseout CCA in residential uses has had a relatively larger effect than government regulation. A voluntary ban in arsenic acid by pesticide manufacturers in the agriculture sector also contributed to arsenic use reductions in the estimated models. That being said, the results suggest that government regulations do matter. The role of the government has evolved from the conventional role of rule maker and enforcer to encourager and facilitator of an information-rich context for private citizens, interest groups, and firms to solve problems alongside regulators. Furthermore, the estimated models show that prioritizing environmental protection through

financial resources, as measured by Congress allocated dollars to the EPA, has reaped environmental benefits in the form of reduced arsenic use.

3.4 Sensitivity Analyses: Impulse Response Functions and Structural Break Analysis

The CCA voluntary agreement's substantial estimated impact on arsenic use is verified by two separate sensitivity analyses, namely impulse response functions and structural break analysis, which are based on different underlying models of the data from the Arellano-Bond estimator. Both analyses are regular tools of analysts and researchers in macroeconomic growth and applied finance studies.²⁹ In what follows, impulse response functions and structural break analysis model how "shocks" in the political economy, such as the CCA voluntary agreement, impact aggregate arsenic use.

Impulse Response Functions

While rarely used in policy evaluation studies, impulse response functions are standard analytical tools in macroeconomics policy analysis.³⁰ Given the availability of the unique time series data from the USGS, impulse response functions (IRFs) are graphed to answer the question, "How do shocks regarding government and industry actions impact arsenic use over time?"

The IRFs are plotted with the aggregate arsenic use data rather with the disaggregated arsenic use data by industry sector because this study is concerned with how CCA voluntary

²⁹For structural break examples, see Perron (1989), Ben-David and Papell (1998), Papell et al. (2000), Hansen (2001), Pastor and Stambaugh (2001), and Granger and Hyung (2004). Impulse response function examples include Bernanke and Binder (1992), Bernanke et al. (1997), Baum et al. (2001), and Love and Zicchino (2006).

³⁰For example, impulse response functions are employed for understanding the response of the national unemployment rate to changes in the federal funds rate, which is the interest rate that the Federal Reserve Bank charges to commercial banks for overnight loans (see e.g., Bernanke & Blinder, 1992)

agreement has impacted *total* arsenic use in the U.S. rather than how CCA voluntary agreement has impacted any one specific industry's arsenic use.

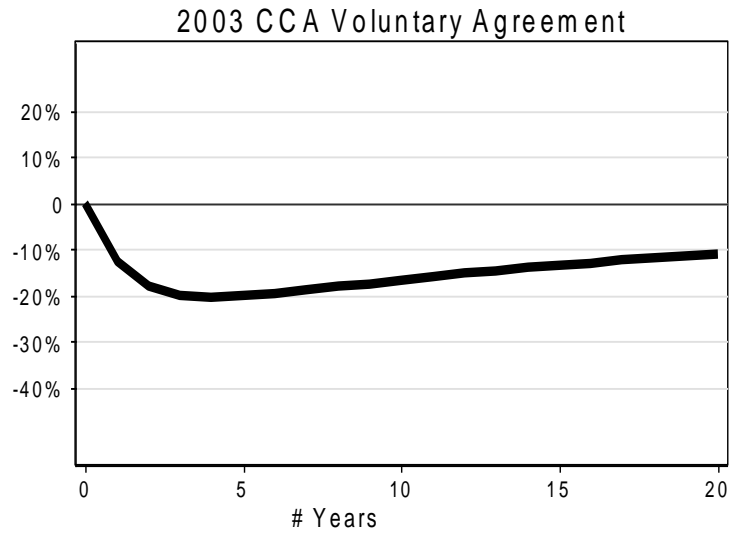
Moreover, by construction, the IRFs that are plotted will not match the regression results quantitatively. This is because a different model, namely a vector autoregressive (VAR) system, which models each variable separately to capture their linear interdependencies through time, is employed (Hamilton, 1994). Rather than analyzing how one variable (the CCA voluntary agreement, for example) affects arsenic use (which is what the estimated coefficients of the regression analysis give us), IRFs plot how unexpected changes that directly affect one variable affect arsenic use. Specifically, what is being analyzed is how the shocks coming from the error term related to the CCA voluntary agreement change arsenic use through time, as effects can be cumulated over time. The expectation is that if the IRFs are qualitatively similar to the regression results then the regression results are corroborated.

The following four figures (Figures 4-7) plot the IRF for the CCA voluntary agreement, the 1993 voluntary ban on arsenic acid, the 1986 TRI, and the 1976 TSCA on log arsenic use, respectively. The x-axis shows the passage of time in years up to 20 years since the enactment of the voluntary ban or government regulation. The y-axis represents percent changes. 0 is the reference point—this represents the starting point—the original time path of log arsenic use prior to the policy “shock”.

In Figure 3, a policy “shock” related the CCA voluntary agreement has a negative impact on log arsenic use. The effect becomes statistically significant right away. About five years after the pressure-treated wood industry's voluntary cancellation of CCA in residential uses, there is expected to be about a 20 percent decrease in arsenic use, holding everything else constant. Arsenic use is not projected to take an upward turn until at least about 10 years later,

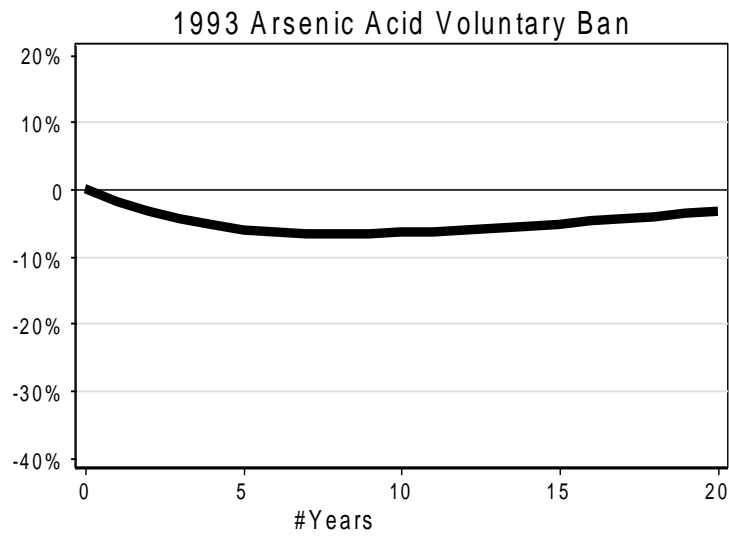
holding everything else constant. Importantly, arsenic use is projected to never return to its original time path.

Figure 3
Impulse Response Function



Impulse: 2003 CCA Voluntary Agreement; Response: Ln(arsenic)

Figure 4
Impulse Response Function

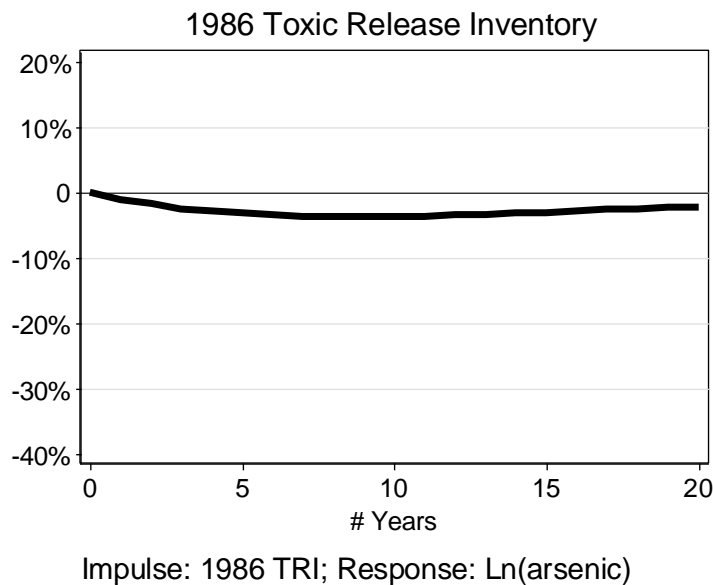


Impulse: 1993 Arsenic Acid Voluntary Ban; Response: Ln(arsenic)

In Figure 4, the 1993 voluntary ban on arsenic acid in the agriculture sector, also an industry driven effort is shown here to have some effect in reducing arsenic use (although not as large of an impact as the CCA voluntary agreement). The effect of the arsenic acid ban plateaus to about negative four percent between 5 to 10 years. 20 years later, arsenic use is projected to be about below its original time path.

A policy “shock” with respect to the 1986 TRI also appears to exert some but minimal impact on arsenic use, which like the 1993 voluntary ban on arsenic acid, will likely equilibrate to be just below its original time path twenty years later (see Figure 5).

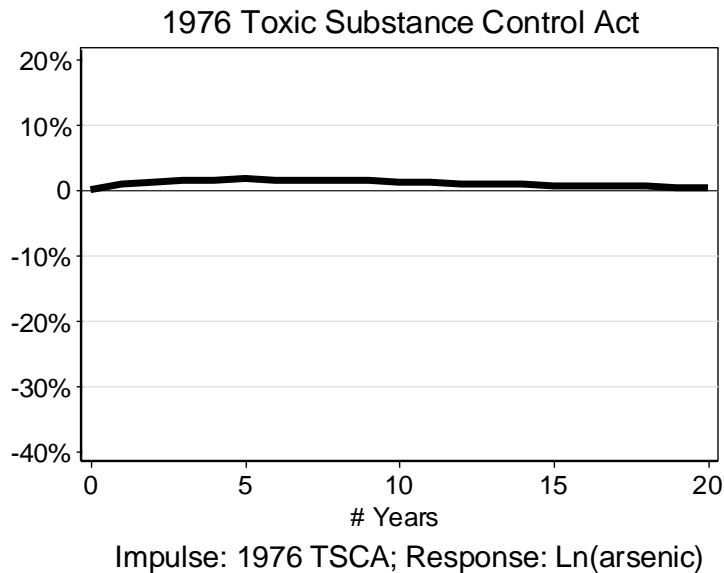
Figure 5
Impulse Response Function



Finally, Figure 6 plots the impact of an error shock related to the 1976 TSCA on arsenic use. Unlike the TRI, a shock associated with the 1976 TSCA induces a very minimal if any increase at all in arsenic use in the first few years following the policy shock. Essentially, the 1976 TSCA introduces no perturbation to the arsenic use time series. This result is not particularly surprising because as mentioned earlier while the TSCA regulates arsenic in the

glass and electronics industries, the TSCA does not regulate CCA and arsenic acid, which represent the first and second largest uses of arsenic, respectively.

Figure 6
Impulse Response Function



The IRFs on balance corroborate with the regression results in the previous section. The important take-away in these IRFs is that federal regulations on balance appear to exert minimal impact on arsenic use relative to the CCA voluntary agreement in the long run horizon. That being said, the TRI has quantifiable negative impact on arsenic use in initial years and restrains arsenic use slightly below its original time path in later years, holding all else constant. An industry voluntary ban in the agriculture sector also has had an effect on arsenic use, according to the IRFs, but to a lesser degree than the CCA voluntary agreement.

Structural Break Analysis

In another sensitivity analysis, I employ Bai and Perron's (1998, 2003) endogenous structural breaks estimation technique to verify whether the exogenously determined structural breaks, i.e., test to see if the regulation and voluntary ban indicator variables in the regression analysis do in fact correspond with the endogenous or actual change points in the data. In other

words, do the regression results match up with what the data are telling us? Like the IRFs, structural break analysis is a mainstay technique in macroeconomic and applied finance research but seldom used in public policy.³¹

The structural break analysis is concerned with assessing deviations from stability in the classical linear regression model, where changes concern divergence from the intercept or the mean of the data.³² Details about the Bai and Perron model are provided in the Appendix.

Table 3 presents the estimated breakdates along with their respective 95 percent confidence intervals. The changepoint test indicates two breakpoints in aggregate arsenic use between 1960 and 2009, which correspond to the following dates: 1985 and 2003.

Table 3

Bai and Perron's Simultaneous Estimation of Multiple Breakpoints			
Series	Sample Period	Break Estimates**	95% CI
<i>lnarsenic</i>	1900-2008	1985	(1984, 1989)
<i>lnarsenic</i>	1900-2008	2003	(2002, 2004)

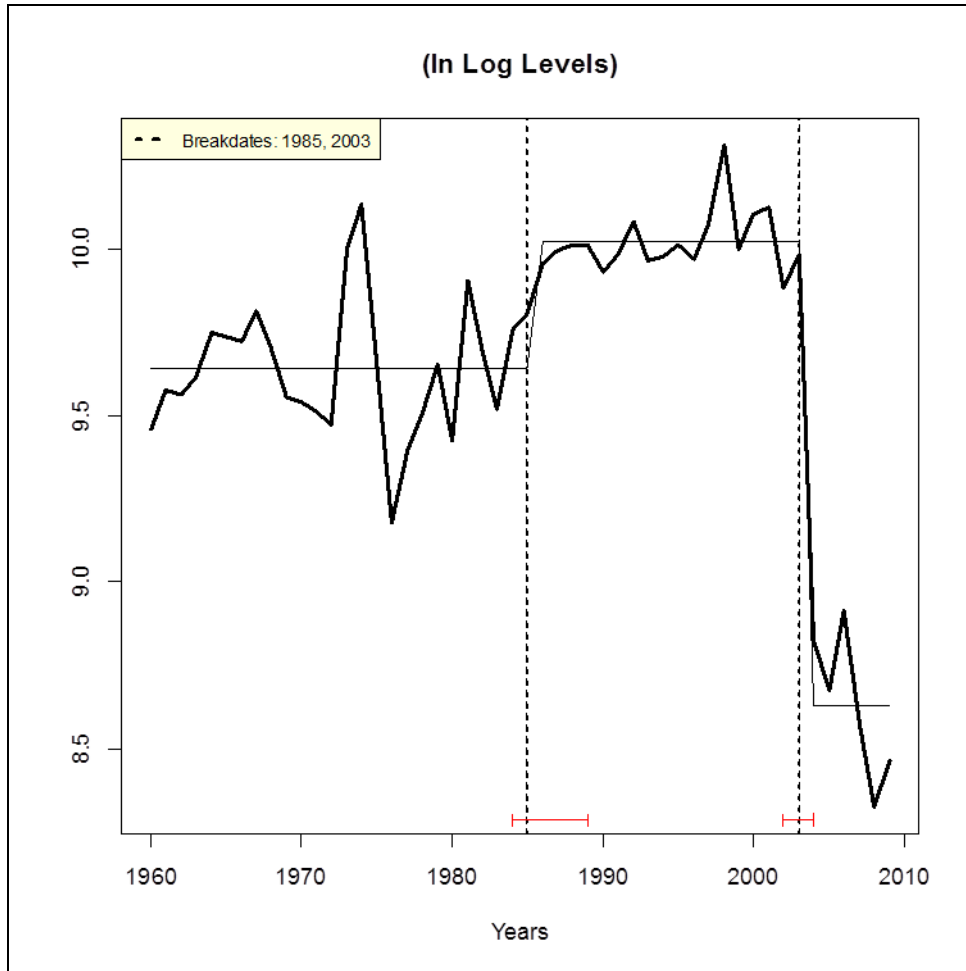
Figure 7 depicts graphically the two estimated mean shifts and their corresponding confidence intervals. Estimated mean shifts are designated by the solid line segment while the corresponding breakdates are shown by the dotted vertical lines in the figure. The 2003 breakpoint appears to be precisely estimated since the 95 percent confidence intervals cover only

³¹ An exception in policy evaluation studies is Fomby and Lin (2006), which employ structural break analysis to estimate the effect of President Reagan's devolutionary policies (i.e., Environmental Federalism) on nitrogen oxides (NOX), sulfur dioxides (SO2) and volatile organic compounds (VOCs). While Fomby and Lin (2006) employ Bai's (1997a, 1997b) single break model, this study utilizes Bai and Perron's (1998, 2003) multiple breaks model.

³² The structural break analysis can be generalized to allow for changes in the trend of the data or changes in both the mean and the trend. See Hsueh (2012a) for structural break analyses that identify changepoints involving mean and trend changes in arsenic and twelve other toxic chemical use time series.

one year before and after the identified structural break. By contrast, the 1985 breakpoint is less certain with a 95 confidence region spanning the periods between 1984 and 1989.

Figure 7
Multiple Structural Breaks
Arsenic Use



Source: USGS.

How well do the results from the regression analysis match the endogenously determined breakpoints? The structural break analysis summarizes the bottom-line of the regression results, which is that major developments in arsenic-using sectors appear to have had more impact than government regulations on aggregate arsenic use. There are two structural breaks in the data after 1960. The estimated mean shifts (“shift up” for the first break and “shift down” for the

second break) match two major events in the arsenic-using sectors: the 1987 discovery of GaAs in semiconductor manufacturing and the 2003 pressure-treated wood industry's voluntary agreement to ban CCA in residential uses. These results are consistent with the impulse response functions presented above.

Both sensitivity analyses corroborate that the CCA voluntary agreement, a nongovernment driven beyond-compliance pollution abatement effort, was a major driver of reductions in arsenic use in the U.S. A natural question arises: how did the bilateral voluntary agreement negotiated between the EPA and the pressure-treated wood industry come about? More specifically, what institutional, political, and economic conditions led to the landmark industry voluntary ban? Moreover, what can we learn from the compliance-related decision-making processes about the factors under which the CCA voluntary agreement and bilateral agreements more generally are effective for reducing pollution? The next section answers these questions by identifying key factors in the compliance-related decision-making processes that led to the CCA voluntary agreement.

4. TRACING THE POLICY PROCESS THAT LED TO THE CCA VOLUNTARY AGREEMENT

While the quantitative analysis evaluates the impact of the CCA voluntary agreement on arsenic use through the passage of time (1975-2009), the following analysis, based on systematic surveys of key stakeholders, is a microscopic look at the compliance-related decision-making processes that led to the pressure-treated wood industry's voluntary cancellation of CCA in residential uses between 2001 and 2004.

The systematic surveys were based on in-depth, open-ended phone interviews with key stakeholders from government, industry, and NGOs.³³ Approximately 20 key stakeholders were identified based on preliminary research into government documents and mass media outlets. Informants were contacted via email with an initial letter of introduction on official letterhead. Approximately 90 percent or 15 of the informants contacted agreed to be interviewed. The bulk of the interviews took place in the Spring and Summer of 2011; all interviews were conducted over the phone with follow-up dialogues via email or phone. The Appendix contains a table detailing this paper's informants by organization, as well as a copy of the pre-tested interview protocol.

This study adopts the lens of an augmented version of the Kingdon's (1984) multiple streams framework to explain the entire process of the CCA voluntary agreement formation, namely how the CCA voluntary agreement became part of the political agenda and adopted as a viable policy solution.³⁴ In the augmented multiple streams model, there are four distinct, but complementary, processes or streams—the problem stream, the policy stream, the politics stream, and the economy stream—which move independently through the policy system (Hsueh, 2012b).³⁵

³³ The qualitative research design and methods had undergone a Human Subjects Review at the University of Washington and had been granted an “Administrative Approval of Certification of Exemption #39396” under 45 CFR 46.101 (b) (2).

³⁴ While Kingdon (1984) used the multiple streams framework to explain agenda-setting in the U.S., subsequent work has used it to elucidate the entire process of policy formation. For example, Zahariadis (2003) applies the multiple streams model to explaining parliamentary politics in Britain and France (see also Birkland, 1997; Zahariadis & Allen, 1995; Zahariadis, 1996).

³⁵ In Hsueh (2012)'s comparative study of two successful cases of bilateral voluntary agreements in toxic chemicals, the author adds an economy stream to the multiple streams framework. Hsueh argues that whenever policymaking concerns aspects of industrial development, including environmental impacts of economic activities, economic factors (e.g., markets, economic actors and institutions) must be examined as part of the compliance-related decision-making processes.

Each stream has its own set of dynamics and rules. In the problem stream, issues and problems are identified and explicitly formulated, and institutional venues for promoting these ideas are chosen (Baumgartner & Jones, 1993; S. Pralle, 2006, 2010). In the policy stream, policy alternatives are proposed and debated amongst regulators, corporate actors, scientists, and NGO activists. Politics shape the receptivity of a given policy on the political agenda. Who is in political leadership often defines the national mood regarding the proposed policy (Zahariadis, 2007). Inciting or deflecting media attention creates favorable or unfavorable politics for a certain policy (Baron, 2005; Dardis, Baumgartner, Boydston, De Boef, & Shen, 2008). In the economy stream, market competition, viable substitutes, and corporate social responsibility accentuate the costs and benefits of policy choices (Hsueh, 2012b). Finally, at critical points in time, the various streams are coupled into a single package by policy actors. These windows of opportunities enhance the chances that a specific policy will be adopted by policymakers (Kingdon, 1984; Zahariadis, 2007).

4.1 Window of Opportunity and the Problem Stream

As a restricted pesticide, CCA, by law must be renewed every 15 years for use in commercial applications. In 1998, the EPA began the agency's routine pesticide reregistration process for CCA.³⁶ A central component of the reregistration process for every pesticide, including CCA, is a formal risk assessment, which takes into account new information about potential risks since the previous renewal. Investigating CCA's potential harm to children was not initially on the agenda of the regulators.

³⁶ This is part of the EPA's pesticide reregistration program, which was instituted by the 1988 amendments to the FIFRA. Source: http://www.epa.gov/oppsrrd1/reregistration/reregistration_facts.htm (Retrieved August 13, 2012)

Around this time, a network of environmental groups devoted to promoting sustainable building materials (henceforth, the green buildings network) decided to use this window of opportunity to present new facts and urge further research on CCA's adverse human and environment impact while in-use and in the waste stream.³⁷ Toward this regard, the green buildings network's strategy was to frame CCA as a consumer product safety hazard involving children. The group's plan was to wage a grassroots campaign (henceforth the Playground Campaign) to shift market demand in the construction industry away from CCA-treated wood.

The Consumer Product Safety Commission (CPSC) was selected as an institutional venue for petitioning the group's grievances. The reason, according to the coordinator of the Playground Campaign was that "CPSC is concerned with ensuring product safety with a focus on vulnerable populations, while the EPA took on a more technocratic view of CCA."

"The EPA regarded CCA as an 'a necessary evil', while the CPSC has more stringent rules for products concerning children. For instance, a 1 in a million risk of cancer from a product intended for children was unacceptable to the CPSC but not necessarily to the EPA."³⁸

By May 2001, the green buildings network amassed more than 50 petition letters addressed to the CPSC.³⁹ Signatures included the directors of local and national NGOs that focused on health and safety and the environment, and the owners of nonprofit businesses that

³⁷ The green buildings network classified CCA as a "worse in class" building material because the group believed CCA "has adverse environment and health impacts, and there are commercially available alternatives that are superior from an environmental-health perspective and comparable in price and performance." Source:

<http://www.healthybuilding.net/about/index.html> (Retrieved March 19, 2012)

³⁸ Interview conducted with the coordinator of the Playground Campaign on July 20, 2011.

³⁹ The petition was titled, "Petition to the United States Consumer Product Safety Commission to Ban Arsenic Treated Wood in Playground Equipment and Review the Safety of Arsenic Treated Wood for General Use." Source: <http://www.cpsc.gov/library/foia/foia01/petition/arsenic.pdf> (Retrieved March 19, 2012)

provisioned sustainable planning and design services.⁴⁰ The petition letters repeatedly cited studies that showed arsenic poisoning amongst children who played on playground equipment made from CCA-treated wood.

While the green buildings network focused much of its campaign on the CPSC, the group also engaged in a cross-country door-to-door letter writing campaign targeting the EPA. The letter drive highlighted the CCA-contaminated soil underneath playgrounds across the U.S. with a focus on Florida, where research had shown that CCA-treated wood had leached into drinking water aquifers.⁴¹ The green buildings network wagered that at least one of the federal agencies will respond to the group's protests.

4.2 Policy Stream: CPSC and the EPA's Responses, Support from Concerned Scientists

The green buildings network's petition to the CPSC elevated the public scrutiny for CCA even though regulatory authority over the industrial use of CCA resided with the EPA. In response to the Playground Campaign's petition, the CPSC commenced a study and updated an earlier report regarding the harmful health effects of children's exposure to CCA (CPSC, 2003). The agency also held regulatory hearings and stakeholder meetings.

In the wake of external pressures, the EPA convened a scientific advisory panel (SAP) which invited outside experts to assist with the agency's risk assessment of children's exposure to CCA. Experts who specialized in the behavior of children at play, on toxic exposure, and on the toxicology of arsenic compounds were invited to participate in the SAP. Third-party

⁴⁰ Notable national NGOs and nonprofit businesses included Greenpeace, HealthLink, Environmental Working Group, and the Healthy Buildings Network. Local NGOs ranged from Green Action, which is based in San Francisco, CA to Watchdogs for an Environmentally Safe Town, which is based in Westminster, MA.

⁴¹ Source: <http://www.ccaresearch.org/publications.htm> (Retrieved March 19, 2012)

stakeholders, such as the green buildings network, chemical manufacturers, as well as wood treaters were invited for public commenting.

There were several scientists on the SAP who were particularly supportive of further research regarding the dangers of CCA. These scientists contributed evidence on the environmental and health impacts of CCA-treated wood and proposed evidence-driven solutions. For example, one research team developed an automated technology that distinguished between CCA and non-CCA treated wood at recycling facilities.⁴²

Another key expert in the community of concerned scientists was a former EPA staff scientist and grassroots activist. As an independent consultant, he was hired by one of the top three CCA manufacturers to conduct an independent assessment of ammonium copper quaternary (ACQ), which at that time was a little known arsenic-free wood preservative marketed by the corporation, and to communicate his findings to the public. The expert's analysis was a key piece of information used by the green buildings network to assert that there was at least one commercially available alternative that was superior to CCA from an environmental-health perspective and was comparable in performance and price.

4.3 Politics Stream: Sympathetic Politicians and Explosive Media Attention, Fragmented Industry

The 1990s were an era of much receptivity toward and experimentation with alternative policy approaches to environmental protection, including bilateral voluntary agreements whereby businesses agree to fine-tune and/or alter their environmental management systems for pollution abatement without the force of law.⁴³ The CCA controversy coincided with the start of President

⁴² Source: <http://www.ccaresearch.org/publications.htm> (Retrieved March 19, 2012)

⁴³ The EPA alone sponsored over 45 voluntary programs during the span of the Clinton and Bush presidencies. Source: <http://www.epa.gov/partners/> (Retrieved August 15, 2012)

George W. Bush's first term in the executive office. By and large, President Bush continued the government sponsored voluntary programs that were created under the Clinton Administration and initiated more voluntary programs.⁴⁴

By mid-2001, the Playground Campaign had become a political "hot button" issue. The CPSC Chairperson at the time of the CCA investigation was Ann Brown, an appointee of President Clinton. Brown was widely known for her progressive politics and special interest in children issues. A former CPSC senior administrator said, "CPSC was more interested in looking at issue like the CCA ban under Ann Brown. In many ways Ann Brown turned CPSC into a children's agency. The CCA investigation was from Brown's personal direction."⁴⁵

The favorable political climate at the CPSC ensured the green buildings network's success in reframing what was initially a technocratic concern regarding CCA's pesticide reregistration into a consumer product safety issue that involved children "who can't think for themselves, whom the adults want to protect."⁴⁶

"Walsh and his group were brilliant. When chemicals can be connected to children exposure, it is much easier to garner public and political support. CPSC is a microcosm for this kind of activism by environmental and consumer groups," according to the former CPSC senior administrator.⁴⁷

Florida senator Bill Nelson also became involved in the CCA case. Nelson wrote a letter to Christine Whitman, the former EPA Director, expressing his concern that CCA-treated

⁴⁴ For example, many of the government's actions on global climate change during the Bush Administration involved inviting the private sector to develop long-term, comprehensive climate change strategies without formal mandates. Source: <http://usinfo.org/enus/life/science/20050518-4.html> (Retrieved June 29, 2012)

⁴⁵ Interview conducted with a former CPSC senior administrator who was at the CPSC during CPSC's CCA investigation. Interview took place on August 2, 2011.

⁴⁶ Ibid.

⁴⁷ Ibid.

playground equipment was reportedly leaching into Florida's soil and acquirers, and about woodworkers who had been poisoned by arsenic while handling the CCA-treated wood. While the green buildings network was never in touch with Nelson directly, the senator's involvement contributed to a favorable political environment.

Once the CPSC agreed to open up investigation, the Playground Campaign escalated. An explosion of media and public attention ensued: the activities of the Playground Campaign, the investigations by the CPSC and the EPA, and Senator Nelson's statements were all reported by the media. An EPA staff described it this way: "[It] felt like everything was happening at the same time. There was news every day about CCA [in the media]."⁴⁸

By contrast, the pressure-treated wood industry was ill prepared to challenge the Playground Campaign because the pressure-treated wood businesses were not united in their opposition to the green buildings network's grassroots efforts. The fact that the chemical manufacturers were at odds with each other gave the green buildings network ample opportunities to plead their case at the CPSC, at the EPA, and to the public via the media. The Playground Campaign became a movement based on an emotive narrative about whether "you were for the children or not for the children."⁴⁹

4.4 Economy Stream: Market Competition, Arsenic-free Substitute, Regulatory Pre-emption

The pressure-treated wood industry faced a highly competitive business climate. There were three major chemical manufacturers and hundreds of local and regional wood treaters. The three chemical manufacturers acted like oligopolists: the corporations competed fiercely to

⁴⁸ Interview conducted with a staff scientist at the EPA, Office of Pesticide Program on August 1, 2011.

⁴⁹ Ibid.

protect their brands. The local and regional wood treaters operated in distinct geographic markets; some markets were more competitive than others.

Around 1999, one of the three CCA manufacturers saw a market opportunity. While the corporation had offered ACQ, the only arsenic-free preservative on the market, alongside CCA since 1996, it had remained a niche product with few customers.⁵⁰ This changed under a new leadership of marketing who had hired a public relations firm to help the corporation promote ACQ. Under the new marketing vice president, the corporation successfully promoted ACQ and expanded the company's business into "environmentally friendly" wood preservatives.⁵¹

The corporation hired a former EPA scientist-turned-consultant to conduct an independent assessment of ACQ and to communicate his findings with the environmental community. Around the same time, the green buildings network was researching about potential alternatives to CCA. The independent third-party consultant certified that ACQ was "equal in performance and environmentally superior to CCA."⁵²

The other two chemical manufacturers as well as a majority of local and regional wood treaters were publicly opposed to the Playground Campaign. These businesses attended regulatory hearings and testified why they believed the EPA should grant pesticide reregistration for CCA to the pressure-treated wood industry. The corporation that marketed ACQ officially stood on the sidelines but informally assisted and shared information with the Playground Campaign about ACQ.⁵³

⁵⁰ The number of arsenic-free preservatives has since expanded to include Copper Azole, Borate, Cyproconazole, and Propiconazole, among others.

⁵¹ Source: <http://www.linkedin.com/pub/david-fowlie/17/9b1/52b> (Retrieved March 19, 2012)

⁵² Interview conducted with the independent consultant/former EPA scientist who conducted an independent assessment of ACQ on July 22, 2011.

⁵³ Interview conducted with the coordinator of the Playground Campaign on July 20, 2011.

In addition to a fragmented industry, a reputable family-owned regional wood treater based in Wisconsin made a “game changing” decision to switch from CCA to using ACQ despite ACQ’s lack of wood preserving credibility outside of laboratory testing and ACQ’s higher costs relative to CCA.⁵⁴ Such action by the largest treater in terms of market shares in the Midwest region was taken notice and the ACQ began to earn “street credit.”

The president of the maverick wood treater said that his company decided to switch to ACQ even though ACQ was initially more expensive [than CCA] because “[we wanted to] create a distance between us and the regulation for handling and using a hazardous substance in case CCA ever get regulated as a hazardous waste. Second, there were minimal cost savings that offset some of the cost increases in ACQ over CCA...Finally, we heard at tradeshow from customers that they had gotten sick from CCA. For example, we heard from customers that after building a deck they had suffered arsenic poisoning.”⁵⁵

The maverick wood treater quickly became the Playground Campaign’s poster child. The NGO network advertised the maverick “green” business model as an example of how an arsenic-free chemical could be used to preserve wood without profit losses to industry. All of this was readily reported by the national media. The Playground Campaign gained ample grounds on the regulatory as well as industry fronts.

4.5 CCA Agreement Finalized

By early 2002, about midway through the EPA’s SAP meetings, the American Chemical Council (ACC), the industry-wide trade association that represented the chemical manufacturers and wood treaters, submitted an official request to the EPA on behalf of the pressure-treated

⁵⁴ In an interview conducted on August 1, 2011, the president of the maverick company said that his company did not receive discounts on ACQ from the chemical manufacturer before or after his company’s switch to CCA.

⁵⁵ Ibid.

wood industry stating that the industry would not be pursuing registration renewal for CCA in residential applications.⁵⁶ A negotiated deadline of December 31, 2003 was set for the complete phase-out of CCA in residential uses.

According to a key SAP scientist, “At least one of the two other manufacturers must have switched sides. This was when a deal was struck and the manufacturers had negotiated some kind of licensing agreement [amongst themselves] for ACQ”⁵⁷

An EPA regulator close to the negotiations summarized the bilateral voluntary agreement this way: “...the proposed CCA ban [in residential uses]...calmed things down.”⁵⁸

4.6 Summary and Discussion

What do the above compliance-related decision-making processes of the CCA voluntary agreement formation suggest about the key factors and conditions under which bilateral voluntary agreements are effective? I posit that the specific roles played by the major stakeholders—namely, environmental NGO activists, regulators, and corporate actors—and the political conditions facing them contributed to the ultimate success of the CCA voluntary agreement.

NGO Activists: Agenda-setting, Coalition Building, and Public Naming and Shaming

The green buildings network successfully coupled the problem, policy, politics, and economy streams by playing several strategic roles: issue definition and agenda setting, coalition building, and public naming and shaming. First, the green buildings network reframed a

⁵⁶ The ACC reportedly brought together the fragmented chemical manufacturers under the auspices of the ACC’s CCA Work Group (now called the “Biocides Panel”) and reached an arrangement behind closed doors.

⁵⁷ Interview conducted a key SAP scientist who is a professor at the University of Florida on August 12, 2011.

⁵⁸ Interview conducted with a section chief at the EPA, Office of Pesticide Program, on August 1, 2011.

previously technocratic pesticide reregistration into a product safety concern that involved children, promoted the Playground Campaign in several institutional venues, and participated in multiple stakeholder meetings sponsored by the government. The green buildings network's framing of CCA as an environmental hazard concerning children is part of a well-tried strategy of environmental activists and politicians that has had substantial impact on the political agenda and policy outputs in the U.S., particularly in the area of pesticide policy (Boothe & Harrison, 2009; Rosenberg, 1991; Schneider & Ingram, 1993).⁵⁹ Schneider and Ingram (1993) posit that focusing on children and constructing "causal stories" about them is a way to mobilize large segments of the population and shift public perceptions because children are positively constructed target populations.

Furthermore, Boothe and Harrison (2009) suggest that activists and politicians in the U.S. are able to engage in issue definition and reframing because of the unique political institutions and opportunity structures in the U.S. The U.S. government is based on the separation of power, which allows for venue shopping in a way that most other systems of governance, such as a parliamentary system, do not permit (Pralle, 2006b, 2010). This fragmentation of authority facilitates bringing new issues to the political agenda (Boothe & Harrison, 2009; Rosenberg, 1991; Schneider & Ingram, 1993).

⁵⁹ A reviewer pointed out that there are parallels between the CCA voluntary agreement and the 1989 controversy over alar, a pesticide that was sprayed on apples to promote color development and increase storage life. In both cases, there was a coordinated environmental activist campaign that centered on the purported risks of the contested pesticide on children, which incited much media and political attention (Moore, 1989; Rosenberg, 1991). In both cases, industry was compelled to voluntarily withdraw the highly contested product from the market. One major difference between the two cases, however, was that a regulatory phase-out for alar had already been set for the following year by the EPA. By contrast, on the eve of the pressure-treated wood industry's voluntary cancellation of CCA, the EPA had not taken any regulatory action against CCA.

Second, the NGO network attracted and built a coalition of allies in government and in the private sector to champion their cause. The green buildings network succeeded in harnessing sympathetic politics in Washington and the support of an active and vocal community of scientists, as well as in promoting the viability of an arsenic-free preservative with the help of an industry maverick. Potoski and Prakash (2011) posit that because regulatory science is politicized in the U.S. the litigious regulatory process of the U.S. gives environmental groups more opportunities to exert external pressures for policy change than in other systems of governance.

Finally, the green buildings network engaged in public naming and shaming by appealing to the media. The activities of the Playground Campaign, the investigations by the CPSC and the EPA, and Senator Nelson's statements were all reported amply by the media. The explosion of media attention became a form of monitoring by external stakeholders, which according to Buthe (2010a), "...as demanders of private regulation, they have agenda-setting power, but also because their monitoring creates incentives for compliance by the targets of private regulation (Buthe, 2010a, p. 21)." When an issue becomes sufficiently salient, threats posed by NGO activists become especially credible. Under such a scenario, firms much undergo costly actions to deflect external pressures from activists (Baron & Diermeier, 2007; Baron, 2001, 2003).

Government: Steering and Commanding

In the CCA voluntary agreement, the government played an important facilitating role, particularly in casting a shadow of public law with the threat of future regulation. The "steering" and "command" roles as described by Wood (2002) for explaining the roles of government in private regulation are particularly apt for depicting how the EPA interacted with the pressure-treated wood industry in the wake of the Playground Campaign. "Steering" encompasses

activities such as providing technical expertise, supporting research, disseminating information, and serving as a regulatory “backstop”, among other activities (Meidinger, 2001; Wood, 2002). Wood (2002) defines the “command” role to entail the issuing of legally binding requirements for adherence to voluntary initiatives by the government through court orders or legislation.

While the EPA regulators did not outright request the manufacturers of CCA to cancel their reregistration of CCA, the government nevertheless played an important “steering” role in several key ways. First, the EPA’s mandatory pesticide reregistration process provided a regulatory opening for the green buildings network to contest the pressure-treated wood industry’s use of CCA. Furthermore, existing environmental law granted the EPA authority to commission technical expertise and disseminate new information about the potential risks to CCA. Toward this regard, the EPA convened a Scientific Advisory Panel, which invited external experts to conduct and share research about the adverse effect of children’s exposure to CCA.

These government activities were by no means coercive actions against the pressure-treated wood industry, but they signaled to the industry that the regulators were seriously concerned about the potential adverse impact of CCA on children’s welfare and thus provided a credible regulatory threat and served as a regulatory “backstop”. Buthe (2010a) writes that private regulators often depend upon public authority as the “enabler or enforcer (Buthe, 2010a, p. 22)”. Along the same logic, Potoski and Prakash (2011) suggest that while the government is never the sole decision maker, the “...state is directly or indirectly involved, either as facilitator or financial provider.”

The EPA also played a “command” role with respect to the CCA voluntary agreement. Once the pressure-treated wood industry voluntarily cancelled their reregistration of CCA in

residential uses the CCA voluntary agreement became legally binding. Any divergence from the bilateral voluntary agreement means that the pressure-treated wood industry would be sanctioned by law and potentially subject to legal fines. This unique feature of the CCA voluntary agreement, as well as most other bilateral voluntary agreements, sets it apart from voluntary environmental programs that lack provisions for sanctioning noncompliance.

Industry: A Poison-free Substitute, Market Competitive Pressures, Regulatory Preemption

Three factors contributed to explaining the pressure-treated wood's beyond-compliance actions in the wake of the media maelstrom incited by the green buildings network.⁶⁰ First, the existence and viability of a poison-free substitute chemical, in part demonstrated by the switch-over to ACQ by a maverick regional wood treater, made phasing out CCA a less costly action than it otherwise would have been. With a viable substitute, CCA was considered to be dispensable by the pressure-treated wood industry.

Second, the highly competitive market and the oligopolistic structure of the chemical manufacturers meant that it was in the self-interest of the three major CCA manufacturers to negotiate licensing agreements amongst themselves to profit from the production and marketing of ACQ. By doing so, the CCA manufacturers in effect created barriers to entry for potential producers and secured future profits to be split amongst themselves for the duration of the licensing agreements. This behavior is consistent with Baron's (2001) and Baron and Diermeier's (2007) predictions that in order to minimize the high cost of deflecting external

⁶⁰ While the CCA voluntary agreement was not a typical pesticide recall (e.g., there were no provisions in the negotiated agreement regarding the buy-back of existing stock) or a product recall, the pressure-treated wood industry's motivation for voluntarily cancelling CCA's reregistration appears to be consistent with the motivation of other firms and industries that have voluntarily removed products off the market, such as public relation concerns, brand protection, and regulatory preemption (Davidson & Worrell, 1992; Dawar, 1998; Gibson, 1995; Govindaraj, Jaggi, & Lin, 2004).

pressures from activists that could affect all firms in the industry, the firms of an industry have an incentive to engage in collective action to avoid negative industry-wide spillover effects.

Third, while there was no imminent regulatory pressure from the EPA, future regulation was perceived to be on way. Mounting evidence on CCA's poisonous effects on children were reported by the media and documented by the SAP. There was also the perceived regulatory threat from the CPSC, although at the time of the CCA voluntary agreement CPSC had not taken any regulatory action for a product recall. The CCA manufacturers were keen to pre-empt legal action in order to avoid the threat of increased costs, decreased demand, and competitive disadvantage from leviathan rules. Whether the threat of imminent government action was real or perceived, research has shown that private regulations, including voluntary environmental programs are often developed and adopted in the shadow of public law (Buthe, 2010a; Cashore et al., 2011; Mayer & Gereffi, 2010; Potoski & Prakash, 2005).

The effectiveness of the CCA voluntary agreement was dependent on the roles of the major stakeholders and the political economic conditions facing them. The NGO activists engaged in a well tried strategy of framing CCA as an environmental hazard concerning children and sought multiple institutional venues to petition their grievances; built coalitions inside and outside of government; and incited an explosion of media attention via public naming and shaming. The government played important facilitating roles of "steering" and "commanding", particularly in casting a shadow of public law with the credible threat of future regulation. Regulators steered the CCA voluntary agreement by commissioning external technical expertise and disseminating new information about the potential risks to CCA. Finally, for the pressure-treated wood industry a poison-free substitute, market competitive pressures, and the threat of

future regulation compelled the industry to enter into a bilateral voluntary agreement to ban CCA in residential uses.

5. CONCLUSION

Arsenic is a poisonous chemical that ranks number one on the EPA's priority list of hazardous substances. As such, it was a significant moment for U.S. toxic chemical policy when the pressure-treated wood industry, the largest industrial user of arsenic, voluntarily phased out copper chromium arsenate (CCA), an arsenic compound, in residential uses by the end of 2003. The CCA voluntary agreement was lauded a success by all parties involved.

While the toxic chemical policy area and the environmental policy area more generally have witnessed a proliferation of voluntary environmental programs, their efficacy remains disputed. This paper answers two retrospective questions about voluntary program efficacy: 1) By how much did the CCA voluntary agreement reduce arsenic use in the U.S.? 2) What institutional, political, and economic conditions led to the voluntary phase-out of CCA in residential uses by the pressure-treated wood industry? This paper employs both quantitative and systematic qualitative methods to answer these questions.

This paper finds that the CCA voluntary agreement led to a substantial reduction in arsenic use: aggregate arsenic use has been lowered to levels not seen since the 1920s. Empirical results from the quantitative analyses suggest that the private sector has been an important driver of arsenic use. That being said, there is evidence to suggest that the 1986 Toxic Release Inventory, a government-driven mandatory information disclosure rule, was effective in decreasing arsenic use. Furthermore, the estimated models show that prioritizing environmental protection through financial resources, as measured by Congress-allocated dollars to the EPA, has reaped environmental benefits in the form of reduced arsenic use. The enhancement of EPA

activities—which is often made possible by larger funding—such as greater rule enforcement and engagement with stakeholders, has had both direct and indirect impact on environmental protection.

Systematic surveys of major stakeholders reveal that an environmental activist campaign succeeded in pressuring the pressure-treated wood industry to acquiesce to a voluntary phase-out of CCA in residential uses. The green buildings network successfully coupled the problem, policy, politics, and economy streams by strategically reframing a pesticide reregistration issue into one concerning the toxic exposure of children to CCA on the playground, promoting the Playground Campaign in multiple institutional venues, building a coalition of supporters in and outside of government, and engaging in public naming and shaming. The government played important facilitating roles of “steering” and “commanding”, particularly in casting a shadow of public law with the credible threat of future regulation. In the wake of the media maelstrom, the pressure-treated industry’s negotiated act of voluntary compliance was a pragmatic and cost-effective way to mend the industry’s public image from further damage given the existence of a viable substitute, market competitive pressures, and the threat of future regulation.

My analyses suggest that the government’s role is broader, more collaborative, and more dynamic than conventionally accepted. The role of public agencies is not just to set and enforce standards, but to establish an information-rich context for private citizens, interest groups, and firms to solve environmental problems. This is in line with what Fung and O’Rourke (2000) term as “populist maximin regulation”: the government’s role is to set up a mechanism for information disclosure by firms such that maximum attention on minimum performers is reinforced by public pressures. In response to a dynamic range of public pressures, minimum

performers will be compelled without coercive force by government to adopt more effective environmental practices.

That being said, the stipulations of command-and-control regulations passed in the 1970s will continue to be important. This is particular true for built-in-rules for periodic risk assessments whereby new information is requested and taken into account for pesticide reregistration, as well as process-oriented rules that call for external reviews and stakeholder participation and public commenting. Finally, monitoring and sanctioning roles by the government continue to be important even as traditional regulations have made room for voluntary governance.

Which roles the government plays have implications for compliance and efficacy. The CCA voluntary agreement and bilateral voluntary agreements more generally combine *ex ante* interactions with industry and other stakeholders with *ex post* legal sanctions for noncompliance. This supports Buthe's (2010b) hypothesis that when governments explicitly delegate public authority to a private rule-maker, and when such delegation is accompanied by commitments to monitoring and enforcement by government agencies, this should result in higher levels of compliance.⁶¹ Outside of environmental policy but in a related policy realm, Richard Locke and his co-authors (R. Locke, Amengual, & Mangla, 2009; R. Locke, Qin, & Brause, 2007; e.g., R. Locke, Piore, & Kochan, 1995; R. Locke & Romis, 2010) have shown that voluntary labor standards that raise working conditions and engage firms in ongoing interactions regarding work/human resource management policies that are not adversarial but also include monitoring

⁶¹ The voluntary program literature, notably Potoski and Prakash (2009), suggest that effective programs have rule structures that mitigate two central collective action problems: attracting firms and other entities to participate in the program (recruitment challenge) and ensuring that participants adhere to program obligations (shirking challenge). Without rule structures that overcome the recruitment and shirking challenges, voluntary programs are not likely to be effective in achieving desirable environmental outcomes.

by a credible, disinterested party, such as the government or NGOs, are more effective in changing firm behavior than formalistic mandates.

This paper raises several issues for future research. First, an issue not yet fully addressed by the voluntary program literature is: how “voluntary” are voluntary environmental programs? There is a wide-ranging degree of “voluntariness” amongst the different types of voluntary environmental programs. This variation in “voluntariness” has implications for program efficacy. Past efficacy studies indicate that studies which have found voluntary programs to have “no effect” on reducing pollution have all been impact analyses focused on public voluntary programs or unilateral initiatives by industry.

By contrast, the few studies that have evaluated bilateral voluntary agreements have shown that these negotiated agreements—which give the government a greater role—generated at least modest if not substantial reductions in pollution (see the introduction for a brief literature review). These studies combined with the current study suggest that bilateral voluntary agreements are more likely than other types of voluntary programs to yield environmental outcomes desirable from a public policy perspective. Why this might be the case should be systematically investigated in future research.

One possible rationale could be that unilateral initiatives by industry and public voluntary programs are more focused on recruitment incentives and membership growth rather than actual environmental outcomes, thus leading to program obligations and compliance-related rules that lack real stringency. For example, Antweiler and Harrison (2007) find that the flexible terms of participation in the Canadian Voluntary Challenge and Registry (ARET), the option for participants to choose their own base years, the lack of transparency, and the absence of third-

party validation of participants' reports ensured that ARET gained industry co-sponsorship, but also ultimately contributed to the ineffectiveness of ARET.

Another example is the chemical industry's Responsible Care (RC) program. Multiple studies show that before RC was robustified in 2002 with rules for third-party verification and enforceable penalties, RC participants reduced their pollution at slower rates than non-participants (Gamper-Rabindran & Finger, 2012; King & Lenox, 2000). In fact, Gamper-Ranbindran and Finger (2012) find that on average plants owned by RC participating firms actually raised their toxicity-weighted pollution by 15.9 percent relative to statistically-equivalent plants owned by non-RC participating firms.⁶²

Second, this study answers the call by Prakash and Potoski (2012) in a recent symposium by the *Journal of Policy Analysis and Management* to identify aggregate country-level effects which could facilitate cross-country comparisons, rather than focus on facility-level analysis. This new direction toward the analysis of time series of aggregate effects merits experimentation with previously untried empirical methodologies in public policy. Moreover, the reality of nonexperimental data in policy efficacy studies, including research on voluntary program efficacy warrants the triangulation between methods. This paper employs the Arrelano-Bond dynamic panel estimator, structural break analysis, and impulse response functions (which are widely used in applied macroeconomics and finance research but are seldom used in policy evaluation studies), as well as the systematic surveys of key stakeholders to independently verify and validate that the CCA voluntary agreement is a plausible causal driver of substantial reductions in aggregate arsenic use.

⁶² This estimated increase is large relative to the yearly four percent reductions in pollution among all plants in Gamper-Ranbindran and Finger's (2012) sample between 1988 and 2001.

Third, this paper suggests that bilateral voluntary agreements and voluntary environmental programs more generally need to be evaluated in relation to their institutional environments, and that politics and economics play focal roles in the compliance-related decision-making processes that lead to government-industry negotiated voluntary agreements. A case can be made to recognize and live with policy complexity instead of seeking a common institutional blueprint or sponsorship. This coheres well with the argument scholars such as Ostrom et al. (1961) and Ostrom (2009) have made about polycentricity, and the need to think about how different public goods might be supplied efficiently in different institutional, political, and economic contexts. Voluntary environmental programs are an example of polycentric governance in the sense that there are multiple centers of decision making (e.g., corporate actors, regulators, and NGO activists) that are formally independent of each other but interact in their various contractual and cooperative undertakings (formal or otherwise). Policy complexity certainly increases with the number of decision nodes. This paper presents one case, the CCA voluntary agreement, and the specific politics and economics that play focal roles in the compliance-related decision-making processes.

The bilateral voluntary agreements that are undertaken for another toxic chemical, in another country, or in a different policy issue area will likely look very different from the CCA agreement. This is the case for the bilateral voluntary agreements on CO₂ emissions in Japan, Denmark, and the UK that have been mentioned in the introduction of the paper (Glachant & Muizon, 2007; Krarup & Millock, 2007; Wakabayashi & Sugiyama, 2007). The bottom-line is that bilateral voluntary agreements allow for flexibility and tailoring of policy based on the political economic contexts of the policy problem at hand. While multi-party negotiation may be

variably costly, bilateral voluntary agreements could be cost effective in taking into account the specific needs of both the regulatory regime and the market.

Finally, there are practical policy implications, which could be drawn from this paper's findings, for toxic chemical policy and environmental policy more generally. First, government-industry bilateral voluntary agreements could be effective in reducing toxic chemical use or other types of pollutants, especially when the largest polluters are the ones engaging in voluntary compliance. Second, policymakers are well advised to monitor sectoral developments, including technological advances and opportunities for encouraging voluntary agreements. Toward this regards, the role of third-party stakeholders, such as environmental NGOs, could be critical. Environmental and consumer groups are often the ones monitoring emerging technologies that could become viable market substitutes, and they, like the groups featured in this paper, have become quite politically and economically savvy in keeping industry accountable in corporate environmental management, including voluntary pollution abatement and control. Lastly, prioritizing environmental protection through financial allocations by Congress could enhance EPA activities in rule enforcement, monitoring, and stakeholder engagement, which could have both direct and indirect impact on pollution control and abatement.

APPENDIX

MULTIPLE STRUCTURAL BREAKS MODEL

Bai and Perron's (1998, 2003) changepoint analysis is a simultaneous test of multiple breakpoints: breakpoint estimates are the global minimizers of the sum of squared residuals determined using an algorithm based on a dynamic programming approach. The optimal number of breakpoints is established based on the Bayesian Information Criterion (BIC) selection procedure. The theoretical foundation for estimating breaks in time series was given by Bai (1994) and was extended to multiple breaks by Bai (1997a, 1997b) and Bai and Perron (1998, 2003).

Fundamentally, Bai and Perron are concerned with assessing deviations from stability in the classical linear regression model:

$$y_t = x_t' \beta_t + \varepsilon_t \quad (t = 1, \dots, T), \quad (1)$$

Where at time t , y_t is the observation of the dependent variable, x_t is a $k \times 1$ vector of regressors, with the first component usually equal to unity, and β_t is the $k \times 1$ vector of regression coefficients, which may vary over time. ε_t is the disturbance at time t . For simplicity, of interest is the presence of abrupt structural changes in the mean of the series. To the Bai and Perron's (1998, 2003) structural break test, a constant is applied as the regressor (i.e., $x_t = \{1\}$).

In this context, I am concerned with testing the hypothesis that the regression coefficients remain constant:

$$H_0 : \beta_t = \beta_0 \quad (t = 1, \dots, T), \quad (2)$$

against the alternative that at least one coefficient varies over time. In many applications, it is reasonable to assume that there are m breakpoints, where the coefficients shift from one stable regression relationship to a different one (Bai & Perron, 1998; Zeileis, Kleiber, Krämer, & Hornik, 2003). Thus, there are $m + 1$ segments in which the regression coefficients are constant, and model (1) can be rewritten as:

$$y_t = x_t' \beta_t + \varepsilon_t \quad (t = t_{j-1} + 1, \dots, T_j, j = 1, \dots, m + 1), \quad (3)$$

where j is the segment index, $T = \{T_1, \dots, T_m\}$ denotes the set of breakpoints that are explicitly treated as unknown, and by convention $T_0 = 0$ and $T_{m+1} = T$. The purpose is to estimate the unknown regression coefficients together with the breakpoints when T observations on (y_t, x_t) are available.

Bai and Perron's procedure for the simultaneous estimation of multiple breakpoints is the minimization of the residual sum of squares (RSS) of equation (3), with the following objective function is:

$$(\hat{T}_1, \dots, \hat{T}_m) = \arg \min_{(T_1, \dots, T_m)} \text{RSS}(T_1, \dots, T_m) \quad (4)$$

The breakpoint estimators are the global minimizers of the objective function. The regression parameter estimates are the estimates associated with the m -partition $\{\hat{T}_j\}$, i.e., $\hat{\beta} = \hat{\beta}(\{\hat{T}_j\})$.

Since the breakpoints are discrete parameters and can only take a finite number of values they can be estimated by a grid search. This method becomes computationally burdensome for $m > 2$ (and any reasonable sample size T). As such, Bai and Perron (2003) present an algorithm for computing the optimal breakpoints given the number of breaks based on the principle of dynamic programming approach. The underlying idea is that of the Bellman principle. The optimal segmentation satisfies the recursion:

$$RSS(T_{m,T}) = \min_{mT_h \leq t \leq T - T_h} [RSS(T_{m-1,t}) + rss(t+1, T)] \quad (5)$$

Therefore, it suffices to know for each point t the “optimal previous partner” if t was the last breakpoint in an m -partition. This can be derived from a triangular matrix of $rss(t,j)$ with $j-t \geq T_h$, the computation of which is again made easier by the recursive relation $rss(t,j) = rss(t, j-1) + r(t,j)^2$, where $r(t,j)$ is the recursive residual at time j of a sample starting at t (Brown et al., 1975).

Finally, the optimal number of breakpoints is established based on the BIC selection procedure as mentioned above. Bai and Perron (2003) cite simulation studies by Yao (1988), Perron (1997), and Bai and Perron (1998) to argue that the BIC is a suitable selection procedure in many situations while the Akaike's information criterion (AIC) tends to overestimate the number of breaks.

QUALITATIVE RESEARCH DESIGN AND METHOD

Table A1 details this paper's informants by organization. Names have been withheld for confidentiality purposes.

Table A1
Informants by Organization

<u>Case</u>	<u>Government</u>	<u>Industry Associations</u>	<u>Key Corporations</u>	<u>Environmental NGOs</u>	<u>Influential Scientists'</u>
CCA Voluntary Agreement	EPA; U.S. Consumer Product Safety Commission; U.S. Geological Survey	American Chemistry Council; Wood Preservative Science Council	Arch Chemicals; Osmose; Viance; Northern Crossarm Inc.	Healthy Building Network; Environmental Working Group; Clean Water Action; Beyond Pesticides	Names withheld for confidentiality purposes

The following is the pre-tested interview protocol that was used for interviews with regulators. Similar protocols were used for interviews with industry and third-party stakeholders, adapted for those said purposes.

INTERVIEW PROTOCOL

REGULATORS

1. What was your role vis-à-vis the private sector (firms, industry associations) in negotiating the voluntary agreement?
 - Did you *initiate* the voluntary agreement, i.e., did you create the chemical reduction/phase-out plan and invite the private sector to participate?
 - If so, was there a particular person or organization you would attribute credit for initiating the voluntary agreement? If so, who or which organization and why?
 - Or did you *encourage* the private sector to initiate a workable chemical phase-out plan?
 - Or did the private sector approach you with a chemical phase-out plan?

Third-party stakeholders

2. Were other stakeholders, such as environmental and citizen groups, involved in the negotiation of the voluntary agreement?
 - If yes, which groups were involved?
 - If yes, how involved were they in the negotiation of the terms of the voluntary agreement? (*Not at all, a little, somewhat, or a lot*)
 - At which phase of the negotiation did these groups become involved? (*from the start, in the middle, or toward the end (during public comments)*)
 - What specific part did they play in the negotiation of the voluntary agreement?

Voluntary agreement objectives and terms

3. What was the voluntary agreement trying to achieve?
 - What were the immediate objectives?
 - Were there longer term objectives for policymaking? If so, what are they?

4. What were the terms of the voluntary agreement?
 - What have individual firms and/or the industry in question agreed to do with respect to chemical phase-out?
 - What was the time frame agreed upon for achieving the chemical phase-out?

Private sector motivation/Incentives

5. What do you think motivated firms to participate in the voluntary agreement?
6. Did you create incentives for firms' participation/involvement? If so, what were these incentives?

Political economy factors

7. Were there factors and/or events in *politics* (including the regulatory environment) that precipitated the creation of the voluntary agreement? If so, what were these factors and/or events?
8. Were there factors/or events in *politics* that shaped the terms of the voluntary agreement? If so, what were these factors and/or events?
9. Related, were there factors/or events in the *economy* that precipitated the creation of the voluntary agreement? If so, what are these factors and/or events?
 - What was the availability of substitute chemicals during this time?
 - Were prices of substitute chemicals falling over time?
10. Were there factors/or events in the *economy* that shaped the terms of the voluntary agreement? If so, what were these factors and/or events?

Outcome and effectiveness

11. What was the final outcome of the agreement?
 - How was the reduction in toxic chemical use due to the voluntary agreement?

- Was the voluntary agreement a precursor to regulation?

12. How effective was the voluntary agreement in phasing out of toxic chemicals?

- Was the voluntary agreement *low, medium, or high* in effectiveness?

Negotiation process

13. Were you satisfied with the way the negotiation process unfolded?

- If so, what was *effective* about the way the voluntary agreement was negotiated?
- If not, what was *ineffective* about the way the voluntary agreement was negotiated?

14. If you could, what would you change about the way in which the voluntary agreement was negotiated?

15. If you could, what would you change about the terms of the agreement?

CHAPTER 3. BUILDING ON THE MULTIPLE STREAMS: MARKETS, ACTORS, AND INSTITUTIONS OF THE ECONOMY STREAM

Abstract

This paper builds on the multiple streams (MS) framework (Kingdon, 1984) to explain compliance-related decision-making processes involving regulators, corporate actors, and NGO activists for the purpose of environmental protection. To the problem, policy, and politics streams of the MS framework, I add an economy stream. In the economy stream, *product substitutes*, *market competition*, *corporate social responsibility*, the *global economy*, and the *market changer* create incentives for businesses to engage in beyond-compliance activities. Without the existence of product substitutes that perform on par with the original product but generate less toxic impact, businesses have no incentive to go beyond-compliance. Businesses primarily engage in beyond-compliance activities to undercut their competitors. Occasionally, competitors coalesce for their mutual benefit in the face of threat from potentially damaging publicity. Businesses invest in corporate social responsibility in order to supply to the market for “green” products and to deflect threats from public and private politics. The market changer is a maverick business that engages in actions that transforms the modus operandi of the industry in which the market changer operates. Finally, the global supply chains and transnational private standards shape the incentives of firms to engage in environmental protection domestically without legal mandates. This augmented MS framework is applied to two cases of “successful” bilateral voluntary agreements in mercury and arsenic use, respectively. While both bilateral voluntary agreements on mercury and arsenic use achieved their respective negotiated chemical reduction objectives, the push and pull of politics, economics, as well as institutional factors led

to two distinctive bilateral voluntary agreements: one was an outcome of industry voluntary stewardship (mercury case) and the other was a result of an activist campaign (arsenic case).

Key Words: Voluntary agreements, policy process, multiple streams, businesses, NGO activists

1. INTRODUCTION

Since the 1980s, President Ronald Reagan's "Environmental Federalism" has increased state and private sector involvement in environmental policy (Economic Report of the President 1982, 44). Experimentation with alternative governance approaches that devolve regulation from the federal government have continued into subsequent presidential administrations. In one such alternative governance approach, firms play a key role in pollution abatement and control by engaging in compliance actions without the force of law in voluntary environmental programs (VEPs). Specifically, VEPs are self-regulation agreements that can be promoted by governments, firms, industry associations, and/or nongovernment organizations (NGOs) to compel businesses to enhance their environmental protection performance (Steelman & Rivera, 2006).

Previous studies have largely focused on the performance and program design of VEPs, and firm/industry's motivation for initiating or participating in such programs.⁶³ In particular, much work has focused on delineating the rational choices of decision-makers, particularly firms/industry in engaging in voluntary compliance.

In the Policy Studies Journal's 2007 Symposium on Voluntary Environmental Programs, Koehler (2007) argues that the contemporary VEPs are multifaceted: VEPs deal with new product development and changing market conditions. To this effect, Koehler proposes casting a wider, more variegated net over VEP activities and subsequent evaluations. Similarly, Prakash and Potoski (2012) call for more research that systematically examines conditions under which

⁶³ See for example, Welch et al. (2000), Takahashi et al. (2001), Gamper-Rabindran (2006), Prakash and Potoski (2006a), Steelman and Rivera (2006), Antweiler and Harrison (2007), Koehler (2007), Morgenstern and Pizer (2007), Prakash and Potoski (2007), Vidovic and Khanna (2007a), Blackman (2010), Gamper-Rabindran and Finger (2012), Hsueh and Prakash (2012b), and Hsueh and Prakash (2012a).

VEPs reduce pollution. (2000) argue “the effects of voluntarism are known to depend on the type of agreement constructed, regulatory context, market factors, and social environment.”

These proposals for future research suggest that identifying the push and pull of economics, politics, institutional factors, and the interplay among diverse actors could enhance our understanding of the variation of VEPs and how this variation relates to VEP performance.⁶⁴

Toward this regards, this paper builds on Kingdon’s (1984) multiple streams (MS) framework to explicate the policy process involving regulators and businesses, along with third-party stakeholders such as industry associations and NGOs, in negotiating bilateral voluntary agreements, which is one form of VEPs.⁶⁵ The MS framework is an ideal framework because the framework posits that collective choices are not merely derivative of individual actors, but rather the combined result of structural forces and internal processes that are context dependent (Zahariadis, 1998).

In the MS framework, as Kingdon originally envisioned it, there are three distinct, but complementary, processes or streams—the problem stream, the policy stream, and the politics stream—which move independently through the policy system. Each stream has its own set of dynamics and rules.⁶⁶ In the problem stream, issues and problems are identified and explicitly

⁶⁴ Scholars in international political economy (IPE) have developed a stream of research on “private authority” in international affairs and “global governance.” Scholars in this line of research focus on the same issues as those working on VEPs in the realm of private politics except that the IPE scholars are concerned with transnational actors or influence. See the *Business & Politics*’s 2010 special issue on “Private Regulation in the Global Economy” for a review of this literature.

⁶⁵ Bilateral voluntary agreements are voluntary agreements to reduce pollution in specific industries that are negotiated between the government and the private sector (Borck & Coglianesse, 2009). These negotiated agreements often lead to legal binding contracts.

⁶⁶ I follow Zahariadis’s (2007) proposal that stream independence is a conceptual devise rather an assumption about empirical reality. It has the advantage of enabling researchers to uncover rather than assume rationality, i.e., the point that solutions are always developed in response to

formulated, and institutional venues for promoting these ideas are chosen (Baumgartner & Jones, 1993; S. Pralle, 2006, 2010). Actors coalesce disparate groups into unified networks of likeminded actors and construct problems using words, symbols and images at their disposal (Pralle, 2006; Stone, 1989).

In the policy stream, policy alternatives are proposed and debated amongst regulators, corporate actors, scientists, and NGO activists. Such proposals and solutions, which must be technically feasible, are not initially built to resolve any given problems per se; rather they float in search of problems to which they can be tied. The role of government—whether regulators choose to be leaders, encouragers, or followers in crafting and championing certain policies, alternatives, and solutions—are played out in the policy stream (Koontz, 2004).

Additionally, politics shape the receptivity of a given policy on the political agenda. Who is in political leadership often defines the national mood regarding the proposed policy (Zahariadis, 2007). With the advent of a new president or changes in the legislative offices certain issues may receive more attention while others may simply be pushed into obscurity.⁶⁷ Inciting or deflecting media attention creates favorable or unfavorable politics for a certain policy (Baron, 2005; Dardis et al., 2008). Media reinforces existing frames in the public domain because individuals tend to resist changing their interpretations of issues based on arguments that contradict their core moral or religious beliefs (Dardis et al., 2008). Moreover, Baron (2005) posits that the media has an incentive to bias its report, and the direction of bias is toward regulation or some kind of mitigating action versus no action.

clearly defined problems. Sometimes policies are in search of a rationale or they solve no problems (Zahariadis, 1996).

⁶⁷ For example, the election of Bill Clinton in 1992 elevated national health care on the agenda to an extent not seen since the Nixon administration; his administration's failure to enact substantial policy change then closed the window of opportunity for change (Zahariadis, 2007).

At critical points in time—in the face of focusing events (Birkland, 1997, 1998) or regulatory openings—the streams are coupled by policy entrepreneurs. These punctuations are policy windows whereby the combination of all three streams into a single package dramatically enhances the chances that a specific policy will be adopted by policymakers (Kingdon, 1984; Zahariadis, 2007).

To the problem, policy, and politics streams of the MS framework this paper adds a new stream: an economy stream. When analyzing policymaking that attempts to control aspects of industry for the purpose of environmental protection, it is imperative to examine economic factors, namely, markets, economic actors, and institutions. These economic factors are part of the compliance-related decision-making processes. Alternative governance approaches, such as private regulation “virtually never occurs unless it also brings political-economic benefits to the supplier (Buthe, 2010b, p. 10).”⁶⁸

The economy stream demarcates the roles that *product substitutes*, *market competition*, *corporate social responsibility*, the *global economy*, and the *market changer* play in creating incentives for businesses to partake in beyond-compliance activities. First, without the existence of product substitutes that perform on par with the original product but generate less toxic impact, businesses would have no incentive to go beyond-compliance. Second, most of the time businesses engage in beyond-compliance activities to undercut their competitors. That being said, occasionally competitors coalesce and engage in bilateral voluntary agreements for their mutual benefit in the face of threat from potentially damaging publicity. Moreover, businesses

⁶⁸ According to Vogel (2010), private regulation employs private, nongovernment, or market-based regulatory frameworks to govern multinational firms and global supply networks. A defining feature of private regulations is that their legitimacy, governance, and implementation are not rooted in government authority. Bilateral voluntary agreements and VEPs more generally fit into this category of alternative governance approaches.

invest in corporate social responsibility in order to supply to the market for “ethical” and “green” products as well as to deflect threats from public and private politics. Fourth, global supply chains and transnational private standards shape the incentives of firms to engage in environmental protection at home without the force of law. Finally, the market changer is a maverick business that engages in an action or a set of actions that transforms the modus operandi of the industry in which the market changer operates. In the empirical context of this paper, the modus operandi that is altered pertains to a firm’s product offerings and/or corporate environmental management. Together, the new economy stream along with the variables of the problem, policy, and politics streams make up the policy process.

This paper’s augmented MS framework is applied to two cases of “successful” bilateral voluntary agreements in mercury and arsenic use, respectively. Arsenic and mercury are poisonous chemicals that continue to be ranked #1 and #3, respectively, on the EPA’s priority list of hazardous substances.⁶⁹ In the late 1990s and early 2000s, two bilateral voluntary agreements were negotiated between the U.S. Environmental Protection Agency (henceforth, EPA) and the largest arsenic and mercury-using industries, respectively, to reduce the industrial use of these chemicals. While both voluntary agreements succeeded in meeting the chemical reduction objectives negotiated between regulators and businesses, one was an outcome of industry voluntary stewardship (mercury case) and the other was a result of an activist campaign

⁶⁹ Source: <http://www.atsdr.cdc.gov/SPL/resources/index.html> (Retrieved March 2, 2012). Moreover, arsenic and mercury are target substances in all major federal environmental legislations as well as subjects of international agreement. Mercury and arsenic are listed as “controlled” chemicals under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.

(arsenic case).⁷⁰ The new economy stream has analytical power for explaining these divergent processes that involved the interactions of regulators, corporate actors, and NGO activists.

In the mercury case, the Chlorine Institute, an industry association, steered the technocratic process of the chlor-alkali industry's commitment to what amounted to marginal reductions in mercury use in the context of the global phase-out of mercury use in chlorine production already under way. By contrast, in the arsenic case, an environmental NGO-led grassroots campaign on the exposure of children to a poisonous chemical successfully compelled the pressure-treated wood industry to concede to a voluntary cancellation of chromated copper arsenate (CCA), an arsenic compound, in residential uses. Aggregate arsenic use in the U.S. fell substantially to levels not seen since the 1920s. In both cases, a viable product substitute combined with fierce market competition provided the conditions for corporate actors in the Fugitive Mercury Stewardship Program (mercury case) and NGO activists in the Playground Campaign (arsenic case) to promote their preferred policy solutions. In the arsenic case, a top chemical manufacturer differentiated itself from competitors by heavily marketing a poison-free product substitute; this action inadvertently helped the NGO activists make a credible case against CCA. Furthermore, competing businesses colluded to safeguard their collective reputations by agreeing to reduce arsenic and mercury use, respectively, without the force of law.

In the Fugitive Mercury Stewardship Program, the chlor-alkali industry engaged in acts of corporate social responsibility to deflect regulatory scrutiny and preempt future regulation. Moreover, global economic forces, namely, the European Union's rule-making and the chlor-alkali industry's prior commitment to Responsible Care, a transnational private standard on the

⁷⁰ Throughout the paper I refer to bilateral voluntary agreements also as voluntary agreements.

environment, further provided the conditions under which the chlor-alkali industry was able to reduce mercury use on its own terms in an industry-initiated stewardship program.

On the other hand, the “game changing” switch to a poison-free product substitute by a maverick wood treater in the Playground Campaign enabled the NGO activists to further gain grounds on the regulatory as well as industry fronts. Under tremendous public pressure, the pressure-treated wood industry entered a bilateral voluntary agreement with the EPA to ban CCA in residential uses.

The economy stream is necessary to fully explain the compliance-related decision-making processes. That being said, the problem, policy, and politics streams of the MS framework generally played roles first conceptualized by Kingdon (1984) and further refined by Zahariadis (1998, 2007). In both cases, the problems were both redefined and reframed. The chlor-alkali industry redefined a problem about “missing mercury” into one about “inventory accounting.” By contrast, the NGO activists in the Playground Campaign reframed a what was initially a technocratic concern—a “policy without publics” (May, 1991)—regarding CCA’s pesticide registration renewal into a consumer product safety issue that involved vulnerable children.

The policy stream in both cases involved various actors, including policy experts and industry and NGO stakeholders. The government played supporting and encouraging roles rather than leading roles in both cases: Regulators encouraged stakeholder involvement and carried out regulatory mandates. Moreover, the corporate actors and NGO activists, respectively, found hospitable institutional venues to implore their grievances and seek policy solutions in the mercury and arsenic cases. Finally, the largely technocratic nature of toxic chemical policymaking shielded the chlor-alkali industry from public opinion and media attention. By

contrast, the Playground Campaign was under constant media limelight; the dangers of children's exposure to CCA were readily reported and scrutinized.

The paper's research design, including case selection strategy and methods are laid out in section 2. In section 3, I delineate the variables of the new economy stream of the augmented MS framework. I present the arsenic and mercury cases in section 4. In the Summary of Cases and Discussion section (section 5), I compare the two different policy processes that led to "successful" voluntary agreements. Finally, I conclude and offer theoretical implications in section 6.

2. RESEARCH DESIGN

This paper's empirical component is a comparative case study of two "successful" bilateral voluntary agreements in mercury and arsenic use. The first case is the chlor-alkali industry's 1998 voluntary agreement to reduce mercury usage by 50 percent between 1998 and 2005. The second case is the pressure-treated wood industry's 2002 bilateral voluntary agreement to phase-out chromated copper arsenate (CCA), an arsenic compound, in residential uses by the end of 2003.

In selecting my cases, I hold the policy issue area and the political administrations constant: The two cases are drawn from the toxic chemical policy domain during the political administrations of President Clinton's two terms and President George W. Bush Jr.'s first term in office. This was an era of much receptivity towards and experimentation with alternative governance approaches to environmental protection, including bilateral voluntary agreements

whereby businesses agree to fine-tune and/or alter their environmental management systems for pollution abatement.⁷¹

Both cases involve the industrial use of the most poisonous of toxic substances and thus are tightly controlled by the EPA, the chief regulator of toxic chemicals in the U.S. Arsenic is ranked #1 and mercury is ranked #3 on the EPA's priority list of hazardous substances. I have not selected lead, which is ranked #2 on this list, as part of the comparative case study because lead has not been a subject of bilateral voluntary agreements negotiated between the government and the private sector.⁷²

While both bilateral voluntary agreements on mercury and arsenic use, respectively, achieved the negotiated chemical reduction objectives, one important distinction between the two cases was that one was an outcome of industry voluntary stewardship and the other was a result of an activist campaign. The purpose of the paper is to show the utility of the new economy stream in the augmented MS framework for explaining the compliance-related decision-making processes that led to desirable pollution abatement outcomes but by different actors.

2.1 Empirical Methods

In-depth, open-ended interviews with key stakeholders from government, industry, and environmental NGOs were conducted during the Spring and Summer of 2011. Approximately 30 key stakeholders were identified based on preliminary research into government documents and mass media outlet; informants were further confirmed by snowball sampling. Informants

⁷¹ The EPA alone sponsored over 45 voluntary programs during the span of these two presidencies compared to less than a dozen in the previous administrations combined. Source: <http://www.epa.gov/partners/>.

⁷² That being said, lead was a candidate toxic substance in the 1998 High Production Volume (HPV) Challenge Program, which was a government-initiated voluntary program that invited industry participants to reduce the use of toxic chemicals without legal mandates. The HPV program was different from a bilateral voluntary agreement because there were no negotiations of the terms between government and industry.

were contacted via email with an initial letter of introduction on official letterhead.

Approximately 25 of the informants contacted agreed to be interviewed. All interviews were conducted over the phone with follow-up dialogues via email or phone.⁷³

Table 1 shows this paper’s informants by organization. Great efforts were made to triangulate the interview data with published information from government, industry, and NGO websites and news media. The Appendix contains a copy of the pre-tested interview protocol.

Table 1
Informants by Organization

<u>Case</u>	<u>Government</u>	<u>Industry Associations</u>	<u>Key Businesses</u>	<u>Environmental NGOs</u>	<u>Influential Scientists</u>
The Fugitive Mercury Stewardship Program (Mercury Case)	U.S. EPA; U.S. Geological Survey	Chlorine Institute	Olin Corporation ⁷⁴	National Wildlife Federation; Sierra Club; Great Lakes United; Pollution Probe	N/A
The Playground Campaign (Arsenic Case)	EPA; U.S. Consumer Product Safety Commission; U.S. Geological Survey	American Chemistry Council; Wood Preservative Science Council	Arch Chemicals; Osiose; Viance; Northern Crossarm Inc.	Healthy Building Network; Environmental Working Group; Clean Water Action; Beyond Pesticides	Names withheld for confidentiality purposes

3. THE ECONOMY STREAM

This paper adds an economy stream. To the MS framework, I hypothesize that economic actors, markets, and the domestic and global economies are as integral to the compliance-related

⁷³ The qualitative research design and methods had undergone a Human Subjects Review at the University of Washington and had been granted an “Administrative Approval of Certification of Exemption #39396” under 45 CFR 46.101 (b) (2).

⁷⁴ Olin Corporation was the only company that agreed to publically share information about their involvement in the Fugitive Mercury Stewardship Program. In 2000, Olin participated in the EPA’s vapor emissions study; the results of which was published in Kinsey et al. (2004).

decision-making processes as the problem, policy, and politics streams. Markets and the domestic and global economies change the costs and benefits and the incentives faced by regulated communities. These forces are especially salient for policymaking that attempts to control industrial development and production for the purpose of environmental protection, including VEPs.

Drawing on scholarship in economics and political science, I detail the parts of the new economy stream in the augmented MS framework. *Product substitutes, market competition, corporate social responsibility, the global economy, and the market changer* all shape the economy stream. The economy stream is both a static environment as well as a dynamic environment. Most of the time, the economy stream is an environment where corporate actors seek profit maximization (and cost minimization) and environmental regulation is viewed as increasing costs and decreasing competitiveness, all else equal (Kitzmueller & Shimshack, 2012). That being said, I also widen the traditional individual rational choice theory to a broader set of attitudes, preferences, and calculations. Social or environmental preferences are exogenously given and the emphasis is on the interactions between firms, regulators, and third-party stakeholders, such as NGOs. A majority of actors in the economy stream operates within this worldview. *Product substitutes, market competition, corporate social responsibility, and the global economy* are concepts that assume a static environment.

By contrast, in a dynamic setting, innovation and technological changes are “shocked” out of their steady state (Kitzmueller & Shimshack, 2012). Environmental innovations are defined as investments and actions that address environmental or social impact—thereby producing public goods or reducing negative externalities—while at the same time improving the quality of the offered products, the productivity of related processes and ultimately a firm’s or

industry's competitiveness in the long run (Porter & Ver der Linde, 1995; Porter, 1991). While only a small number of actors adopt this frame of reference, their existence can be game-changing for the formation of VEPs. The role of the *market changer* assumes a dynamic environment.

The existence and viability of *product substitutes* affect the incentives of corporate actors to engage in beyond-compliance actions. Without the existence of substitutes that perform on par with existing products on the market businesses will not find it in their profit interest to relinquish a currently viable product that has not been banned by regulators or made untenable by public outcry.⁷⁵ For instance, for a firm to switch to a higher cost input that cannot be offset somewhere else in its core business is irreconcilable with the firm's profit motive. However, if a viable (i.e., affordable and efficient) substitute exists that is less toxic, a business's profit calculus changes. In fact, it is in the profit interest of corporate actors to manufacture and/or market the substitute in order to appropriate consumer demand and "corner the market" for the green product.

Market competition is another key component in the economy stream. The way in which an industry is structured influences the extent to which there is product market competition. The fiercer is the competition among businesses, the more likely businesses will attempt to differentiate themselves from their competitors. A sizeable literature has grown to explain businesses' engagement in a specific type of product differentiation—the voluntary provision of products or services that are considered more "green" than what the market offers, while earning

⁷⁵ When a product is outright banned by regulators and/or condemned by the public (i.e., consumers and mass media), businesses will take into account the potentially excessive costs of not relinquishing the product. Costs of noncompliance include legal fines and potentially future losses in profits. Under these circumstances, the substitutes that are adopted may or may not in fact perform on par with the existing product.

a profit for it.⁷⁶ Research shows that businesses have the incentive to engage in various forms of voluntary compliance, including VEPs, in order to undercut their competitors and to capture consumers who prefer “green” products (Bagnoli & Watts, 2003; Buthe, 2010b). Also, firms that already use clean technology or produce products with multiple safety features, for instance, may seek to establish more stringent environmental or consumer protection through voluntary compliance in order to gain an advantage vis-à-vis their competitors (Vogel, 1995). Prakash and Potoski (2006a) have documented such a competitive “race-to-the-top” dynamic for voluntary compliance with ISO 14,000-series standards for environmental impact assessment.

That being said, there are occasions when competitors will join forces, often under the auspices of an industry association, to serve a shared purpose for their mutual benefit: On such occasions, collective efforts by businesses yield larger benefits than what could be achieved by individual businesses. Opportunities for collaboration for mutual benefit arise when an industry as a whole is at risk of reputational damage and/or financial loss from a real or perceived liability. In this context, an industry association initiates or agrees to participate in beyond-compliance actions on behalf of in its membership to quell bad press, bolster reputation, or alter public perception about some aspect of the industry’s manufacturing process or business management that is under public or regulatory scrutiny.

A related literature on *corporate social responsibility* (CSR) specifies the economic and political incentive structures that lead to “the creation of public goods and the curtailment of public bads jointly with the production of private goods” (Besley & Ghatak, 2007, p. 1646). Lyon and Maxwell (2008) define CSR in the environmental policy arena as “environmental

⁷⁶ The scholarship on the voluntary or private provision of public goods dates back to the classic contributions by Warr (1983) and Bergstrom et al. (1986). See Cornes and Sandler (1996) for an extensive treatment.

friendly actions not required by law, also referred to as going beyond compliance . . . (Firms) voluntarily internalize externalities (Lyon & Maxwell, 2008, p. 2).”

CSR posits that businesses have the incentives to engage in beyond-compliance activities for environmental protection in the absence of government regulation. With attention to a broader group of stakeholders, Besley and Ghatak (2007) show that CSR is consistent with profit-maximization in competitive markets and has the greatest advantage over direct government intervention when the public good is naturally bundled with the production of a private good. This is the case when manufacturers (e.g., sneakers) choose whether to use certain inputs (e.g., child labor) in their production process. In the equilibrium, businesses sell ethical brands and neutral brands, and consumers self-select according to their valuation of the public good (Besley & Ghatak, 2007). Given there is consumer demand for environmentally sustainable product or services, acts of corporate social responsibility, such as participation in VEPs, are consistent with profit-seeking by businesses. CSR firms are merely supplying to what the “market of virtue” demands (Vogel, 2005).⁷⁷

Not all the incentives to engage in CSR activities are purely economic. Corporate actors sometimes engage in voluntary compliance in response to private and public politics. Private politics refers to social activism by NGOs or civil society, while public politics stands for actual or potential government engagement with firms via law and regulation (Baron, 2003; Buthe, 2010b). The corporate incentive is to respond to both types of politics and to change behavior before any activist or legal action is taken. This behavior stems from the threat posed by increased costs, decreased demand, and competitive disadvantage (Baron & Diermeier, 2007;

⁷⁷ A related research agenda has emerged within the advertising and marketing literature. Firms use CSR to differentiate and advertise their product or to build brand loyalty. For examples, see Navarro (1988) and Becker-Olsen et al. (2006).

Baron, 2001, 2003; Klein, Smith, & John, 2004; Lyon & Maxwell, 2004). Firms and industries are keen to build positive reputations with stakeholders to avoid being the target of private and public politics. The logic is comparable to hedging against future risk in financial markets. Here, the corporate actor ensures itself against a potential campaign by an activist or a regulatory action taken by a government (Kitzmueller & Shimshack, 2012).

Firms' decisions to respond to the existence of product substitutes; how to contend with market competition; and to engage in CSR do not happen in a vacuum. The *global economy* influences businesses' incentives to participate in compliance actions without the force of law through two pathways: global supply chains and/or transnational private standards.⁷⁸ First, businesses operate internationally due to their supply chains, from inputs, to product markets, to foreign direct investments. Much research has tested the linkages between global supply chains and business-specific and industry level technology and knowledge transfers (Ernst & Kim, 2002; Gereffi, 1999). I argue that these technology and knowledge transfers from the global supply chains shape the incentives for businesses to alter their corporate environmental management. Specifically, the marginal incentive for voluntary compliance increases when global market forces and/or rules adopted in another country motivate the multinational business to undertake similar beyond-compliance actions. This phenomenon is akin to the race to the top argument (as opposed to the race to the bottom argument) in the environmental law and politics literatures (O'Neill 2000; Prakash and Potoski 2006a; Revesz 1992; David Vogel and Kagan 2004).

⁷⁸ Here, I focus my discussion on the supply side of the global economy. The demand side is part of my discussion on *market competition* about the rising consumer demand for "green" products.

How do the global supply chains shape the incentives of businesses to engage in voluntary compliance domestically? Consider the hypothetical scenario in which domestic corporate actors that sell to Europe must adhere to a new European Union mandate to upgrade their pollution abatement technology. For these corporate actors, the marginal cost of volunteering to undertake the same investments in their home country is comparably low given the fixed and sunk cost associated with the EU mandate. The bottom-line: if corporate actors are obligated to expend investments elsewhere, it becomes less costly to do the same in the home country even without a legal mandate to do so. In fact, the benefits of voluntary compliance may very well outweigh the costs because of the political benefits associated with regulatory and social goodwill. After all, regulators and watch-dog NGOs might at some future time demand similar mandates on businesses that could be more costly (Baron & Diermeier, 2007; Prakash & Potoski, 2006a).

Second, the rise of private forms of regulation in the global economy is coincident and reinforced by the U.S. regulatory trend toward alternative policy instruments (Buthe & Mattli, 2011; Buthe, 2004; Cutler, Haufler, & Porter, 1999; Vogel, 1997, 2005, 2008). Private regulation on the global scale has been most prevalent in the form of transnational private standards. These rules, adopted on a voluntarily basis by businesses and other organizations, are set by a range of non-governmental bodies: industry associations, NGOs, networks of businesses, or technical experts. These private rules stipulate that businesses, for example, include particular safety features in their products, maintain or demand certain financial reserves, or keep records about their inputs or labor conditions at every step along the entire supply chain (Buthe, 2004).

Buthe (2004) and Buthe and Mathli (2011) offer several reasons for why businesses might voluntarily subject themselves to these rules. First, businesses may follow a leader (in

another country) with whom they engage in trade in the global supply chain. Second, businesses may attempt to get ahead of the global curve to create or retain industry barriers of entry. Third, businesses may adhere to transnational private standards as a means of creating or reinforcing an oligopolistic market structure.

A well-known example of transnational private standards is the International Standard Organization's ISO 14,000-series standards for environmental management and impact assessment. Businesses that are ISO 14,001 certified must adhere to a set of institutionalized environmental management protocols, which include third party audits of businesses' internal environmental management systems. Prakash and Potoski (2006b) investigate conditions under which trade linkages can encourage ISO 14,001 adoption. The authors find that trade linkages encourage ISO 14,001 adoption if countries' major export markets have adopted this voluntary regulation.

I posit that businesses that voluntarily adhere to transnational private standards will be more likely engage in VEPs.⁷⁹ The global private rules motivate various economic actors to voluntarily engage in the domestic setting in what Vogel (2005) term "virtuous" activities for two reasons. First, given that businesses are already engaged in beyond-compliance activities because of their adherence to transnational private standards it becomes less costly to participate in VEPs. Second, businesses that are already part of a culture of virtuous activities will be more likely participate in activities that reinforce similar norms of voluntary compliance.⁸⁰

⁷⁹ There is also evidence that participation in such VEPs, for example, the global chemical industry's Responsible Care program, have positive spillover effects onto *nonmembers'* environmental performance (King & Lenox, 2000).

⁸⁰ Arimura et al. (2011) find that the adoption of ISO 14,001 by participants increases the likelihood of facilities to engage in a more advanced form of beyond-compliance actions, namely the adoption of green supply chain management.

Finally, another key variable in the economy stream is the occasional existence of a *market changer*. A market changer is an industry maverick who views voluntary compliance as an investment in an environmental innovation that will reap rewards in the future even if it may have to take a loss in the current period. Moreover, the market changer sees its voluntary compliance as “win-win” for the firm’s competitiveness and for environmental protection. The market changer is what Vogel (2005) calls “altruistic or public-spirited” rather than “strategic” or “defensive” in its acts of corporate social responsibility (Vogel, 2005, p. 2).

At some critical juncture which can only be empirically verified ex-post, the market changer decides to use “green” inputs in its manufacturing process or produce or market “green” products even if it does not appear ex ante profitable to do so. The market changer makes a financial gamble in changing the rules of the game. It is only when the policy solution (voluntary compliance in this paper) the market changer implicitly advocates for succeeds, does the market changer recoup the investments it has appropriated in pursuing the alternative, financially risky path. In doing so, the market changer upsets “business as usual” in the market segment in which it operates. In effect, the market changer is a renegade corporation that engages in an action or a set of actions that completely transforms the modus operandi of the industry.⁸¹

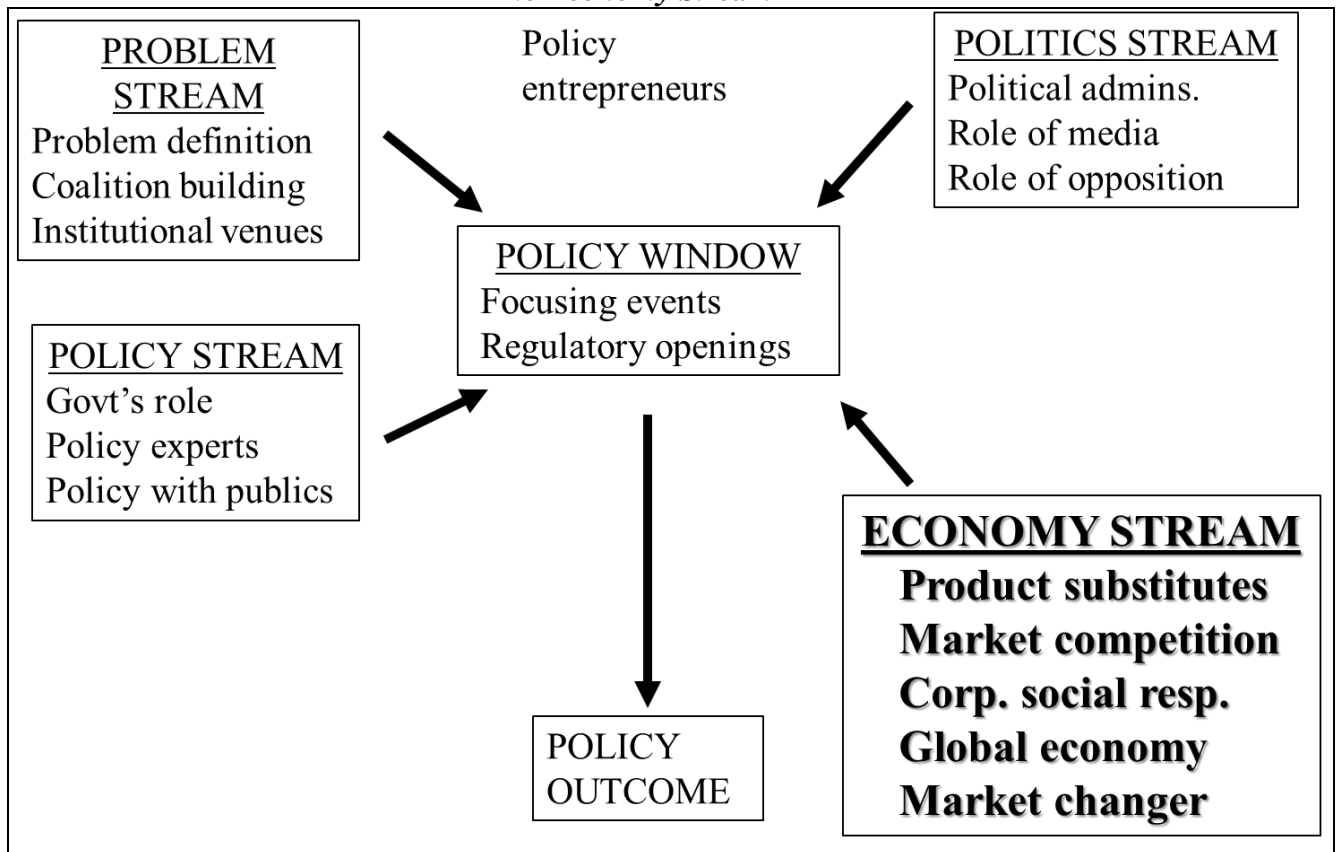
In the economy stream, businesses make multiple decisions: whether to adopt product substitutes, how to thwart market competition, whether to engage in acts of corporate social responsibility, how to respond to developments vis-à-vis the global supply chains, whether to comply with transnational private rules, and whether to be a market changer. In times of open

⁸¹ The renegade corporation does not have to be an existing “market leader,” i.e., a firm with the largest market share in the market, per se. In fact, the market changer could be a small firm that simply illustrates that this action is possible.

policy windows, businesses' decisions on one, several or various combinations of these factors in the economy stream affect whether and how businesses engage in VEPs. Ultimately, market competition, product substitutes, corporate social responsibility, and the global economy accentuate the costs *and* benefits of compliance-related choices in the policy process.

Figure 1 depicts the augmented MS framework: The new economy stream is part of the six structural elements: problems, policies, politics, economy, policy windows, and policy entrepreneurs.

Figure 1
Augmented Multiple Streams Framework
The Economy Stream



4. PRESENTATION OF CASES

In this section, I present the mercury and arsenic cases using the lens of the augmented MS framework. I contend, by applying the new economy stream that, *product substitutes*,

market competition, corporate social responsibility, the global economy, and the market changer enabled the chlor-alkali industry in the mercury case and a coalition of environmental NGOs in the arsenic case to ensure that their desired policy—a bilateral voluntary agreement on their own terms—become part of the political agenda and adopted as a viable policy solution. The push and pull of politics, economics, as well as institutional factors across the four streams contributed to the distinctive form of the mercury and arsenic voluntary agreements, respectively. That being said, it takes the addition of the economy stream to explain the process fully.

4.1 The Fugitive Mercury Stewardship Program

Case Background

Mercury is a critical input in the manufacturing of chlorine by the mercury cell technology.⁸² The mercury cell technology, also known as the Castner-Kellner process was developed in the 1890s. The mercury cell technology has been regulated in the U.S. since the early 1970s, largely as a response to the Minamata mercury dumping disaster in Japan, which revealed the potentially devastating human health effects of mercury exposure. Since then, mercury use and emission have become subject to all major federal environmental legislations, including the 1970 Clean Air Act (and the 1990 Amendments) and the 1976 Toxic Chemical Substances Control Act.

By the EPA's estimates, approximately six tons of mercury were emitted annually into the environment by mercury cell plants. In the inaugural issue of the *Journal of Industrial Ecology*, Ayres pointed out that this figure did not match the chlor-alkali industry's annual purchases of around 160 tons of mercury for replenishing production losses (Ayres, 1997).

⁸² In the mercury cell process, sodium forms an amalgam with the mercury at the cathode. The amalgam reacts with the water in a separate reactor where hydrogen gas and caustic soda solution are produced. The purity of the chlorine produced through this process had made it an especially attractive technology for the chlor-alkali industry.

Ayres contended that the discrepancy between annual purchases and estimated annual releases are “missing mercury”, which was an amount harmful to workers and nearby communities and thus must be accounted for. In fact, the amount of “missing mercury” approached the EPA’s estimates for total U.S. atmospheric mercury emissions. This alleged “missing mercury” became a key focusing event: it prompted immediate attention from both regulators and the chlor-alkali industry.

That same year the EPA launched a periodic reevaluation of the agency’s regulation of air emissions from mercury cell plants, as mandated by the 1990 Clean Air Act Amendments. The focusing event of the “missing mercury” coupled with this regulatory opening became an open policy window for the chlor-alkali industry to exert influence on U.S. toxic chemical policy pertaining to mercury use.

According to the chlor-alkali industry, in the absence of better technology for measuring emissions the most effective way to reduce emissions was to curtail use by the industry. Under the auspices of the Chlorine Institute, the industry association representing the industry on environmental, health, and safety issues, the chlor-alkali industry proposed a bilateral voluntary agreement with the EPA to reduce the industry’s mercury use.⁸³ The chlor-alkali industry called the bilateral voluntary agreement a “voluntary stewardship program” (henceforth, the Fugitive Mercury Stewardship Program).

The EPA agreed to the chlor-alkali industry’s proposed voluntary stewardship program and assigned the EPA’s Regional 5 Office to oversee the government-industry bilateral voluntary

⁸³ Based on interviews with the former director of the Chlorine Institute who was the industry association’s public face behind the voluntary stewardship program, EPA regulators, and environmental NGO representatives who were involved in the Great Lake Binational Toxic Strategy Mercury Workgroup meetings where the bilateral voluntary agreement was discussed in detail.

agreement. Through negotiations between the EPA and the chlor-alkali industry, the chlor-alkali businesses agreed to mercury use reductions by 50 percent from an agreed upon 1998 baseline. By 2005, the chlor-alkali industry not only met but far exceeded their initial target with a 90 percent overall reduction (Chlorine Institute, 2009). The bilateral voluntary agreement on mercury use was lauded a major success by all key stakeholders.⁸⁴ However, a retrospective study finds that when placed in the context of the global phase-out of mercury use that was well under way, the industry's mercury use curtailment amounted to marginal reductions in aggregate mercury use.⁸⁵

Figure 2 depicts industrial mercury use in the U.S. between 1960 and 2000.⁸⁶ The vertical dotted and dashed lines, respectively, represent two changes of the fundamental structure in the mercury use trend, in 1962 and 1988, respectively.⁸⁷ Aggregate mercury use in the U.S. (of which the chlor-alkali industry made up the largest share) had been on the decline since the 1960s, as shown by the first vertical dotted line. The 1988 structural change represented a transition to sharper declines as indicated by the steeper slope of the mercury use trend after 1988 (see vertical dashed line). This structural shift, which occurred an entire decade before the chlor-alkali industry's voluntary stewardship program, suggests that the mercury use reductions attributed to the voluntary stewardship program were part of an earlier downward shift in mercury use curtailments rather than a new structural change in the mercury use trend.

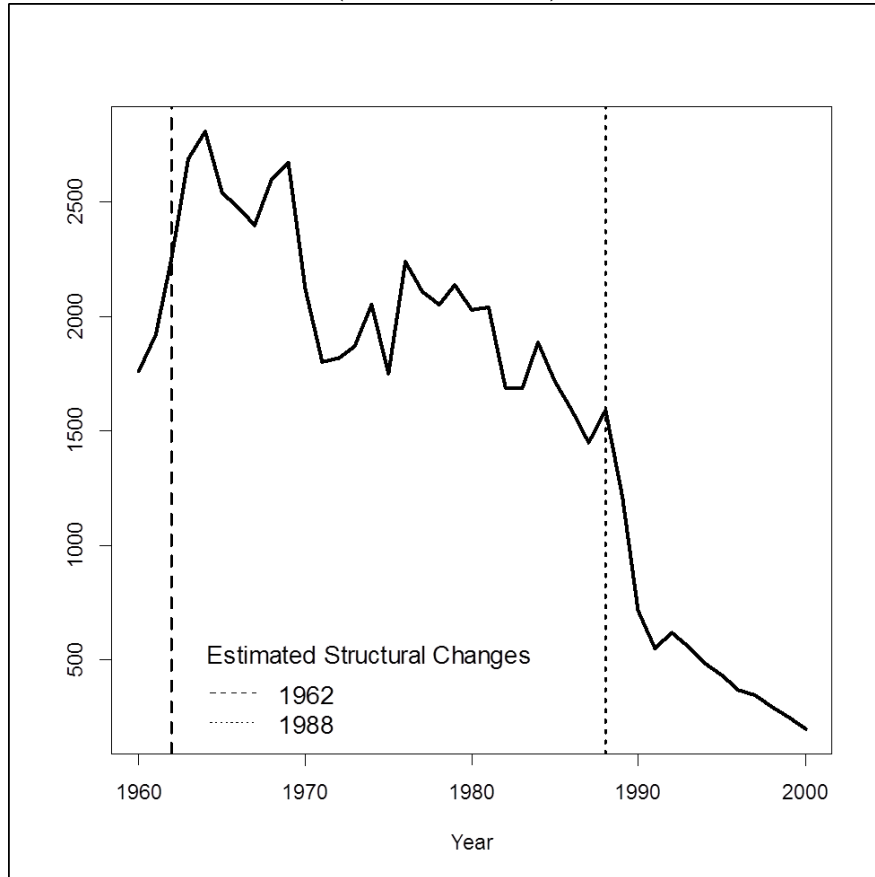
⁸⁴ Ibid.

⁸⁵ This is finding based on a time series analysis of mercury use conducted by the author.

⁸⁶ Aggregate mercury use data are obtained from the U.S. Geological Survey. Data are available through 2000. I limit my analysis to post-1960s to focus on mercury use after the founding of the EPA and the start of the environmental regulatory era (R. L. Revesz, 2001; Stavins, 2004b).

⁸⁷ The structural changes or changepoints in the mercury use trends are computed in the R software by employing Bai and Perron's (1998, 2003) endogenous structural break estimation technique. In brief, the structural change analysis is concerned with assessing deviations from stability in the classical linear regression model, where changes concern divergence from the intercept or the mean of the data.

Figure 2
Mercury Use in the U.S.
(In Metric Tons)



Source: USGS. Estimated structural changes in the mercury use trend are based on the author's time series analysis in the R software.

In spite of this, the bilateral voluntary agreement was lauded a major success by regulators, corporate actors, and NGO activists.⁸⁸ By and large, the major stakeholders involved in the compliance-related decision-making process considered the bilateral voluntary agreement an exemplary model for future industry initiative and government-industry collaboration. According to an EPA regulator, “Having this project helped get the laggards up to a higher standard... [This was a way] to get folks to a level of practice that was higher before regulation sets a maximum achievable control technology for the sector...”

⁸⁸ Based on interviews with the former director of the Chlorine Institute, EPA regulators, and environmental NGO representatives in April and May of 2011.

“[Moreover,] the voluntary action prompted industry to work on further reductions and share information that they otherwise would not have... The chlor-alkali industry folks were very good citizens. They came to [meetings] even when they were not part of the agenda; provided insights, comments.”⁸⁹

What factors and conditions enabled the chlor-alkali industry to initiate and execute a “successful” voluntary stewardship program on its own terms? A product substitute technology, as well as facilitating conditions in the global economy enabled otherwise competing businesses to coalesce under the auspices of the industry’s professional association on health and safety to deflect potentially damaging publicity. Furthermore, the industry’s deliberate act of corporate social responsibility garnered much goodwill from regulators and NGO activists, ensuring that the industry was able to initiate and execute a “voluntary stewardship program” on its own terms.

Product Substitutes

The existence and viability of *product substitutes* affect the incentives of corporate actors to engage in beyond-compliance actions, such as entering into bilateral voluntary agreements with government. A currently viable product that has not been banned by regulators will not be relinquished unless an alternative substitute that performs at least on par with the existing product appears on the market and proves to be cost effective.

In chlorine production, alternative substitute technologies, namely the diaphragm cell and membrane cell processes, have existed since the 1960s and 1970s, respectively. In spite of this, the purity of chlorine produced by the mercury cell process as well as the cost economies has privileged the mercury cell technology above the other two technologies in the U.S. and Europe. With that said, in recent decades, rising energy costs and increasing public scrutiny over mercury

⁸⁹ Quote by an EPA Regional 5 staff scientist interviewed in May 2011.

exposure have led to the rapid adoption of the membrane cell technology. The consumption of electric energy under the membrane cell process is the lowest of the three manufacturing processes. Furthermore, unlike the mercury cell technology, the membrane cell process does not require toxic chemical inputs, which further increased the appeal of the membrane cell technology.⁹⁰

By the time of Ayres's publication about "missing mercury", a gradual phase-out of the mercury cell technology was already underway. In 1996, there were 14 operating mercury cell plants in the U.S.; this was down from about twice that number in the mid-1970s. By 2007, less than 10 years after the chlor-alkali industry's voluntary commitment to reduce mercury use, there were fewer than seven mercury cell plants in the U.S. In 2011, there was one existing mercury cell plant in the U.S. (Chlorine Institute, 2009).

The Chlorine Institute was in a position to initiate the Fugitive Mercury Stewardship Program in part because the chlor-alkali industry was already reducing mercury use as part of its technology transfer from mercury cell technology to membrane cell technology. Consequently, the existence and active employment of a substitute technology enabled the chlor-alkali industry to initiate the voluntary stewardship program with little additional cost burden to the industry's profit line. The chlor-alkali industry was "getting credit for things that they could do... why not do it in the context they could get credit for it?"⁹¹

Market Competition

⁹⁰ Based on interviews with a chlor-alkali industry representative in May 2011 and with a USGS mineral specialist in April 2011. See also <http://www.eurochlor.org/the-chlorine-universe/how-is-chlorine-produced.aspx> for more information on the different technologies used to produce chlorine.

⁹¹ Quote by an EPA Regional 5 office staff scientist based on a May 2011 interview.

In a market economy, the fiercer is the competition among businesses, the more likely businesses will attempt to differentiate themselves. To undercut their competitors, businesses voluntarily engage in beyond-compliance activities as a means to capture consumers who prefer “green” products. That being said, there are times when market competitors have the incentive to join forces, such as under the auspices of an industry association, to combat a perceived threat for their mutual benefit. On such occasions, for example, when an industry’s reputation is at stake, businesses choose to collectively engage in beyond-compliance actions in order to quell bad press, bolster reputation, or alter public perception about their manufacturing process or business management. Together, these businesses will at the minimum preserve the original size of the industry’s aggregate market shares.

In the Fugitive Mercury case, the chlor-alkali industry consisted of oligopolistic multinational producers, along with a competitive fringe of domestic producers that served regional markets. The chlorine producers were collectively concerned that Ayres’s publication about “missing mercury” would impair the environmental image of the chlor-alkali industry. In an attempt to thwart negative publicity, a majority of the businesses operating mercury cell plants agreed to let the Chlorine Institute represent them in the industry’s engagement with regulators and other stakeholders.

The Chlorine Institute became a unified voice for the chlor-alkali industry. When the professional organization spoke, it spoke for the entire industry. When an individual business spoke it spoke on behalf of the Chlorine Institute.⁹² In fact, an EPA scientist remarked, “While there were businesses that were along a spectrum of progressiveness on [the missing mercury

⁹² Based on April and May 2011 interviews with the former director of the Chlorine Institute and a Chlorine Institute member firm representative, respectively, who played key roles in implementing the Chlorine Institute’s Fugitive Mercury Stewardship Program.

issue] they were invisible to the EPA. The industry put up a united front through the Chlorine Institute when they engaged with the government.”⁹³

While competitive with one another in the product market, the chlor-alkali businesses coalesced under the Chlorine Institute because as an industry they did not want to be saddled with a negative reputation associated with the damaging publicity brought on by the Ayres’s revelation of “missing mercury.” In doing so, these businesses safeguarded their public image by projecting a united front through the professional arm of the industry.

Corporate Social Responsibility

Businesses engage in acts of corporate social responsibility as preemptive actions to deflect threats of increased costs, decreased demand, and competitive disadvantage that are associated with regulatory action or NGO activism. In doing so, businesses seek to improve their relationships with regulators as well as with NGO activists in the form of regulatory and social goodwill.

The chlor-alkali industry did not think additional regulation was needed to resolve the “missing mercury” problem. At the same time, the industry was “not looking for regulatory forgiveness.”⁹⁴ Rather, under the auspices of the Chlorine Institute, the industry believed that through its voluntary stewardship initiative it could demonstrate to regulators why and how the “missing mercury” was not an outcome of business negligence, but a technicality of inventory accounting.⁹⁵ In fact, the few mass media outlets that covered the Chlorine Institute’s efforts,

⁹³ Based on an interview with the former director of the Chlorine Institute who directed the voluntary stewardship program to reduce mercury use in April 2011.

⁹⁴ Quote by a Chlorine Institute representative based on an interview conducted in April 2011.

⁹⁵ The Chlorine Institute formed technical teams to produce guidance reports to member companies for mercury use reductions.

such as industry news wires, touted the chlor-alkali industry's voluntary reductions as an act of corporate social responsibility.⁹⁶

The Chlorine Institute formed several technical teams with experts and individual business representatives that met regularly to deal with what they perceived as an inventory accounting issue. These teams generated reports and made presentations at stakeholder meetings attended by regulators and NGO activists.⁹⁷ All annual reports and meeting minutes prepared by the Chlorine Institute that described the progress of the voluntary stewardship program were published on the EPA's website devoted to the bilateral voluntary agreement.⁹⁸

The Chlorine Institute's active engagement with regulators through the Fugitive Mercury Stewardship Program improved the chlor-alkali industry's relationship with the EPA.⁹⁹ When a mandated review of the Clean Air rules were made in 2005 by the EPA the chlor-alkali industry was in a strong position to comply with the new mercury emission directives. In fact, the chlor-alkali industry was ahead of the curve because of their "early action" through the Fugitive Mercury Stewardship Program; many of the chlor-alkali businesses were already in compliance with the 2005 revised rules.¹⁰⁰ By 2005, the chlor-alkali industry had curtailed mercury usage by 90 percent from the 1998 baseline, which was beyond the initial target of 50 percent at the start of the industry's voluntary stewardship program.

⁹⁶ For example, see "Olin to end Hg releases from chlor-alkali plants," April 29, 1999, Chemical & Engineering News.

⁹⁷ Staff scientists and policy analysts from the EPA's Regional 5 Office regularly attended these stakeholder meetings. Several environmental NGOs, such as the National Wildlife Federation, Sierra Club, Great Lakes United, and Pollution Probe were also frequent participants.

⁹⁸ Source: <http://www.epa.gov/Region5/mercury/binational.html> (Retrieved May 20, 2011)

⁹⁹ Based on interviews with the former director of the Chlorine Institute, a Chlorine Institute member firm representative, and two EPA staff at the EPA's Regional 5 Office, all of whom were actively involved in Fugitive Mercury Stewardship Program.

¹⁰⁰ Based on interview with a staff scientist at the EPA's Regional 5 Office in May 2011.

A former director of the Chlorine Institute who led the Fugitive Mercury Stewardship Program said, “The Chlorine Institute is considered a credible source by the EPA. We generally had a collaborate relationship: CI explained technical issues that concern the industry [to the EPA] and why certain rule proposals could be drafted better. In general, CI did not take positions against EPA’s rulemaking.”¹⁰¹

Moreover, the Chlorine Institute cultivated a friendly rapport with environmental NGOs that were involved in stakeholder meetings.¹⁰² In fact, mainstream and centrist environmental groups, such as the World Wildlife Federation and the Sierra Club, Great Lakes United, and several Canadian NGOs (e.g., Pollution Probe) by and large approved of and certified the Fugitive Mercury Stewardship Program. NGO stakeholders generally concurred that exchanges between industry representatives, regulators, and NGO activists were amiable rather than antagonistic or adversarial.¹⁰³

The regulatory and social goodwill that the Chlorine Institute achieved on behalf of the chlor-alkali businesses was taken notice by the World Chlorine Council (WCC), the international industry association that represented multinational chlorine producers. The Chlorine Institute’s CSR initiative was touted as a global model for government-industry collaboration, particularly

¹⁰¹ Quote based on an April 2011 interview with the former director of the Chlorine Institute.

¹⁰² According to an environmental NGO representative who was active at the stakeholder meetings, there were other environmental groups (e.g., Mercury Policy Project and National Resource Defense Fund) that advocated for the total elimination of mercury in industrial sectors, but they were not active participants in the GLBTS Mercury Workgroup. These said groups devoted more resources in seeking other venues (such as the courts) for addressing their grievances. For example, a 1999 lawsuit by the National Resource Defense Council forced the EPA to require coal-fired power plants to monitor and report publicly on their mercury emissions. Source: <http://www.nrdc.org/about/victories.asp> (Retrieved September 13, 2012).

¹⁰³ Based interviews with staff members of environmental NGOs who were regular participants at the Great Lake Binational Toxic Strategy’s (GLBTS) Mercury Workgroup. One of the informants served an advisory role to regulators about stakeholder involvement in the GLBTS’s voluntary initiatives.

for the phase-out of the mercury cell technology in developing countries.¹⁰⁴ The WCC invited the Chlorine Institute to share best practices at forums that the international professional organization sponsored in India and Brazil. Representatives of the Chlorine Institutes, along with EPA regulators attended and presented at these workshops.¹⁰⁵

The Chlorine Institute's voluntary stewardship program was perceived to be an act of corporate social responsibility by corporate actors, regulators, and NGO activists. By engaging in pollution abatement activities that went beyond the legal requirement, the chlor-alkali industry fostered regulatory and social goodwill, which deflected hostile and confrontational responses from potential opponents.

The Global Economy

Global supply chains and/or transnational private standards influence businesses' incentives to participate in environmental protection beyond the force of law. On the supply side, businesses imitate domestically environmental leadership abroad because when they are obligated to expend investments elsewhere, for example, because of stricter regulations abroad, it becomes less costly to do the same in the home country. Along the same logic, for businesses that are already engaged in beyond-compliance activities due to their voluntary compliance with transnational private standards, it is relatively inexpensive to participate in similar activities at home. Finally, businesses that are already part of a culture of "virtuous" activities will more likely participate in activities that reinforce similar norms regarding voluntary compliance.

In 1996, a year prior to Ayres's "missing mercury" publication, the European Union initiated an EU Directive—the Integrated Pollution Prevention and Control (IPPC)—which took

¹⁰⁴ Source: <http://www.epa.gov/Region5/mercury/binational.html> (Retrieved May 12, 2011)

¹⁰⁵ Based on interviews with Chlorine Institute representatives and EPA regulators in April and May 2011.

a command-and-control approach to pollution abatement. The EU's IPPC policy required permits for manufacturers to use toxic inputs. The EU only issued permits if manufacturers met certain conditions, such as the installation of the best available techniques (BAT). Under the IPPC, the mercury-cell process is not considered to be BAT for the chlor-alkali industry (Foerster, 2002). In fact, a gradual phase-out of the mercury cell technology was mandated by the IPPC. Many U.S. based multinational chlorine producers who produced in and/or sold to the European markets took steps toward IPCC compliance.¹⁰⁶

At the time of Ayres's revelation of "missing mercury," a majority of the corporations represented by the Chlorine Institute were already participants in the International Council of Chemical Association's Responsible Care program, an international private voluntary program that focuses on "sustainable development, effective management of chemicals along the value chain, greater industry transparency, and improved harmonization and consistency of Responsible Care around the world."¹⁰⁷

As part of an industry-wide standard for business practice, many of these corporations have permanent employees whose main job function was to administer the series of codes, guides, and performance measures for environmental management as part of the Responsible Care program. Furthermore, the Chlorine Institute was itself a Responsible Care Partnership Association.

¹⁰⁶ There are more mercury cell plants in Europe than in the U.S. because unlike in the U.S. the mercury cell technology has dominated chlorine production in Europe. That being said, like in the U.S., there is a move away from mercury cells toward the membrane cell technology for similar rationales (see the *Product Substitutes* subsection). The final phase-out for Western European mercury cell chlor-alkali plants has been set for 2020 to accommodate the large scale of phaseout there.

¹⁰⁷ Source: <http://www.icca-chem.org/en/Home/Responsible-care/> (Retrieved April 25, 2011)

A scientist at the EPA's Regional 5 Office remarked, "These environmental staff work for their [respective] companies...that said, most environmental staff wants to do their jobs well: they make sure company is in compliance [and] workers are safe. They are the voice within company to do better [environmentally]." ¹⁰⁸

The fact that many if not most chlor-alkali businesses was already participants in the international private voluntary program, it took minimal effort to extend what the businesses were already doing in streamlining and improving overall environmental management to reduce mercury use. Moreover, the leviathan regulatory developments in the EU served as a harbinger of the sun setting of the mercury cell process in the global economy. In light of these global economic developments, the Fugitive Mercury Stewardship Program was part of a larger international supply-side initiative toward "increased resource efficiencies, increased cost-savings, as well as reduced pollution." ¹⁰⁹

Other Political Economy Factors: Problem, Policy, and Politics Streams

The new economy stream explains how markets, economic actors, and institutions incentivized the chlor-alkali industry to initiate the Fugitive Mercury Stewardship Program. The elements of the MS framework—namely, problem, policy, and politics streams—also played a part in the formation of the Fugitive Mercury Stewardship Program as a viable policy solution to the "missing mercury" problem. They by and large played the roles Kingdon (1984) had first conceptualized and Zaharidias (2007) and others have refined. The problems, policy, and politics streams explain components of the process, but it takes the addition of the economy stream to explain the process fully.

¹⁰⁸ Quote based on an interview with a staff scientist at the EPA's Regional 5 office in May 2011.

¹⁰⁹ Quote based on interviews with Chlorine Institute representatives in April and July 2011.

In the problem stream, the chlor-alkali industry's response to Ayres's (1997) article was to contain the "missing mercury" problem by reframing it. To chlorine producers, the "missing mercury" problem was an inventory accounting issue rather than a problem of business negligence.¹¹⁰ Thus, they believed that the "missing mercury" problem should be resolved by the businesses that operated mercury cell plants. Thus, the Fugitive Mercury Stewardship Program was the industry's proposed solution to the reframed "inventory accounting" problem.¹¹¹ In framing the "missing mercury" problem as a technical issue, the chlor-alkali industry was able to relegate the "missing mercury" problem to a "policy without publics" (May, 1991) that only concerned a narrow group of regulators, specialists, and technical experts.

At the time, there were other policy solutions under consideration. A relatively narrow but dedicated community of scientists and engineers of which Ayres was a member published articles on the life cycle production process of chlorine, conducted epidemiology studies on human exposure to mercury, and contributed data to regulators and third-party stakeholders, such as the National Wildlife Federation and the Sierra Club, among other environmental NGOs. A majority of these studies implicated mercury as a toxic substance that had adverse effect on human health and the environment (see e.g., Ayres, 1997; Grandjean et al., 1997; Kinsey, John, Anscombe, F. R., Lindberg, Steven E., & Southworth, George R., 2004). By and large, contrary to the chlor-alkali industry's initiative these researchers advocated for increased regulatory oversight.

¹¹⁰ In an interview with C&EN newswire, the former director of the Chlorine Institute said that it was difficult to measure emissions from a process he described as "'football field-sized' lines of 30 to 50 mercury cells, each holding 10,000 pounds of mercury. Because electrolysis is used to pull chlorine from salt, heat is generated, which contribute to mercury volatilization, but the area must be open to allow air flow to remove heat from fumes (Jeff Johnson, 1999)."

¹¹¹ Based on an April 2011 interview with the former director of the Chlorine Institute.

In 1996, about a year prior to the publication of Ayres (1997), the EPA Administrator Carol Browner announced voluntary national goals for the “virtual elimination of persistent toxic substances” of over 10 toxic chemicals, including mercury and PCBs, dioxins and furans, as part of the Great Lakes Binational Toxics Strategy (GLBTS), which was an environmental forum on the Great Lakes Basin between Canada and the U.S.¹¹²

The Chlorine Institute believed that the GLBTS would be a hospitable institutional venue for carrying out the Fugitive Mercury Stewardship Program because the GLBTS was formed on the premise of stakeholder involvement in solving industrial pollution problems.¹¹³ In fact, the EPA and Environment Canada invited state and provincial and tribal governments, industry, and NGOs to assist in developing and implementing pollution control strategies for all the target toxic chemicals. The Fugitive Mercury Stewardship Program was prototypical of the kind of voluntary industry initiative promoted by the GLBTS, although the GLBTS endorsed both voluntary and regulatory solutions.

The EPA’s Regional 5 Office served as a liaison between the government and the chlor-alkali industry.¹¹⁴ The EPA regulators formed a stakeholders’ forum, called the Mercury Workgroup, within the GLBTS to iron out the technical details of the bilateral voluntary agreement. The EPA regulators served as encouragers rather than enforcers of the Fugitive Mercury Stewardship Program; they largely left the technical aspects of the bilateral voluntary agreement to the Chlorine Institute. Also in attendance at these meetings were a small number of

¹¹² Source: <http://www.epa.gov/bns/> (retrieved May 30, 2011)

¹¹³ Based on an April 2011 interview with the former director of the Chlorine Institute. Also, see <http://www.epa.gov/greatlakes/p2/bnsintro.html> for more on the GLBTS’s history and objectives.

¹¹⁴ Based on April and May 2011 interviews with the EPA Regional 5 Office staff scientists and representatives from participating environmental NGOs. Also see: <http://www.epa.gov/Region5/mercury/binational.html>

environmental NGOs, state and local government representatives, and other mercury-using businesses outside of the chlor-alkali industry. These third-party stakeholder groups occasionally submitted comments but did not play a major role.

Finally, the Fugitive Mercury Stewardship Program never became a hot button political issue. In fact, the Fugitive Mercury Stewardship Program was considered apolitical and part of a larger agenda of the GLBTS to encourage industry engagement in pollution control.¹¹⁵ The Fugitive Mercury Stewardship Program never made it to the national media headlines: there was very little media attention because “our voluntary stewardship program was never controversial.”¹¹⁶

4.2 The Playground Campaign

Case Background

The second case I examine is the pressure-treated wood industry’s voluntary ban of CCA, an arsenic compound, in residential uses. Unlike the chlor-alkali industry’s voluntary stewardship program, the CCA voluntary agreement is not an industry initiative but rather the outcome of a successful activist campaign by a coalition of environmental NGOs. While environmental NGOs did not play an active in the mercury case, environmental NGOs were instigators of policy change in the arsenic case.

The CCA voluntary agreement was lauded as a success by regulators, industry representatives, and NGO activists involved in its development. It was considered a landmark

¹¹⁵ All stakeholders from government, industry, and NGOs whom I interviewed underscored the fact that the Fugitive Mercury Stewardship Program was a voluntary initiative by the chlor-alkali industry and that it never became a political contest between “us versus them”.

¹¹⁶ Based on a May 2011 interview with an environmental manager of a chlor-alkali business that operated a mercury cell plant; he was an active in the Chlorine Institute on behalf of his firm. The informant’s company volunteered one of its mercury cell facility for the EPA’s vapor emissions study in 2000.

decision by all major stakeholders because the largest arsenic-using industry's voluntary compliance ensured that the industrial use of arsenic, a poisonous chemical that is ranked #1 on the EPA's priority list of hazardous substances, would be lowered.¹¹⁷

As a restricted pesticide, CCA, by law must be renewed every fifteen years for use in commercial applications. In 1998, the EPA began the agency's routine pesticide registration renewal process for CCA. A central component of the registration renewal process for all pesticides is a formal risk assessment, which takes into account new information about potential risks since the previous renewal. Investigating CCA's potential harm to children was not initially on the agenda of government regulators.

A network of environmental groups (henceforth, the green buildings network) spearheaded by the Healthy Buildings Network, a NGO devoted to promoting sustainable building materials saw the pesticide registration renewal process as an open window of opportunity: The green building network's strategy was to cast CCA as a consumer product safety hazard involving children and to wage a grassroots campaign (henceforth the Playground Campaign) to shift market demand in the construction industry away from CCA-treated wood.

Subsequently, at the center of the CCA voluntary agreement is the controversy over the pressure-treated wood industry's use of CCA as a wood preservative in residential products, such as residential decks, picnic tables, and playground equipment. The contention was about the exposure of children who play on CCA-treated wooden playsets to arsenic, a poisonous chemical.¹¹⁸ Both the Consumer Product Safety Commission (CPSC) and the EPA conducted

¹¹⁷ The largest end-user of arsenic is the pressure-treated wood industry (88%), followed by the agriculture (4%), glass (4%), and semiconductor (4%) industries ("USGS Minerals Information," 2012).

¹¹⁸ A Consumer Product and Safety Commission study (CPSC, 2003) found that the principle exposure to arsenic from CCA-treated wood in playground equipment occurs through the

risk analysis studies and invited stakeholder participation. In particular, the EPA convened a scientific advisory panel (SAP) and summoned outside experts to assist with the agency's risk assessment of children's exposure to CCA.

In early 2002, the EPA announced that the manufacturers of CCA had requested that the registrations of CCA be cancelled for residential uses, including playground equipment, to be effective December 31, 2003. According to the terms of the agreement, CCA-treated residential wood products prior to year-end 2003 remained in circulation. Furthermore, the EPA accepted the pressure-treated wood industry's claim that children's exposure to CCA-treated wood used for nonresidential purposes (e.g., highway utility poles) was relatively negligible, thus CCA registration was permitted for nonresidential uses.¹¹⁹

Figure 3 depicts the industrial arsenic use in the U.S. between 1960 and 2004.¹²⁰ The vertical dotted and dashed lines, respectively, represent two changes to the fundamental structure of the arsenic use trend, in 1985 and 2003, respectively. The two estimated structural changes (a "shift up" for the first change and a "shift down" for the second change) matched two major events in the arsenic-using sectors: the 1987 discovery of gallium arsenide (GaAs) in semiconductor manufacturing and the 2003 pressure-treated wood industry's voluntary agreement to ban CCA in residential uses.

The second structural change, which occurred in 2003, shows that the bilateral voluntary agreement between the EPA and the pressure-treated wood industry to ban CCA was a major

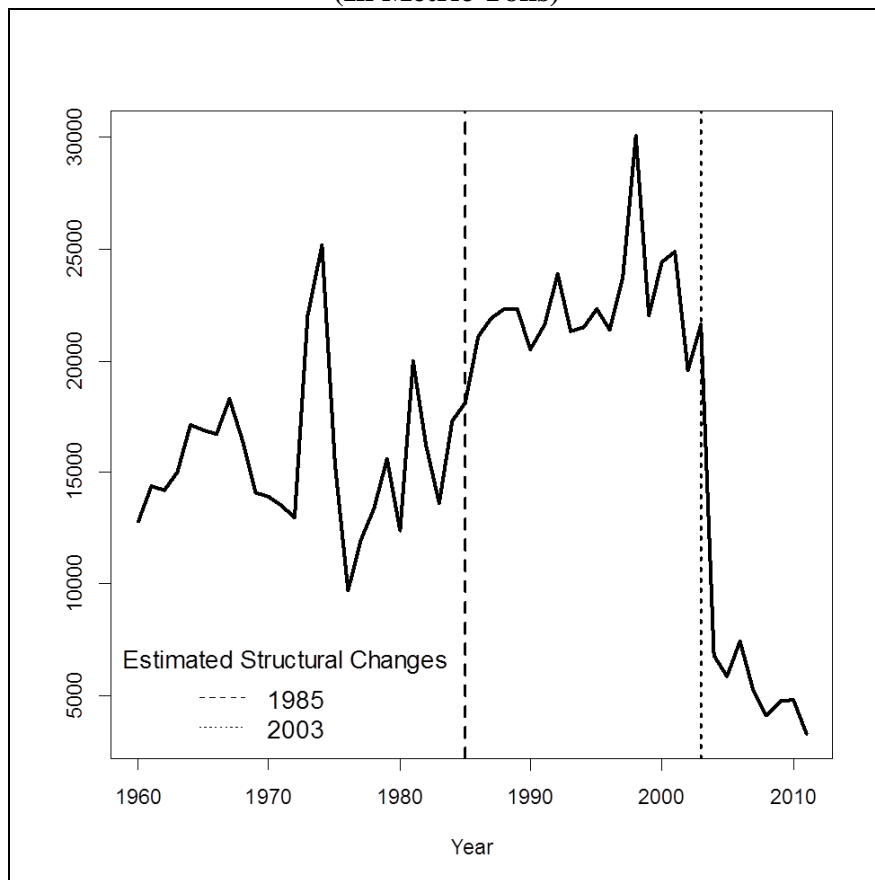
transfer of wood surface residues to a child's hands and subsequent hand-to-mouth transfer that can occur when children put their hands or fingers in their mouths.

¹¹⁹ Source: <https://www.federalregister.gov/articles/2003/04/09/03-8372/response-to-requests-to-cancel-certain-chromated-copper-arsenate-cca-wood-preservative-products-and> (Retrieved August 14, 2012)

¹²⁰ Aggregate arsenic use data are obtained from the U.S. Geological Survey. Data are available through 2004. Like in the mercury case, I limit my analysis to post-1960s to focus on chemical use after the founding of the EPA and the start of the environmental regulatory era.

driver of reductions in arsenic use in the U.S. In fact, in a retrospective study, Hsueh (2012c) finds that the CCA voluntary agreement has lowered arsenic use in the U.S. to levels not seen since the 1920s. What factors and conditions led to the formation of a landmark industry voluntary ban that was lauded as a success by regulators, industry representatives, and environmental NGO activists involved in its development?

Figure 3
Arsenic Use in the U.S.
(In Metric Tons)



Source: USGS. Estimated structural changes in the arsenic use trend are based on the author's time series analysis in the R software.

A viable product substitute, as well as facilitating conditions in a competitive market, and the actions of a market changer enabled the green buildings network to wage a successful activist campaign to eliminate CCA-treated wood in residential construction. The manufacturer

of an arsenic-free alternative wood preservative heavily promoted the product and collaborated with the NGO activists to ensure that information about the alternative technology's "green" credentials vis-à-vis CCA were readily circulated in the news media. Moreover, a maverick wood treater adopted ACQ and thus demonstrated the product substitute's viability. All of these factors allowed the Playground Campaign to gain ample grounds on the regulatory as well as industry fronts.

Product Substitutes

Only when a *product substitute* that performs at least on par with the existing product appears on the market and is deemed to be cost effective would corporate actors have the incentives to engage in beyond-compliance actions, such as entering into bilateral voluntary agreements with government.

In 1938, CCA was introduced as a key input in the manufacturing of agricultural pesticides, including wood preservatives (Bleiwis 2000). From the 1940s onwards, CCA has been used primarily to treat wood products, such as fences, docks, decks, and playground equipment and picnic tables, to prevent them from decay. That being said, ammonium copper quaternary (ACQ), an arsenic-free preservative has been on the market, alongside CCA since 1996.¹²¹ ACQ, however, remained a niche product with few customers until a new leadership of marketing was installed at the corporation that manufactured ACQ in the late 1990s.

The manufacturer of ACQ was also one of three major producers of CCA. In promoting ACQ, the corporation hired a former EPA scientist-turned-consultant to conduct an independent assessment of ACQ and to communicate his findings with the environmental community. The

¹²¹ The number of arsenic-free preservatives has since expanded to include Copper Azole, Borate, Cyproconazole, and Propiconazole, among others.

independent third-party consultant certified that ACQ was “equal in performance and environmentally superior to CCA.”¹²²

The promotion of ACQ coincided with the EPA’s reregistration process for CCA. The green buildings network used this opportunity to target CCA as a “worse in class” building material because the group believed CCA “has adverse environment and health impacts, and there are commercially available alternatives that are superior from an environmental-health perspective and comparable in price and performance.”¹²³ Toward this effort, the green buildings network presented new facts about the danger of CCA, some of which were disseminated by the manufacturer of ACQ, and urged further research on CCA’s adverse human and environmental impact while in-use and in the waste stream.

The existence of a *product substitute* that was poison-free, heavily promoted by its manufacturer, and certified by a third-party scientist ensured that the green buildings network had verifiable facts and figures for waging a credible activist campaign against the dangers of CCA as a building material in residential construction.

The Market Changer

A market changer is an industry maverick who views voluntary compliance as an investment in an environmental innovation that will reap rewards in the future even if it may have to take a loss in the current period. Ultimately, the market changer makes a financial gamble in changing the rules of the game but sees its voluntary compliance as “win-win” for the firm’s competitiveness and for environmental protection.

¹²² Interview conducted with the independent consultant/former EPA scientist who conducted an independent assessment of ACQ on July 22, 2011.

¹²³ Source: <http://www.healthybuilding.net/about/index.html> (Retrieved March 19, 2012)

A reputable family-owned regional wood treater based in Wisconsin made a “game changing” decision to switch from CCA to using ACQ despite ACQ’s lack of wood preserving credibility outside of laboratory testing and ACQ’s higher costs relative to CCA.¹²⁴ Such action by the largest treater in terms of market shares in the Midwest region was taken notice and the ACQ began to earn “street credit.”

The president of the maverick wood treater said that his company decided to switch to ACQ even though ACQ was initially more expensive [than CCA] because “[we wanted to] create a distance between us and the regulation for handling and using a hazardous substance in case CCA ever get regulated as a hazardous waste. Second, there were minimal cost savings that offset some of the cost increases in ACQ over CCA although not all right away...Finally, we heard at tradeshow from customers that they had gotten sick from CCA. For example, we heard from customers that after building a deck they had suffered arsenic poisoning. We want to do something that was good for everybody.”¹²⁵

The maverick wood treater quickly became the Playground Campaign’s “poster child.”¹²⁶ The green buildings network advertised the maverick “green” business model as an example of how an arsenic-free chemical could be used to preserve wood without profit losses to industry. All of this was readily reported by the national media. The Playground Campaign gained ample grounds on the regulatory as well as industry fronts.

¹²⁴ In an interview conducted on August 1, 2011, the president of the maverick company said that his company did not receive discounts on ACQ from the chemical manufacturer before or after his company’s switch to CCA.

¹²⁵ Ibid.

¹²⁶ Based on an August 2011 interview with former CPSC senior administrator who was at the CPSC during CPSC’s CCA investigation.

The substitution of ACQ for CCA by a maverick wood treater was a “game changing” move because before this action there were little practical evidence that ACQ was a viable substitute for preventing wood from rot and decay. The *market changer*’s switch to ACQ provided corroborating evidence for the Playground Campaign’s allegations against CCA and the activist campaign’s claim that a viable and poison-free alternative existed on the market.

Market Competition

To undercut their competitors, businesses will attempt to differentiate themselves to capture consumers who prefer “green” products. That being said, there are times when market competitors have the incentive to join forces, such as under the auspices of an industry association, to combat a perceived threat for their mutual benefit. On such occasions, for example, when an industry’s reputation is at stake, businesses sometimes choose to collectively engage in beyond-compliance actions in order to quell bad press, bolster reputation, or alter public perception about their manufacturing process or business management.

The pressure-treated wood industry faced a highly competitive business climate. There were three major chemical manufacturers and hundreds of local and regional wood treaters. The three chemical manufacturers acted like oligopolists: the corporations competed fiercely to protect their brands and for the business of wood treaters. The local and regional wood treaters operated in distinct geographic markets; some markets were more competitive than others.¹²⁷

In the late 1990s, one of the three CCA manufacturers saw a market opportunity. As mentioned above, while one of the manufacturers had offered ACQ, which was the only arsenic-free preservative on the market, alongside CCA since 1996, ACQ had remained a niche product

¹²⁷ Based on interviews with key stakeholders from government, industry, and NGOs in June and July 2011.

with few customers. This changed under a new leadership of marketing who had hired a public relations firm to help the corporation promote ACQ in addition to seeking independent certification of ACQ. Under the new marketing vice president, the corporation successfully promoted ACQ and expanded the company's business into "environmentally friendly" wood preservatives.¹²⁸

The other two chemical manufacturers as well as a majority of local and regional wood treaters were publicly opposed to the Playground Campaign. These businesses attended regulatory hearings and testified why they believed the EPA should grant pesticide reregistration for CCA to the pressure-treated wood industry. The corporation that marketed ACQ officially stood on the sidelines but informally assisted and shared information with the Playground Campaign about ACQ.¹²⁹

By early 2002, the Playground Campaign appeared successful in inciting a media maelstrom about the dangers of CCA, particularly as it pertains to children's exposure to the toxic chemical, and the viability of ACQ as a poison-free alternative. Amidst the explosive media attention, about midway through the EPA's SAP meetings, the American Chemical Council (ACC), the industry-wide trade association that represented the chemical manufacturers and wood treaters, submitted an official request to the EPA on behalf of the pressure-treated wood industry stating that the industry would not be pursuing registration renewal for CCA in residential applications. A negotiated deadline of December 31, 2003 was set for the complete phase-out of CCA in residential uses.

¹²⁸ Source: <http://www.linkedin.com/pub/david-fowlie/17/9b1/52b> (Retrieved March 19, 2012)

¹²⁹ Interview conducted with the coordinator of the Playground Campaign on July 20, 2011.

According to a key SAP scientist, “At least one of the two other manufacturers must have switched sides. This was when a deal was struck and the manufacturers had negotiated some kind of licensing agreement [amongst themselves] for ACQ”¹³⁰

The ACC brought together the chemical manufacturers under the auspices of the ACC’s CCA Work Group and negotiated an arrangement, which the three major manufacturers agreed to behind closed doors. The ACC then approached the EPA with the offer of a voluntary agreement. In a bilateral voluntary agreement, the pressure-treated wood manufacturers agreed to phase-out the use of CCA but would continue to use CCA in industrial applications, citing that there was much less human contact with CCA in industrial applications. CCA-treated residential wood products currently in-service would also be exempt from the voluntary agreement.

An EPA regulator close to the negotiations summarized the voluntary agreement this way: “...the proposed CCA ban [in residential uses]...calmed things down.”¹³¹

Fierce market competition led one of the three manufacturers of CCA to promote ACQ, an arsenic-free product substitute that the corporation had patented, as a means of differentiating itself from its competitors. Initially, the other two manufacturers stood behind CCA and opposed the efforts of the Playground Campaign. However, in the face of negative publicity these businesses collectively cancelled the reregistration of CCA in residential applications to quell bad press and bolster reputation. Together, the manufacturers negotiated among themselves a business deal that would preserve each of their market shares and safeguard their reputations.

Other Political Economy Factors: Problem, Policy, and Politics Streams

¹³⁰ Interview conducted with a key SAP scientist who is a professor at the University of Florida on August 12, 2011.

¹³¹ Interview conducted with a section chief at the EPA, Office of Pesticide Program, who was privy to the details of the government-industry bilateral voluntary agreement, on August 1, 2011.

Like the Fugitive Mercury case, it takes the addition of the economy stream to fully explain the compliance-related decision-making process that led to the CCA voluntary agreement in the Playground Campaign. That being said, the factors in the problem, policy, and politics streams of the original MS framework also help to explain components of the process.

In the problem stream, the green building network reframed what was initially a technocratic concern—a “policy without publics”—regarding CCA’s pesticide registration renewal into a consumer product safety issue that involved children “who can’t think for themselves, whom the adults want to protect.”¹³² Part of what made the Playground Campaign effective was that it did not merely contest CCA’s standing but offered an “environmentally friendly” and independently certified arsenic-free alternative.

The Playground Campaign selected the CPSC as a key institutional venue for petitioning the group’s grievances. A former CPSC senior administrator stated, “Walsh and his group were brilliant. When chemicals can be connected to children exposure, it is much easier to garner public and political support. CPSC is a microcosm for this kind of activism by environmental and consumer groups.”¹³³

In May 2001, the green buildings network amassed more than 50 petition letters addressed to the CPSC.¹³⁴ Signatures included the directors of local and national NGOs that focused on health and safety, and the environment, and the owners of nonprofit businesses that provisioned sustainable planning and design services.¹³⁵ The petition letters repeatedly cited

¹³² Based on an August 2011 interview with former CPSC senior administrator who was at the CPSC during CPSC’s CCA investigation.

¹³³ Ibid.

¹³⁴ Source: <http://www.cpsc.gov/library/foia/foia01/petition/arsenic.pdf>.

¹³⁵ Notable national NGOs and nonprofit businesses included Greenpeace, HealthLink, Environmental Working Group, and the Healthy Buildings Network. Local NGOs ranged from

studies that showed arsenic poisoning amongst children who played on playground equipment made from CCA-treated wood.

The green buildings network's petition to the CPSC elevated the public scrutiny for CCA even though regulatory authority over the industrial use of CCA resided with the EPA. In response to the Playground Campaign's petition, the CPSC commenced a study and updated an earlier report regarding the harmful health effects of CCA on children's exposure (CPSC, 2003). The agency also held regulatory hearings and stakeholder meetings.

In the wake of external pressures, the EPA convened a scientific advisory panel (SAP) and invited outside experts to assist with the agency's risk assessment of children's exposure to CCA. Experts who specialized in the behavior of children at play, on toxic exposure, and on the toxicology of arsenic compounds were invited to participate in the SAP. The green buildings network as well as chemical manufacturers and wood treaters were invited for public commenting.

There were several scientists on the SAP who were particularly supportive of further research regarding the dangers of CCA. These scientists contributed evidence on the environmental and health impacts of CCA-treated wood and proposed evidence-driven solutions. For example, one research team developed an automated technology that could distinguish between CCA and non-CCA treated wood at recycling facilities.¹³⁶

Another key expert was a former EPA staff scientist and grassroots activist. As an independent consultant, he was hired by one of the three manufacturers of CCA to conduct an independent assessment of ACQ. The expert's analysis was a key piece of information used by

Green Action, which is based in San Francisco, CA to Watchdogs for an Environmentally Safe Town, which resided in Westminster, MA.

¹³⁶ Source: <http://www.ccaresearch.org/publications.htm> (Retrieved March 19, 2012).

the green buildings network to assert that there was at least one commercially available alternative that was superior to CCA from an environmental-health perspective and was arguably comparable in performance and price.

By mid-2001, the Playground Campaign had become a political “hot button” issue. The CPSC Chairperson at the time of the CCA investigation was Ann Brown, an appointee of President Clinton. Brown was widely known for her progressive politics and special interest in children issues. A former CPSC senior administrator said, “CPSC was more interested in looking at issue like the CCA ban under Ann Brown. In many ways Ann Brown turned CPSC into a children’s agency. The CCA investigation was from Brown’s personal direction.”¹³⁷

Florida senator Bill Nelson also became involved in the CCA case in response to public outcry in Florida. Nelson wrote a letter to Christine Whitman, the former EPA Director, expressing his concern that CCA-treated playground equipment was reportedly leaching into Florida’s soil and acquirers, and about woodworkers who had been poisoned by arsenic while handling the CCA-treated wood. While the green buildings network was never in touch with Nelson directly, the senator’s involvement contributed to a favorable political environment.

Once the CPSC agreed to open up investigation, the Playground Campaign escalated. An explosion of media and public attention ensued: the activities of the Playground Campaign, the investigations by the CPSC and the EPA, and Senator Nelson’s statements were all reported by the media. An EPA staff described it this way: “[It] felt like everything was happening at the same time. There was news every day about CCA [in the media]. It became about whether you were for the children or not for the children”¹³⁸

¹³⁷ Based on an August 2011 interview with former CPSC senior administrator who was at the CPSC during CPSC’s CCA investigation.

¹³⁸ Interview with a staff scientist at the EPA, Office of Pesticide Program in August 2011.

5. SUMMARY OF CASES AND DISCUSSION

Table 2 summarizes the two cases—Fugitive Mercury Stewardship Program and the Playground Campaign—with respect to the key variables of the augmented MS framework in a tabular form.

In both cases, major stakeholders applauded the outcome of the Fugitive Mercury Stewardship Program and the Playground Campaign, respectively, even though two distinct compliance-related decision-making processes led to the divergent final policy outcomes. It takes the addition of the economy stream to fully explain the contrasting policy processes of the mercury and arsenic cases. The existence and active promotion and employment of a *product substitute* and fierce *market competition* incentivized corporate actors in the Fugitive Mercury Stewardship Program and NGO activists in the Playground Campaign to promote their preferred policy solutions. When an alternative technology performs on par and passes the benefit-cost test but is less toxic—which was the case for the membrane technology (mercury case) and ACQ (arsenic case)—an argument could be made more easily for its adoption over the incumbent technology. Moreover, competitive forces, in both the mercury and arsenic cases, worked in the favor of reducing toxic substances without the force of law. In both cases, competing businesses colluded to safeguard their collective reputation. That being said, in the Playground Campaign, it was also intense market competition that compelled one of the manufacturers to promote the alternative technology to assert its market leadership in the first place.

Table 2
Bilateral Voluntary Agreements:
Fugitive Mercury Stewardship Program and the Playground Campaign

	The Playground Campaign (Arsenic Case)	Fugitive Mercury Stewardship Program (Mercury Case)
Stewardship/campaign period	Mid to late 1990s to 2003	Mid to late 1990s to 2005
ECONOMY STREAM		
<i>Product substitutes</i>	Ammonium copper quaternary (ACQ), which is arsenic-free	Membrane cell and diaphragm cell technologies; an active adoption of the membrane cell technology was underway
<i>Market competition</i>	<ul style="list-style-type: none"> ▪ Oligopolistic manufacturers, thousands of local wood treaters ▪ A top manufacturer heavily marketed ACQ to beat out competition ▪ Manufacturers collectively entered into bilateral voluntary agreement to ban CCA in the face of public scrutiny 	Oligopolistic multinational producers with a fringe of regional players; businesses coalesced behind the Chlorine Institute to deflect negative publicity
<i>Corporate social responsibility</i>	N/A	Chlorine Institute advertised the stewardship program as an act of corporate social responsibility
<i>Market changer</i>	A maverick wood treater independently curtailed the use of CCA and switched to ACQ without immediate financial benefits	N/A
<i>Global economy: International supply chains, global private rules</i>	N/A	<ul style="list-style-type: none"> ▪ The EU's Integrated Pollution Prevention and Control policy directive was a harbinger of the global phase-out of the mercury cell technology ▪ Many businesses were already part of the global chemical industry's Responsible Care Program
OTHER DYNAMICS		
Policy windows		

<i>Focusing event and regulatory opening</i>	CCA pesticide registration renewal process	Ayres (1997) drew attention to “missing mercury”; EPA reviewed air emissions regulation for the mercury cell sector
Problem stream		
<i>Problem definition</i>	CCA = toxic hazard on the playground = children poisoning	Fugitive mercury = inventory accounting problem not business negligence
<i>Institutional venues</i>	CPSC and EPA	Great Lake Binational Toxics Strategy (GLBTS)
Policy stream		
<i>Government’s role</i>	CPSC and EPA launched investigations on children’s exposure to CCA and convened meetings with external experts and stakeholders	EPA Region 5 regulators provided institutional support and forum for information sharing
<i>Policy communities</i>	Scientists certified ACQ as a poison-free and environmentally friendly product substitute	Scientists published studies that documented toxicity of mercury and advocated for increased regulatory scrutiny
Politics stream		
<i>National political mood</i>	<ul style="list-style-type: none"> ▪ Political climate was receptive to voluntary environmental initiatives by industry ▪ Florida senator and CPSC administrator lent their support 	Political climate was receptive to voluntary environmental initiatives by industry
<i>Role of opposition</i>	Major manufacturers were initially fragmented	Amicable environmental NGOs
<i>Role of media</i>	Explosive news media scrutiny on the dangers to the exposure of CCA by children	Muted news media
Policy Outcome	“Successful” Voluntary Agreement: Toxic Chemical Use Reductions	““Successful” Voluntary Agreement: Toxic Chemical Use Reductions

In the Fugitive Mercury Stewardship Program, the chlor-alkali businesses of the oligopolistic industry coalesced under the Chlorine Institute. These businesses turned to the Chlorine Institute because they did not want to be saddled with a negative reputation associated with the damaging publicity brought on by Ayres's revelation of "missing mercury."

In the Playground Campaign, to quell negative publicity and bolster reputation, two manufacturers who were initially on the opposing side made an about-face decision to join a third manufacturer, who was the producer of ACQ, to phase-out CCA in residential applications, as part of an industry wide beyond-compliance effort. Together, the manufacturers negotiated a business deal amongst themselves that would preserve each of their market shares and restore their reputations.

In the Fugitive Mercury Stewardship Program, regulatory preemptive actions in the guise of corporate social responsibility and global economic forces further enabled the chlor-alkali industry to voluntarily carry out mercury reductions on the industry's own terms. In the industry's transparency in carrying out the stewardship program, the chlor-alkali industry fostered regulatory and social goodwill with the EPA regulators and NGO activists. The Chlorine Institute's CSR initiative became a global model for industry-government collaboration, particularly for mercury cell technology phase-outs in developing countries. The World Chlorine Council invited the Chlorine Institute to share best practices at forums the worldwide industry association had sponsored in India and Brazil. Representatives of the Chlorine Institutes, along with EPA regulators attended and presented at these workshops.

With the new regulations in the EU and the chlor-alkali businesses' participation in the International Council of Chemical Association's Responsible Care program, it appeared that businesses were phasing down globally. The Fugitive Mercury Stewardship Program was part of

a larger international supply-side change toward “increased resource efficiencies, increased cost-savings, as well as reduced pollution.”

On the other hand, the “game changing” switch to the use of ACQ from CCA by a maverick wood treater in the Playground Campaign gave the green buildings network another campaign tool—the maverick wood treater became the activist campaign’s “poster child”.¹³⁹ Before this action there was little practical evidence that ACQ was a viable substitute for preventing wood from rot and decay. Subsequently, the Playground Campaign gained further grounds on the regulatory as well as industry fronts.

Finally, in both cases, the variables of the problem, policy, and politics streams contributed to explaining the compliance-related decision-making processes that led to the chlor-alkali industry’s stewardship program and pressure-treated industry’s voluntary ban, although as discussed it is the new economy stream that explains the processes fully. Among the various factors, the roles of the government as well as the news media, and the political climate were particularly salient in both cases. In the Fugitive Mercury Stewardship Program and the Playground Campaign, the government played supporting or encouraging roles rather leadership roles. In the mercury case, the GLBTS provided the institutional forum and the EPA regulators served as facilitators at stakeholder meetings in which the Chlorine Institute presented updates on its stewardship program. Similarly, in the arsenic case, the CSPC and the EPA carried out investigations and hosted and facilitated stakeholder meetings; external experts, industry, and other stakeholders were invited to participate.

¹³⁹ Based on an August 2011 interview with former CPSC senior administrator who was at the CPSC during CPSC’s CCA investigation.

The role of the news media also contributed to the success of the green buildings network's activist campaign and the chlor-alkali industry's stewardship program, respectively. In the Playground Campaign, the news media was explosive while it was muted in the Fugitive Mercury Stewardship Program. In the mercury case, the muted media enabled the Chlorine Institute to carry out the stewardship program on its own terms without intrusion from public opinion. In the arsenic case, the extensive media coverage elevated the Playground Campaign to the national stage, which resulted in much public scrutiny on CCA-treated wood intended for residential uses. Despite the initially fragmented pressure-treated wood industry, the manufacturers responded collectively by entering into a bilateral voluntary agreement with the EPA to ban CCA in residential construction.

Furthermore, the political climate was favorable in both cases for the key instigators of policy change, namely the chlor-alkali industry in the mercury case and the green buildings network in the arsenic case. In the former case, the largely technocratic nature of toxic chemical policymaking confined the bilateral voluntary agreement to a narrow concern of industry and the regulatory communities unlike in the Playground Campaign. Thus, the chlor-alkali industry's voluntary stewardship program was largely shielded from public opinion and media attention.

By contrast, the political climate was much more contentious in the Playground Campaign. Sympathetic politicians and top administrators lent their support to the green buildings network. In particular, Ann Brown, the CPSC chairperson who was widely known for her progressive politics and special interest in children issues personally raised the profile of the CCA investigation at the CPSC.

6. CONCLUSION

This paper builds on the multiple streams (MS) framework (Kingdon, 1984). To the problem, policy, and politics streams of the MS streams framework, I add an economy stream and delineate its key variables. The economy stream explains the decisions involving regulators, corporate actors, and NGO activists that led to two distinctive bilateral voluntary agreements for reducing the industrial use of poisonous chemicals: one was an outcome of industry voluntary stewardship and the other was a result of an activist campaign.

The new economy stream explicates how the marketplace and the global economy shaped engagement between key stakeholders. Businesses are participants in the national and the global economies; their actions and their competitors' actions influence the markets in which they operate, which in turn shape and constrain problem definition, policy formulation, and the influence of politics. I contend that the existence of *product substitutes*, the extent of *market competition*, the incentives for *corporate social responsibility*, the forces of the *global economy*, and the rare but transformative role of the *market changer* plays must be taken into account when analyzing the efficacy of alternative governance approaches; these governance systems involve businesses and other third-party stakeholders more than traditional command-and-control regulation. This is particularly true for voluntary environmental programs, of which bilateral voluntary agreements are one form.

Empirically, I examine the Fugitive Mercury Stewardship Program (mercury case) and the Playground Campaign (arsenic case) under the augmented MS framework to explain how two bilateral voluntary agreements, both of which succeeded in meeting the chemical reduction objectives negotiated between regulators and businesses were outcomes of two distinctive compliance-related decision-making processes. In the mercury case, the Chlorine Institute, an

industry association, steered the technocratic process of the chlor-alkali industry's commitment to what amounted to marginal reductions in mercury use in the context of the global phase-out of mercury use in chlorine production already under way. By contrast, in the arsenic case, a coalition of environmental NGO activists led a successful grassroots campaign to compel the pressure-treated wood industry to acquiesce to an industry voluntary ban of chromated copper arsenate (CCA), an arsenic compound, in residential uses. Aggregate arsenic use in the U.S. fell significantly to levels not seen since the 1920s.

In both cases, a viable product substitute combined with fierce market competition provided the conditions for corporate actors to promote their preferred policy solutions. In the arsenic case, a top chemical manufacturer heavily marketed a poison-free product substitute in order to gain competitive advantage over rival firms; this action inadvertently conferred credibility to the NGO activists' campaign against CCA. In both cases, competing businesses colluded to safeguard their collective reputations by agreeing to reduce arsenic and mercury use, respectively, without the force of law.

In the Fugitive Mercury Stewardship Program, the chlor-alkali industry engaged in acts of corporate social responsibility to deflect regulatory scrutiny and preempt future regulation. Moreover, global economic forces, namely, the European Union's rule-making and the chlor-alkali industry's adherence to transnational private standards, further provided the conditions under which the chlor-alkali industry was able to reduce mercury use on its own terms in an industry-initiated stewardship program. On the other hand, a maverick wood treater made a "game-changing" switch to a poison-free product substitute in the Playground Campaign, which provided corroborating evidence for the activist campaign's allegations against CCA and further

fueled the Playground Campaign. Under much public pressure, the CCA manufacturers agreed to a voluntary phase-out of the use of CCA in residential applications.

This paper makes several contributions to the understanding of policy processes. First, this paper's augmented MS framework can help explain and analyze a larger class of governance systems to which voluntary environmental programs belong. For example, the augmented MS framework can be used to explain the creation and adoption of international private standards. In these forms of private regulation, multinational businesses, industry associations, and third-party non-profit organizations sponsor, create, and adopt voluntary rules and standards in a variety of policy issue areas without direct government involvement. Prominent examples include the International Council of Chemical Association's creation of the Responsible Care Program and the adoption of the various ISO series, such as environmental management and labor standards, by businesses. The augmented MS framework will have the most analytical traction when explaining how novel domestic or international policy ideas that involve private actors, markets, and the economy become part of the policy agenda and are adopted as policy solutions.

Related, my addition of the economy stream makes the MS framework more applicable across policy domains. Any policy issue area—foreign policy, trade policy, labor policy, energy policy or healthcare policy—that requires a sophisticated understanding of the way the markets and the domestic and/or the global economies form and shape the incentives of corporate actors, regulators, NGO activists, and other stakeholders will likely find the augmented MS framework to be of utility.

APPENDIX

The following is the pre-tested interview protocol that was used for interviews with industry informants. Similar protocols were used for interviews with regulators and third-party stakeholders, adapted for those said purposes.

INTERVIEW PROTOCOL

FIRMS/INDUSTRY REPRESENTATIVES

1. What was your role vis-à-vis the government in negotiating the voluntary agreement?
 - Did you *initiate* the voluntary agreement, i.e., did you approach regulators with a chemical phase-out plan already in mind?
 - Or did regulators invite you to participate in a chemical phase-out plan already crafted?
2. What specific part did you play and what specific part did the regulators play in the negotiation of the voluntary agreement?

Other stakeholders' role

3. Were other stakeholders, such as environmental and citizen groups, involved in the negotiation of the voluntary agreement?
 - If yes, which groups were involved?
 - If yes, how involved were they in the negotiation of the terms of the voluntary agreement? (*Not at all, a little, somewhat, or a lot*)
 - At which phase of the negotiation did these groups become involved? (*from the start, in the middle, or toward the end (e.g., during public comments)*)
4. What specific part did they play in the negotiation of the voluntary agreement?

Voluntary agreement objectives and terms

5. What was the voluntary agreement trying to achieve?
 - What were the immediate objectives?
 - Were there longer term objectives? If so, what are they?
6. What were the terms of the voluntary agreement?
 - What have individual firms and/or the industry as a whole agreed to do with respect to chemical phase-out?
7. What was the time frame agreed upon for achieving the chemical phase-out?

Private sector motivation/Incentives

8. What motivated firms to participate in the voluntary agreement?
9. Did regulators create incentives for firms' participation/involvement? If so, what were these incentives?

Political economy factors

10. Were there factors and/or events in *politics* (including the regulatory environment) that precipitated the creation of the voluntary agreement? If so, what were these factors and/or events?
11. Were there factors/or events in *politics* that shaped the terms of the voluntary agreement? If so, what were these factors and/or events?
12. Related, were there factors/or events in the *economy* that precipitated the creation of the voluntary agreement? If so, what were these factors and/or events?
 - What was the availability of substitute chemicals during this time?
 - Were prices of substitute chemicals falling over time?

13. Were there factors/or events in the *economy* that shaped the terms of the voluntary agreement? If so, what were these factors and/or events?

Outcome and effectiveness

14. What was the final outcome of the voluntary agreement?

- Was the reduction in toxic chemical use due to the voluntary agreement?
- Was the voluntary agreement a precursor to regulation?

15. How effective was the voluntary agreement in phasing out of toxic chemicals?

- Was the voluntary agreement *low, medium, or high* in effectiveness?

Negotiation process

16. Were you satisfied with the way the negotiation process unfolded?

- If so, what was *effective* about the way the voluntary agreement was negotiated?
- If not, what was *ineffective* about the way the voluntary agreement was negotiated?

17. If you could, what would you change about the way in which the voluntary agreement was negotiated?

18. If you could, what would you change about the terms of the agreement?

Relationship with regulators and environmental and citizen groups

19. How would you characterize your relationship with regulators?

- Is your relationship *bad, neutral, good, or very good*?

20. How would you characterize your relationship with other stakeholders, such as environmental and citizen groups?

- Is your relationship *bad, neutral, good, or very good*?

CHAPTER 4. ENVIRONMENTAL REGULATORY EFFICACY AND THE LONG-RUN POLICY HORIZON: THE CASE OF U.S. TOXIC CHEMICAL POLICY

Abstract

Time series econometric have not been widespread in the area of environmental and resource economics. One reason that may have hampered the ready use of time series econometrics is the identification problem between unit root and structural change. Accounting for one but not the other leads to bias: There is bias toward accepting a false unit root null hypothesis when structural breaks are ignored. Yet, the potential benefits of time series analysis are two folds: proper time series methods can aid in optimal regulatory policy as well as developing empirical verification of theories put forth to explain economic phenomena. Recent advances in time series econometrics have circumvented the identification problem (Harvey, Leybourne, & Taylor, 2009; M. Kejriwal & Lopez, 2010; Perron & Yabu, 2009a). This paper demonstrates the utility of employing advanced time series econometrics to investigate whether major U.S. federal regulations have had an effect on the industrial use of toxic chemicals and to determine endogenously what the time series properties of the data can reveal about policy efficacy in the long-run policy horizon. Empirical results suggest that structural changes occurred around the time of economic booms and busts, WWII, environmental regulations, and industry developments. The 1986 Toxic Release Inventory, which is an information-based regulation, has had impact on the consumptive use of more poisonous industrial chemicals than command-and-control regulations. Moreover, evidence suggests that government policies aimed at the use of *individual* toxic chemicals will likely have more restraining effect than policies that target *aggregate* chemical use or chemical use by end-use industry sectors because of the

stochastic nature of the latter series. Finally, results show that while some toxic chemicals have been successfully reduced or phased-out by regulatory efforts, a majority of the toxic chemicals used in commercial products share a long-run equilibrium with national accounts and industrial production, suggesting that toxic chemical use in the U.S. have been largely driven by changes in U.S. GDP, industrial production, and private investments in research and development, rather than by common political economic and institutional factors, such as government regulations.

Key Words: structural change, unit root, cointegration, time series, toxic chemicals, industrial pollution

1. INTRODUCTION

Time series econometric methods that are mainstay tools in applied macroeconomics and finance have not been widespread in the area of environmental and resource economics. While research over the past two decades has utilized time series techniques to confirm or deny the existence of the Environmental Kuznet Curve in OCED countries (Chang & Lee, 2008; Friedl & Getzner, 2003) and examine the stochastic properties of natural resource prices (Ahrens & Sharma, 1997; Berck & Roberts, 1996; Labson, 1995; Lee, List, & Strazicich, 2006) the dynamics of pollution data have seldom been investigated with time series analysis. Yet, the potential benefits of time series analysis are two folds: proper time series methods can aid in optimal regulatory policy as well as empirical verification of theories put forth to explain economic phenomena.

That being said, a new line of research in pollution time series dynamics is emerging. Lee and List (2004), McKittrick (2007), Fomby and Lin (2006), and Jones and Zivot (2009) investigate the time series properties of the NO_x, SO₂, and VOCs emissions: these authors focus on analyzing the effectiveness of the 1970 Clean Air Act. They have generally found evidence to suggest that that the 1970 Clean Air Act has had a permanent negative effect on air pollution. The current study contributes to this research, but what distinguishes my approach from earlier research is that I examine the effect of *multiple* policy changes on the industrial use rather than on the emissions of poisonous pollutants. Furthermore, I employ state-of-the-art techniques for estimating structural changes, detecting unit roots, and determining cointegrating relations.

One reason that may have hampered the ready use of time series econometrics is the identification problem between the existence of unit roots and structural changes.¹⁴⁰ In short, accounting for one but not the other, leads to bias. The identification problem is exacerbated by the fact that there is a circular testing problem between unit root and structural breaks. The distributions of traditional statistical tests for structural changes, i.e., shifts in trend, depend on whether the noise component of the data can be perceived as being stationary, i.e., $I(0)$, or as having an unit root, i.e., $I(1)$. Differencing the data first, as is commonly done, does not help because differenced data, which is essentially equivalent to assuming an $I(1)$ noise component, have very poor properties when the data in fact have an $I(0)$ noise component (Perron & Yabu, 2009a; Vogelsang, 1998).

Similarly, the distributions of unit root pretests to determine if the data is $I(0)$ or $I(1)$ depend on the whether or not there are structural changes and if the timing of the breaks are known. The presence of a break in slope or level can adversely affect both size and power properties of conventional unit root tests (e.g., Zivot & Andrews, 1992), where typically a structural break is allowed in the alternative but not in the null hypothesis. In effect, there is bias toward not rejecting the null hypothesis of a false unit root when structural breaks are ignored (Amsler & Lee, 1995; Perron, 1989).

Recent advances in time series econometrics have circumvented this problem of circularity (Harvey et al., 2009; M. Kejriwal & Lopez, 2010; Perron & Yabu, 2009a). The way to solve this circular problem is to have tests for structural changes in level and/or slope that are valid whether the noise components is $I(0)$ or $I(1)$ (Kejriwal & Lopez, 2010; Kejriwal & Perron,

¹⁴⁰ I refer to structural changes also as structural breaks, changepoints, structural shifts, and shifts in the mean and/or slope of the trend, depending upon the usage in the literature cited.

2010; Perron & Yabu, 2009). Once structural changes are determined or ruled out, unit roots conditional on the presence or absence of breaks can then be administered (Carrion-i-Silvestre, Kim, & Perron, 2009; Kim & Perron, 2009). A valid determination of the stochastic properties of the data enables further analysis, such as the estimation of the trend coefficients and the inference on cointegration among I(1) series.

This paper demonstrates the utility of employing advanced time series econometrics to investigate whether major U.S. federal regulations, most of which were originated after 1970, have had an effect on the industrial use of toxic chemicals and to determine endogenously what the time series properties of the data can reveal about policy efficacy over the long-run. Specifically, I ask and answer three questions. First, which of the U.S. Environmental Protection Agency (EPA) promulgated government regulations on toxic chemical use have had an effect on toxic chemical use? Second, how effective have the government and industry-sponsored voluntary programs been in reducing toxic chemical use? Third, given the economic significance of these toxic chemicals as inputs into the manufacturing of commercial products, what has had more effect on the long-run time path of these toxic chemicals—political economic and institutional factors (e.g., government regulations) or macroeconomic factors (e.g., GDP, industrial production)?

My empirical strategy is the following: I first employ recently developed tests for shifts in trend, namely Kejriwal and Perron's (2010) sequential testing procedure, with estimated break dates that have the same distribution whether the data are difference-stationary (DS) or trend-stationary (TS) to examine the time paths of 13 elemental toxic chemical use time series over the period 1900-2011, as well as the time path of these time series combined into aggregate chemical use. Furthermore, I examine the time paths of toxic chemical use in end-use industry sectors

between 1975 and 2003. For trending data like toxic chemical use (see Figures 1-10, to be discussed later), government policies or voluntary programs are said to have a permanent effect if they permanently change the trend path of the data. Existence of a trend break (i.e., a reduction in the mean and/or the slope of the trend) in toxic chemical use around the timing of a government policy provides strong evidence of the effectiveness of the policy.

Second, given the evidence of at least one structural break I apply new unit root tests which allow for the presence of multiple structural breaks in the level and the slope under both the null and alternative hypotheses (Carrion-i-Silvestre et al., 2009). Such a symmetric treatment of breaks alleviates the unit root tests from size and power problems that plague tests based on search procedures. If no evidence is found of instability either in the level or the slope, I apply the standard (no break) Augmented Dickey Fuller unit root test. A series that is $I(0)$ with a broken trend suggests that a given policy intervention will likely be relatively effective because the series/variable will remain close to the new trend (that is induced by a given policy) rather than drift in a random walk fashion. By contrast, a series represented by $I(1)$ with a broken trend suggests that the series/variable will likely drift in a random walk fashion. The empirical implication is that a given policy intervention will less likely have its intended effect in restraining toxic chemical use in the case of a unit root series with a broken trend.

Finally, for the toxic chemical series that are deterministic $I(1)$, cointegration analyses determine whether there is a long-run equilibrium relationship among chemicals that are regulated under the same laws and whether there are clusters of chemicals (e.g., end-users of the same chemicals) that share common trends, which could suggest common economic and institutional drivers. The cointegration analyses provide insights into whether the major

umbrella federal environmental legislations that regulate a wide range of industrial toxic chemicals have had a comprehensive impact as purported by law.

My empirical results show that no economic or institutional factors appear to have induced a structural shift in aggregate chemical use, i.e., when the 13 elemental toxic chemical use time series are considered together. By contrast, for a majority of the individual chemical use series, structural changes occurred around the time of economic booms and busts, World War II, environmental regulations, and industry developments. The establishment of the Toxic Release Inventory, which is an information-based regulation by the EPA in 1986 has impacted the consumptive use of more individual chemicals and end-use industry sectors than the command-and-control regulations enacted in the 1970s. There is little evidence that government sponsored voluntary programs have had a permanent effect. However, results reveal that two industry voluntary initiatives have had an impact on the trend of arsenic and mercury use; arsenic and mercury are two of the most poisonous chemicals according to the EPA.

With respect to the unit root hypothesis, evidence suggests that aggregate toxic chemical use is DS, as are the majority of end-use industry sector series. By contrast, more than half of the chemical use series at the individual chemical level are TS series. This suggests that policies aimed at the use of individual toxic chemicals will likely have more restraining impact than policies that target aggregate chemical use or chemical use by end-use industry sectors.

The test for cointegrating relations administered on toxic chemical use that are DS at all levels of aggregation/disaggregation reveals that toxic chemical use share a long-run equilibrium with macroeconomic variables. This provides further evidence that policymaking on toxic chemical use is likely to be most effective when it targets chemical use at the individual chemical level rather than aggregate chemical use or chemical use at the end-use industry sector level.

That being said, there is some evidence that the time paths of individual chemicals are cointegrated for individual DS chemicals regulated under the same laws.

The remainder of the paper is as follows. In section 2, I present background information on public policy in the U.S. regarding toxic chemical use. In section 3, I formulate hypotheses. In section 4, I show and discuss graphical results. In section 5, I present the empirical methods. In section 6, I report and discuss the results. I conclude with policy implications in section 7.

2. BACKGROUND: TOXIC CHEMICAL USE AND PUBLIC POLICY

Table 1 lists the elemental toxic chemicals under study and documents their respective commercial applications and human health hazards. These toxic chemicals are economically important: A majority of these toxic chemicals are part of the National Defense Stockpile for military industrial and essential civilian use during a national emergency (“USGS Minerals Information,” 2012). Moreover, these toxic chemicals are key inputs in the manufacturing of steel (cobalt, manganese), electronics (arsenic, beryllium, mercury), batteries (cadmium, manganese, lead), pesticides (arsenic, bromine, selenium, zinc), among other commercial products.

At the same time, in most cases these chemicals are also hazardous to human health and the environment. For example, exposure to asbestos can cause serious lung problems and cancer. Cadmium damages the kidneys, lungs, and bones. Additionally, lead, which is the EPA’s number one priority chemical, has been found to damage the nervous system, kidneys, and the reproductive system, and cause behavioral problems in children. That being said, in some cases—namely, selenium, manganese, cobalt, and zinc—small doses could help maintain good health. For example, zinc supplements have been recommended for the treatment of acute diarrhea by the World Health Organization since 2004.

Table 1
Toxic Chemicals
Commercial Applications and Health & Environmental Hazards

Elemental Toxic Chemicals	Commercial Applications	EPA Priority Ranking*	Human Carcinogen	Human Health Hazards
Antimony	Flame retardant in lead storage batteries, solder, sheet and pipe metal, bearings, castings, and pewter; enamels for plastics, metal, and glass	232		Breathing high levels of antimony for a long time can irritate the eyes and lungs, and can cause problems with the lungs, heart, and stomach.
Arsenic	Wood preservatives, input for purifying glass, semiconductors, pesticides	1	✓	At high levels, inorganic arsenic can cause death. Exposure to lower levels for a long time can cause a discoloration of the skin and the appearance of small corns or warts.
Asbestos	Construction material for insulation and a fire retardant	94	✓	Asbestos exposure can cause serious lung problems and cancer.
Beryllium	Input in nuclear weapons and reactors, aircraft and space vehicle structures, instruments, x-ray machines, and mirrors. Beryllium ores are used to make specialty ceramics for electrical and high-technology applications. Beryllium alloys are used in automobiles, computers, sports equipment, and dental bridges.	43	✓	Lung damage has been observed in people exposed to high levels of beryllium in the air. People sensitive to beryllium and may develop chronic beryllium disease, an irreversible and sometimes fatal scarring of the lungs.
Bromine	Flame retardants, drilling fluids, brominated pesticides, water treatment; input in dyes, insect	153		Unlikely to cause any human to human health or the environment in its currently-registered uses in brominated pesticides;

	repellents, perfumes, pharmaceuticals, and photographic chemicals; other applications include chemical synthesis, mercury control, and paper manufacturing			however, decabromodiphenyl ether, a brominated flame retardant is classified as possible human carcinogen for liver and thyroid cancers.
Cadmium	Rechargeable nickel cadmium batteries; pigments, coatings and plating, and as stabilizers for plastics; solar cell manufacturing.	7	✓	Cadmium damages the kidneys, lungs, and bones.
Chromium	Enhances hardenability in stainless steel and other nonferrous alloys; chrome plating, dyes and pigments, leather tanning, and wood preservatives.	78	✓	Chromium (VI) at high levels may damage the nose and cause cancer. Ingesting high levels of chromium (VI) may result in anemia or damage to the stomach or intestines. Chromium (III) is an essential nutrient.
Cobalt	A strategic and critical metal used in many industrial and military applications: aircraft engines, magnets, grinding and cutting tools, artificial hip and knee joints; color to glass, ceramics and paints; drier for porcelain enamel and paints; radioactive form used in diagnostic medicine.	52		At low levels, it is part of vitamin B12, which is essential for good health. At high levels, it may harm the lungs and heart.
Lead	Batteries, ammunition, metal products (solder and pipes), and devices to shield X-rays.	2	✓	Lead can damage the nervous system, kidneys, reproductive system, and cause behavioral problems in children.
Manganese	Enhances hardness, stiffness,	N/A		Small amounts maintain health. At high

	and strength in steel production; a gasoline additive to improve the octane rating of the gas.			levels, it may cause damage to the brain.
Mercury	Industrial chemicals (e.g., chlorine-alkali); electrical and electronic applications.	3	✓	Mercury at high levels may damage the brain, kidneys, and developing fetus.
Selenium	Electronics; nutritional supplement; pigments in plastics, paints, enamels, inks, and rubber; pharmaceuticals; pesticides; antidandruff shampoos; constituent of fungicides; radioactive form used in diagnostic medicine.	146		Small amounts maintain health, At high levels, selenium may cause neurological effects, brittle hair and deformed nails; dizziness, fatigue, irritation of mucous membranes, and respiratory effects at medium exposure.
Zinc	Coatings to prevent rust in dry cell batteries, and mixed with other metals to make alloys like brass, and bronze; zinc compounds make paint, rubber, dyes, wood preservatives, and ointments.	75		Small amounts maintain health. At high levels, zinc may cause stomach cramps, anemia, and changes in cholesterol levels.

Source: <http://www.atsdr.cdc.gov/spl/index.html>

The virtues and vices of toxic chemicals have meant that they are highly controlled substances: these toxic chemicals are target substances in all major federal environmental legislations as well as the subjects of international agreements (e.g., Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal).

U.S. industrial toxic chemical use can be demarcated into two periods: a commercial era, covering 1900 to mid-1960s and a regulatory era, spanning 1970 to present day.¹⁴¹ The regulatory era comprises of roughly three environmental governance approaches: Command-and-control regulation, environmental federalism, and private regulation. Before the mid-1960s, there was very little environmental policymaking at the federal level; whatever little government intervention occurred at the state level (Ringquist, 1993). By and large, this was an era marked by much industrial development and commercialization. The occurrence of two world wars, namely World War I and World War II (henceforth, WWI and WWII), led to the development and manufacturing of weaponry and commercial products that required toxic chemical inputs. Wartime research and development during WWII produced many chemicals with newly discovered insecticidal properties. In fact, widespread usage of pesticides garnered much public and political support due to the resulting post war food surplus made possible by higher crop yield from significantly lower pest damage (Finegan, 1988).

As the modern environmental movement gained political force (e.g., with the 1962 publication of Rachel Caron's *Silent Spring*), the federal government began to lay out broad environmental goals and required federal agencies to assess the environmental impact of their programmatic actions (R. L. Revesz & Stavins, 2007). The passage of the 1969 National

¹⁴¹ Commercial applications did not end after the “commercial era”, but rather, these toxic chemicals became subjects of regulatory scrutiny during the regulatory era.

Environmental Policy Act (NEPA) and the subsequent establishment of the EPA ushered in the environmental regulatory era (Hahn, 1990). Since then toxic but economically important chemicals have been by and large regulated by command-and-control regulations (R. L. Revesz, 2001; Stavins, 2004b). These laws have granted wide discretion to the EPA to set tolerance levels for various pollutants and limits on contaminants allowed in water systems, and to create a system of strict joint-and-several liability for parties responsible for abandoned hazardous waste sites, among other explicit directives regarding pollution control levels or methods, such as requirements by industrial plants to invest in the “best available technology economically achievable (R. L. Revesz & Stavins, 2007).”

Between 1970 and 1990, eight major federal statutes that targeted some aspect of the cradle-to-grave life cycle of toxic chemicals (from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling) across multiple media (air, water, land) were passed.¹⁴² These laws make up the core environmental statutes with which amendments have been made and new rules have been promulgated (Klyza & Sousa, 2008). Three of these laws pertained to the consumptive use of toxic chemicals in the manufacturing process: the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) of 1972, the Toxic Substances Control Act (TSCA) of 1976, and the Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986, which established the Toxics Release Inventory (TRI). The first two of the three laws were conventional

¹⁴² These legislations are: The Occupational Health and Safety Act of 1970, the Clean Water Act of 1972, the Federal Insecticide, Fungicide, Rodenticide Act of 1972, the Safe Drinking Water Act of 1974, the Resource Conservation and Recovery Act of 1976, the Toxic Substances Control Act of 1976, the Comprehensive Environmental Response, Compensation, and Liability (otherwise known as the Superfund Act) of 1980, the Emergency Planning and Community Right-to-Know Act of 1986, and the Clean Air Act of 1990.

command-and-control regulations that stipulate the use of the “best available technology economically achievable” (R. L. Revesz & Stavins, 2007), among other directives. By contrast, the third rule was the first time Congress legislated an information disclosure regulation, whereby the emphasis is on increasing the transparency of chemical hazards present in local communities. Table 2 details key attributes of these environmental laws.

The FIFRA and the TSCA are conventional command-and-control regulations. The FIFRA, the first version of which was enacted in 1910 and revised in 1947, 1972, 1988, and 1996, sets up the basic U.S. system of pesticide regulation regarding the distribution, sale, and use of pesticides.¹⁴³ Several of the toxic chemicals examined in this study are key ingredients in the manufacturing of pesticides. (Table 3 indicates which of the 13 elemental toxic chemicals examined in this paper are regulated under FIFRA and/or under other government policies and voluntary programs.)

The TSCA of 1976 grants authority to the EPA to obtain more information on targeted chemicals and to control those that pose an unreasonable risk.¹⁴⁴ TSCA places the burden of proof on the EPA to demonstrate that a chemical poses a risk to human health or the environment before the EPA can regulate its production or use (GAO, 2007). As such, not all chemicals regulated under the TSCA are subject to formal “rulemaking” even though the EPA has the authority to promulgate rules. Food, drugs, cosmetics, and pesticides, which are regulated under FIFRA are excluded from the TSCA. This means that, for example while arsenic compounds used in the manufacturing of electronics and glass are regulated under TSCA, CCA and arsenic

¹⁴³ Source: <http://www.epa.gov/lawsregs/laws/fifra.html> (Retrieved June 13, 2012)

¹⁴⁴ Source: <http://www.epa.gov/lawsregs/laws/tsca.html> (Retrieved June 13, 2012)

acid, which are pesticides for preserving wood and treating cotton, respectively, are excluded from the TSCA.

**Table 2
Federal Regulations on Toxic Chemical Use**

Federal Regulations	Descriptions
Fungicide, and Rodenticide Act (FIFRA) of 1972	Command-and-control; Before a pesticide could be registered for use, the applicant must show, among other things that using the pesticide according to specifications “will not generally cause unreasonable adverse effects on the environment.” ¹⁴⁵ The EPA is authorized by FIFRA to establish maximum levels for pesticide residues in food. Pesticides that have been already registered must undergo a periodic reregistration review process whereby a formal risk assessment with new information is conducted.
Toxic Substances Control Act (TSCA) of 1976	Command-and-control; TSCA authorizes the EPA to obtain information on chemicals through reporting, record-keeping and testing requirements, and to control those that pose an unreasonable risk. Not all chemicals regulated under the TSCA are subject to formal “rulemaking” even though the EPA has the authority to promulgate rules if deemed necessary. Food, drugs, cosmetics and pesticides, which are regulated under FIFRA are excluded from the TSCA.
Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986, which established the Toxic Release Inventory (TRI)	Information disclosure; EPCRA established the Toxics Release Inventory (TRI), which requires manufacturing companies in certain industrial sectors to publicly report environmental releases and transfers of toxic chemicals. Manufacturing companies across a wide range of industries, including paper, gas, metal mining, coal mining, electric utilities, chemical wholesale distributors, hazardous waste management facilities and solvent recovery facilities that produce more than 25,000 pounds or 10,000 pounds a TRI-listed toxic chemical must report it to the TRI.

Source: US. EPA.

Environmental federalism was first articulated in President Reagan’s 1982 Economic Report of the President (Council of Economic Advisors, 1982). The basic idea is that the

¹⁴⁵ FIFRA defines the term “unreasonable adverse effects on the environment” to mean: “(1) any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of any pesticide, or (2) a human dietary risk from residues that result from a use of a pesticide in or on any food inconsistent with the standard under section 408 of the Federal Food, Drug, and Cosmetic Act.”

responsibility for providing a particular service should be placed with the smallest jurisdiction whose boundaries encompass the various benefits and costs associated with the provision of the service (Oates & Portney, 2003). The passage of the EPCRA in 1986 occurred during this period when environmental policymaking was substantially shifted from the federal level to the state and local levels and to the private sector in the form of government-industry collaborations.

The 1986 EPCRA is an explicit effort by the government at “regulation through-information,” whereby private individuals, businesses, non-profit organizations, and government entities are provided with pertinent information concerning potential chemical hazards present in their communities, so that they could assess current environmental conditions and status of various environment programs for policymaking at the local and state levels. Toward this effort, the EPCRA established the Toxics Release Inventory (TRI), which is a compulsory information disclosure policy whereby manufacturers across a myriad of toxic chemical using industries to publicly report environmental releases and transfers of toxic chemicals. No legal limits are set with respect to permissible exposure or contamination (henceforth the EPCRA is referred to as the TRI).

Environmental federalism led the way to innovations in private forms of regulation.¹⁴⁶ By President Bush Sr.’s second term (1989-1993), there was an increase in an emphasis away from mandatory government intervention toward voluntary programs, government-industry cooperation, and the use of market incentives in an eye toward towards cost-effectiveness (Hahn, Olmstead, & Stavins, 2003; Hahn, 1990).

¹⁴⁶ Private regulations employ private, nongovernment, or market-based regulatory frameworks to govern multinational firms and global supply networks. A defining feature of private regulations (or civil regulations) is that their legitimacy, governance, and implementation is not rooted in government authority (Vogel, 2010) .

In the face of excess costs and untapped benefits, regulators increasingly recognize that firms' internal management is an important ingredient in combating the nation's environmental problems (Coglianese & Nash, 2006). One such alternative approach is voluntary programs, which are a form of private regulation that is based on the exchange between government and business on the design of a framework of incentives in a context of cooperation (Crocì, 2005). Voluntary programs impose obligations on firms that are beyond the legal requirements (or where the law is silent) to induce them to voluntarily reduce pollution and adopt pollution abatement technologies. These programs are sponsored by the government, firms, industry associations, or non-governmental organizations (NGOs).

There have been a handful of industry-sponsored voluntary programs to phaseout or ban specific toxic chemicals (see the last column of Table 3). High profile industry-initiated programs include the 2003 voluntary agreement by the pressure-treated wood industry to ban chromated copper arsenate, a poisonous arsenic compound, in residential applications, and the 1998 voluntary stewardship initiative by the chlor-alkali industry to reduce mercury use in chlorine production.

Two prominent government-sponsored voluntary programs pertaining to toxic chemical use are the 1996 Great Lakes Binational Toxic Strategy (GLBTS) and the EPA's 1998 High Production Volume (HPV) Challenge. The GLBTS was an environmental forum on the Great Lakes Basin between Canada and the U.S where voluntary national goals for the "virtual elimination of persistent toxic substances", including cadmium, mercury, and lead were set.¹⁴⁷ The GLBTS was formed on the premise of stakeholder involvement in solving industrial pollution problems: state and provincial and tribal governments, industry, and NGOs were

¹⁴⁷ Source: <http://www.epa.gov/bns/> (retrieved May 30, 2011)

invited to assist in developing and implementing pollution control strategies for all the target toxic chemicals. The chlor-alkali industry's stewardship program was an outcome of the GLBTS.

The HPV Challenge Program invited firms and industries to make health and environmental effects data publicly available on chemicals produced or imported in the U.S. HPV chemicals are classified as those chemicals produced or imported in the U.S. in quantities of 1 million pounds or more per year. More than 2,200 HPV chemicals have been "sponsored" by industry, including several of the toxic chemicals in this study (see Table 3).¹⁴⁸

Table 3 contains information about which of the government regulations and private regulations described above are the toxic chemicals a subject of in this study.

¹⁴⁸ Source: <http://www.epa.gov/hpv/pubs/general/basicinfo.htm> (retrieved September 25, 2012)

**Table 3
Toxic Chemicals
Government and Private Regulations**

Elemental Toxic Chemicals	Government Regulation					Private Regulation
	1972 FIFRA	1976 TCSA	TCSA Rule-Making	1986 TRI	Other Regulatory Actions	Voluntary Programs
Antimony		✓		✓		1998 HPV Challenge Program
Arsenic	✓	✓		✓		1993 Arsenic Acid Voluntary Ban; 2003 Chromated Copper Arsenate Voluntary Ban (a widely used wood preservative)
Asbestos		✓	✓	✓	1977 CPSC Regulatory Ban on Textured Paint, Wall Patching Compounds; 1989 Asbestos Ban and Phaseout Rule overturned by 1991 Fifth Circuit Court of Appeals; revised to ban certain asbestos-containing products and new uses of asbestos.	
Beryllium		✓		✓		
Bromine	✓			✓		2012 decabromodiphenyl ether (Deca-BDE) Voluntary Ban (a widely used flame retardant)
Cadmium		✓		✓		1998 HPV Challenge Program; A Great Lakes Binational Toxics Strategy Substance
Chromium		✓		✓		

Cobalt		✓		✓		1998 HPV Challenge Program
Lead		✓		✓	1973 EPA Initial Phaseout of Lead; 1982-1987 Phaseout Continued; 1992 Residential Lead-Based Paint Hazard Reduction Act; 1996 Regulatory Ban on Lead gasoline;	1998 HPV Challenge Program; Great Lakes Binational Toxics Strategy Substance
Manganese	✓	✓		✓		1998 HPV Challenge Program
Mercury		✓		✓	Mercury-Containing and Rechargeable Battery Management Act of 1996; Mercury Export Ban Act of 2008; 2005 Clean Air Mercury Rule; SNUR 2012, 2010, 2007	Great Lakes Binational Toxics Strategy Substance; 1998 Chlor-alkali Mercury Cells Voluntary Phaseout
Selenium	✓	✓		✓		
Zinc	✓	✓		✓		

Source: U.S. EPA.

3. HYPOTHESES REGARDING REGULATORY EFFICACY AND LONG-RUN IMPACT

Which of the government regulations—the command and control regulations (1972 FIFRA, 1976 TCSA) or the information-based regulation (1986 TRI)—have had an effect on toxic chemical use? How effective have the various voluntary programs been in reducing toxic chemical use? Moreover, given the economic significance of these toxic chemicals as inputs into the manufacturing of commercial products, what have had more effect on the long-run time path of these toxic chemicals—political economic and institutional factors (e.g., government regulations) or macroeconomic factors (e.g., GDP, industrial production)?

The general consensus among economists and policy researchers is that command-and-control regulations have been overly prescriptive and burdensome on firms and industries and do not pass benefit-cost tests (Fung & O'Rourke, 2000; Hahn, 2000; R. L. Revesz & Stavins, 2007; Stavins, 2004b). The government's own evaluations of the TSCA find the law to place too much burden on the EPA to demonstrate that a chemical poses a risk to human health or the environment before the EPA can promulgate formal rules to regulate its production or use (GAO, 1994, 2005, 2007). This suggests that the TSCA has not had the much opportunity to be “effective” in reducing toxic chemical use.¹⁴⁹

Studies have shown the TRI to be effective under certain conditions, such as when decision-makers use the disclosed information for everyday decision-making (Khanna, Quimio, & Bojilova, 1998; Weil, Fung, Graham, & Fagotto, 2006).

¹⁴⁹ The EPA has promulgated regulation for less than a dozen toxic chemicals since the passage of TSCA (asbestos is one of them; see Table 3).

By contrast, studies on the effectiveness of voluntary programs have generally been mixed. Government-sponsored and industry-initiated voluntary programs have tended to yield modest or no impact on abating pollution (Antweiler & Harrison, 2007; Gamper-Rabindran & Finger, 2012; Gamper-Rabindran, 2006; Morgenstern & Pizer, 2007; Takahashi et al., 2001; Vidovic & Khanna, 2007b; Welch et al., 2000). However, bilateral voluntary agreements negotiated between government and industry that stipulate guidelines for compliance and sanctions for noncompliance have fared considerably better than other types of voluntary programs in their efficacy (T. Arimura et al., 2008; Darnall & Kim, 2012; Dasgupta et al., 2000; Glachant & Muizon, 2007; Hsueh, 2012c; Krarup & Millock, 2007; Morgenstern & Pizer, 2007; Potoski & Prakash, 2005).

The availability of toxic chemical use time series from the USGS permits an evaluation of the effectiveness of multiple government policies on reducing toxic chemical use. Structural break analysis adjudicates the efficacy of the various forms of government regulations, and government-sponsored and industry-initiated voluntary programs, respectively. Government policies or voluntary programs are said to have a permanent effect if they permanently change the trend path of the data (Fomby & Lin, 2006; Jones & Zivot, 2009). As such, existence of a trend break (reduction in the mean and/or the slope of the trend) in toxic chemical use around the timing of a government policy provides strong evidence of the effectiveness of the policy.

An analysis of the time series properties of the data reveals insights into policy efficacy in the long-run policy horizon. A series that is $I(0)$ with a broken trend suggests that a given policy intervention will likely be relatively effective because the series/variable will remain close to the new trend (that is induced by a given policy) rather than drift in a random walk fashion. By contrast, a series represented by $I(1)$ with a broken trend suggests that the

series/variable will likely drift in a random walk fashion. The empirical implication is that a given policy intervention will less likely maintain its intended effect in restraining toxic chemical use over the long-run in the case of a unit root series with a broken trend.

Aside from unit root tests, a cointegration analysis determine whether there is a long-run equilibrium relationship among chemicals that are regulated under the same laws and whether there are clusters of chemicals (e.g., end-users of the same chemicals) that share common trends, which could suggest common economic and institutional drivers.

I propose three hypotheses to answer the above research questions on regulatory efficacy. Corollaries that follow each hypothesis indicate what each of the hypotheses implies for the paper's structural change estimations, unit roots tests, or cointegration analysis.

Hypothesis 1: Command-and-control regulations have not been in general effective in reducing aggregate toxic chemical use but have been variably effective in reducing toxic chemical use in specific chemicals and/or industries. By contrast, the information disclosure rule has been more successful in reducing toxic chemical use. Moreover, regulatory actions that target specific toxic chemicals and/or industries have been effective in reducing toxic chemical use.

- 1) *Corollary:* Structural breaks should correspond to the passage of the 1986 TRI and industry-specific regulatory actions rather than command-and-control regulations in aggregate chemical use and consumptive use of individual chemicals and end-use industry sectors.
- 2) *Corollary:* Chemicals that regulated under same law more likely to be cointegrated.

Hypothesis 2: Government-sponsored voluntary programs do not have an effect on toxic chemical use, while industry initiated voluntary phase-outs and bans in specific toxic chemicals and/or industries have been effective in controlling toxic chemical use.

1) *Corollary:* Structural breaks should correspond to industry-specific voluntary programs to reduce toxic chemical use rather than government-sponsored voluntary programs.

Hypothesis 3: On the whole, toxic chemical use has been more affected by business cycles than political and institutional factors in the long-run horizon.

- *Corollary:* Structural breaks should correspond to business cycle expansions and contraction, for example, at the start or the end of wars or during periods of industrial development and commercialization rather than coincide with government regulations or voluntary programs.
- *Corollary:* Chemicals with unit roots are likely to be cointegrated with national accounts and industrial production.

Hypothesis 4: The effectiveness of government interventions in the long-run policy horizon is dependent on whether toxic chemical use is stationary or stochastic.

4. TOXIC CHEMICAL USE DATA AND GRAPHICAL PRESENTATION

In this paper, I analyze the consumptive time path of 13 elemental toxic chemicals from the United States Geological Survey (USGS).¹⁵⁰ Table 4 lists these chemicals alphabetically and details their respective data availability from the USGS, including end-use panel data. By and large, data for chemical use by individual chemicals are available from 1900 through 2011.

Toxic chemical use data are a combination of published and calculated industrial use data. Use data are estimated by the USGS using the following equation for most years: Chemical Use =

¹⁵⁰ To my knowledge, there is no other source of comprehensive data for the industrial use of toxic chemicals. Data are publically available on the USGS website (<http://minerals.usgs.gov/ds/2005/140/>). The USGS houses data on the production, trade, and commercial use of over 80 mineral commodities in the U.S. This paper is only concerned with 13 of these minerals, which are elemental toxic chemicals that are naturally occurring or are byproducts of industrial processes and are used as key inputs in the manufacturing of commercial products.

Production + Imports – Exports ± Stock Changes. Data for the other years come from published data from the USGS Mineral Facts and Problems and the Mineral Yearbook.

Table 4
Toxic Chemical Use
Data Availability

Elemental Toxic Chemical Use	Data Availability	
	USGS Annual Data	USGS End-Use Panel Data
Antimony	1900-2011	
<i>Glass (12%)</i>		1975-2003
<i>Chemicals (16%)</i>		1975-2003
<i>Flame Retardants (36%)</i>		1975-2003
<i>Transportation incl. Batteries (23%)</i>		1975-2003
<i>Other Applications (13%)</i>		1975-2003
Arsenic	1900-2011	
<i>Pressure-treated Wood (88%)</i>		1975-2004
<i>Agriculture (4%)</i>		1975-2004
<i>Glass (4%)</i>		1975-2004
<i>Electronics (4%)</i>		1975-2004
Asbestos	1910-2011	
<i>Friction Products (7%)</i>		1975-2001
<i>Packing Products (15%)</i>		1975-2002
<i>Roofing Products (69%)</i>		1975-2003
Beryllium	1935-2011	
<i>Aerospace (10%)</i>		1975-2003
<i>Electrical (23%)</i>		1975-2003
<i>Electronics (63%)</i>		1975-2003
<i>Other Applications (5%)</i>		1975-2003
Bromine	1900-2006	N/A
Cadmium	1903-2011	
<i>Batteries (78%)</i>		1975-2003
<i>Coating (8%)</i>		1975-2003
<i>Paint Pigments (12%)</i>		1975-2003
<i>Plastics (2%)</i>		1979-2003
Chromium	1900-2011	
<i>Metal (90%)</i>		1975-2003
<i>Other Applications (10%)</i>		1975-2003

Cobalt	1900-2011	
<i>Cement (9%)</i>		1975-2003
<i>Chemicals (26%)</i>		1975-2003
<i>Magnetic Alloys (4%)</i>		1975-2003
<i>Steel (17%)</i>		1975-2003
<i>Superalloys (45%)</i>		1975-2003
Lead	1900-2011	
<i>Brass (2%)</i>		1975-2003
<i>Glass & Paint Pigments (3%)</i>		1975-2003
<i>Gasoline (N/A)</i>		1975-1994
<i>Lead Sheet (1%)</i>		1975-2003
<i>Solder (3%)</i>		1975-2003
<i>Batteries (88%)</i>		1975-2003
<i>Other Applications (3%)</i>		1975-2003
Manganese	1900-2011	
<i>Steel (81%)</i>		1975-2003
<i>Cast Iron (2%)</i>		1975-2003
<i>Alloys (4%)</i>		1975-2003
<i>Batteries (8%)</i>		1975-2003
<i>Chemicals (5%)</i>		1975-2003
Mercury	1900-2000	
<i>Chemicals (63%)</i>		1975-2002
<i>Electronics & Electrics (16%)</i>		1975-2002
<i>Instruments (21%)</i>		1975-2002
Selenium	1910-2011	
<i>Glass (35%)</i>		1975-2003
<i>Chemicals (20%)</i>		1975-2003
<i>Electronics (12%)</i>		1975-2003
<i>Other Applications (33%)</i>		1975-2003
Zinc	1900-2011	
<i>Galvanizing (55%)</i>		1975-2003
<i>Brass (13%)</i>		1975-2003
<i>Alloys (17%)</i>		1975-2003
<i>Other Applications (15%)</i>		1975-2003

Source: USGS.

Data between 1975 and 2003 are available for end-use sectors of all but the following toxic chemicals: bromine (no end-use data available), cadmium (1979-2003), and mercury

(1975-2000). The estimated end-use distributions are based on apparent demand information collected from industry contacts and Internet sources.¹⁵¹ End-use figures sum up to total use figures.

In this paper's time series analyses, the toxic chemical series are in their natural log form. The log transformation of toxic chemical use retains the structure of the data but reduces fluctuation. Specifically, the logarithm function squeezes the outliers of high values by pulling the outliers back in closer to the rest of the data; in essence the log transformation stabilizes the variance of the data. For the sake of brevity, I refer to the natural logarithm of toxic chemical use as toxic chemical use (arsenic use, mercury use, and so on) for the rest of the paper.

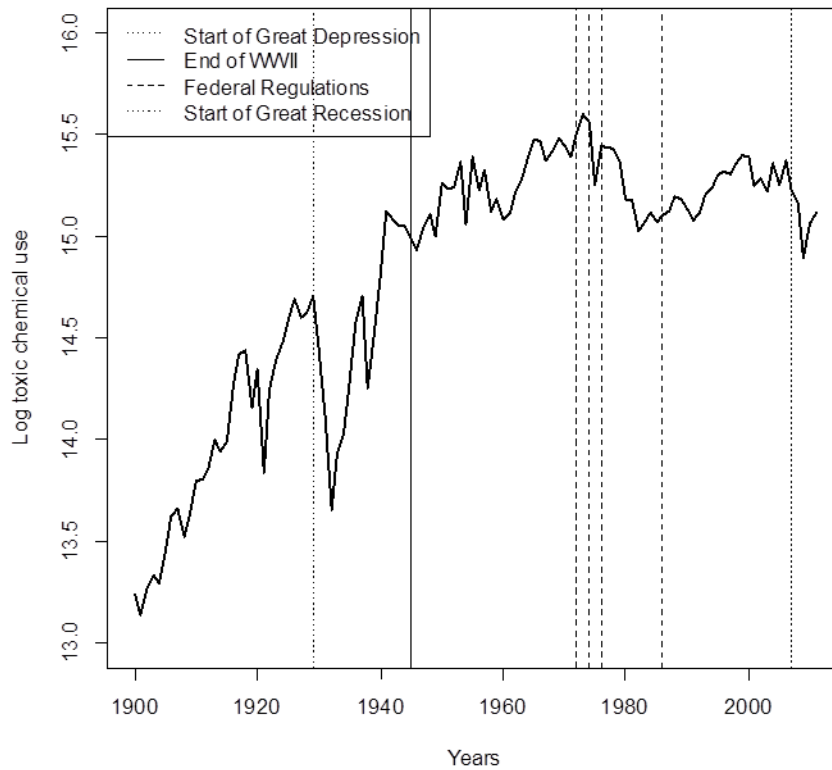
Figure 1 graphs the time path of *aggregate* toxic chemical use, i.e., the summation of the individual 13 toxic chemical use time series. The dotted vertical lines represent the start of the Great Depression (1929) and the start of the Great Recession (2007). The end of WWII (1945) and the 1973 Oil Crisis (1973) are shown by the solid vertical lines. The dashed vertical lines represent the federal regulations that pertain to toxic chemical use: FIFRA (1972); the TSCA (1976); and the TRI (1986).

There was substantial growth in the industrial use of toxic chemicals during the first half of the 20th Century, albeit a sharp decline was observed in the late 1920s and early 1930s, which coincided with the Great Depression. Post WWII marked the beginning of a period of fluctuating but overall subdued growth relative to the first half of the 20th Century (the regulatory era). After the 2007 Great Recession toxic chemical use decreased to a level not seen since the Second World War.

¹⁵¹ This information is provided in an email exchange on May 11, 2009 between the author and Dr. William E. Brooks, the commodity specialist at the USGS for Silver, Mercury, and Arsenic.

Figure 1

Aggregate Toxic Chemical Use



Source: USGS.

Figures 2-4 show toxic chemical use of the individual 13 elemental toxic chemicals. To ease comparison among toxic chemicals, the y-axis of all 13 toxic chemical use figures is in the range of 2 and 14 log points (with the exception of cadmium and selenium use, which starts with 1 log-point). The dotted vertical lines represent the start of the Great Depression (1929) and the start of the Great Recession (2007). The end of World War II (1945) is shown by the two-dashed vertical line. The dashed vertical lines represent the federal regulations that pertain to the consumptive use of specific toxic chemicals: Amendments to the FIFRA (1972) or the TSCA (1976); and the TRI (1986). Furthermore, industry developments are shown by solid lines.

Figure 2 Panel A

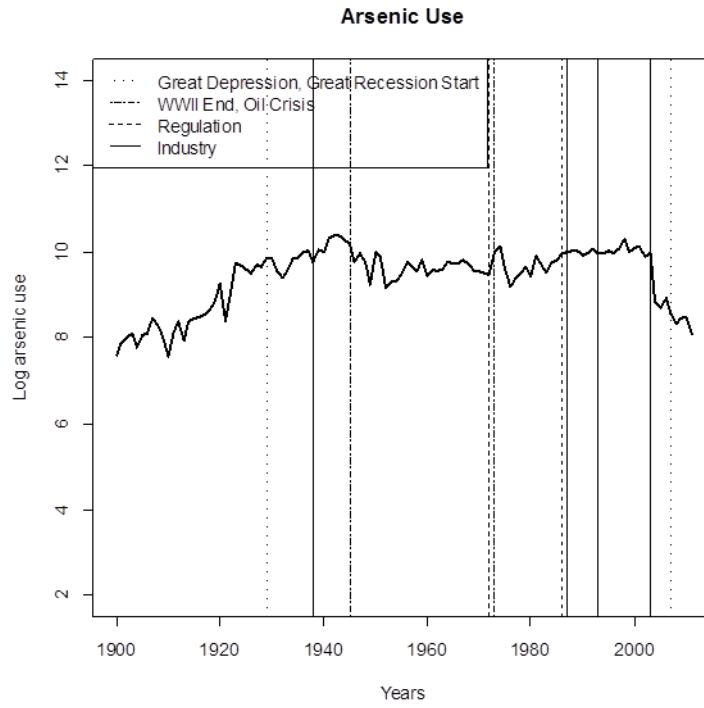


Figure 2 Panel B

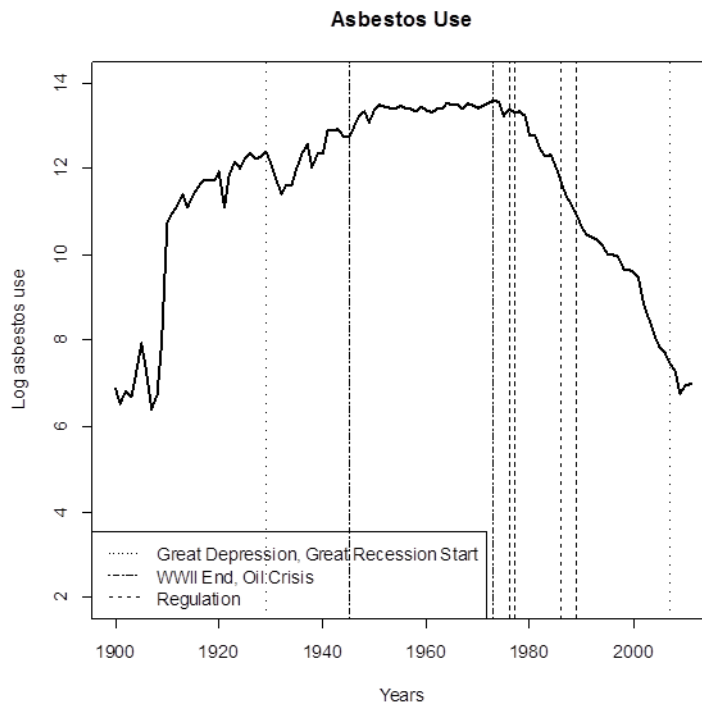


Figure 2 Panel C

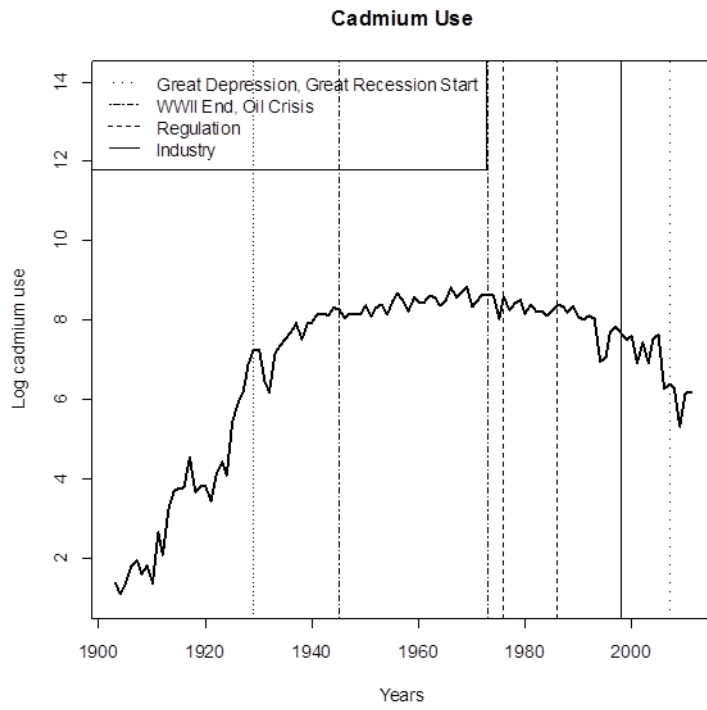
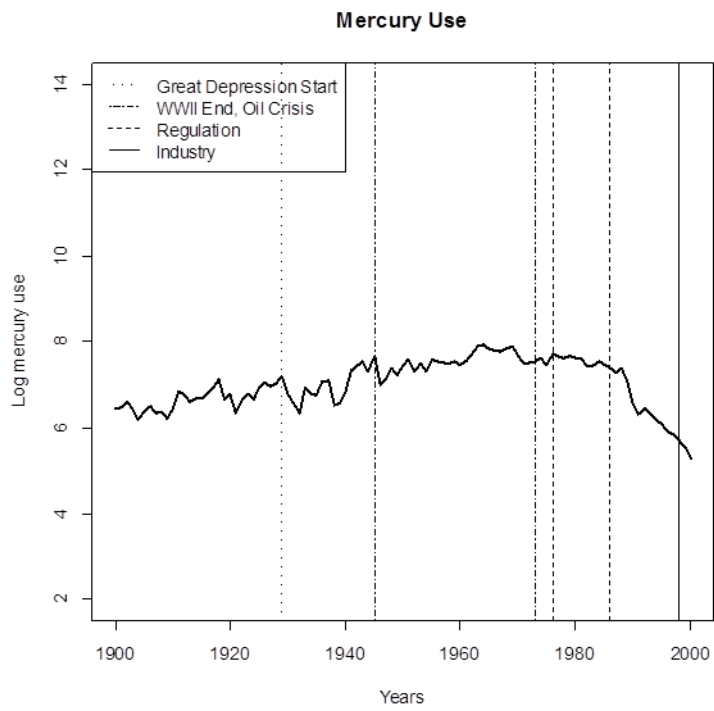


Figure 2 Panel D



By visual inspection I categorize toxic chemical use into three categories: The first category is the “Environmental Kuznets Curve” or *EKC* chemicals. Figure 2 Panels A-D show the chemical use time paths of arsenic, asbestos, cadmium, and mercury.¹⁵² These four toxic chemical use time series appear to be inverted U-shaped by visual inspection: arsenic, asbestos, cadmium, and mercury use have risen to their peaks and have since declined to levels that are at or below levels recorded in the early 1900s. In fact, mercury use is currently below its 1900 level. An informal inspection of these plots suggest the possibility of at least one level and/or slope shift (i.e., structural break) in the trend function of the toxic chemical use time paths corresponding to political, economic or institutional shocks.

The second category of chemicals is the “Kinked growth” or the *kinked growth* chemicals. Figure 3 Panels A-E show the consumptive use time paths of five toxic chemicals: Chromium, cobalt, manganese, selenium, and zinc. These toxic chemicals, particularly chromium, manganese, and zinc, are used in high quantities in commercial applications. By visual inspection, all use series show share the same feature of a steady rise and then a kink-like turning point, at which point consumptive use of the said chemicals flattens out to what appears to be steady horizontal growth with little perturbation. The by and large well defined time paths of these toxic chemicals suggest that they are likely to be stationary with a structural break at the kink-like turning points.

¹⁵² I categorize toxic chemicals according to what they appear visually in the aggregated data. The time path plots of the disaggregated data, namely industry sector end-use series, may deviate from these trends due to industry sector specific factors. Of note, while my analyses are organized according to these categories they do not drive the empirical results because I have not excluded models/analyses that depart from these categories. For example, to test for evidence of cointegrating relationships among chemicals regulated under the same laws, I consider the difference-stationary *EKC* chemicals and *growth* chemicals separately and then all possible pairs of *EKC* and *growth* chemicals together (see Table 10).

Figure 3 Panel A

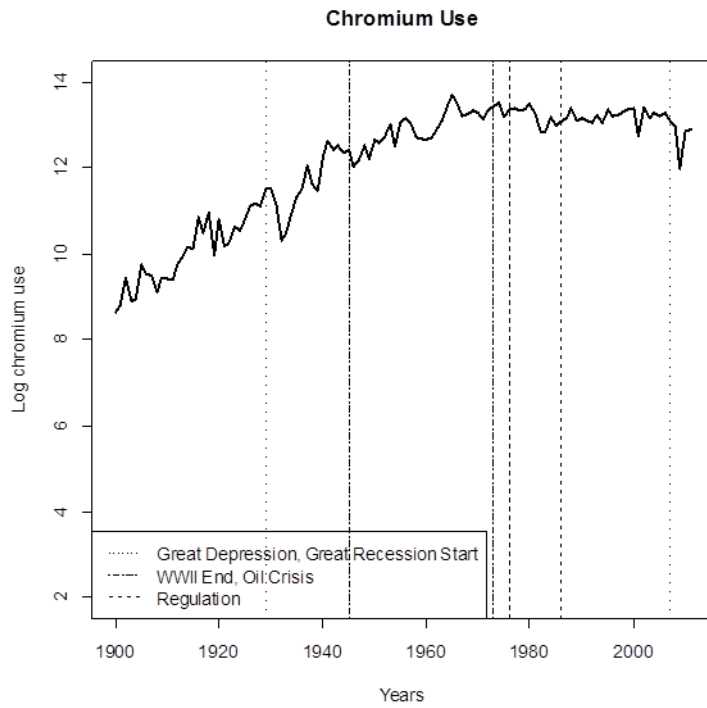


Figure 3 Panel B

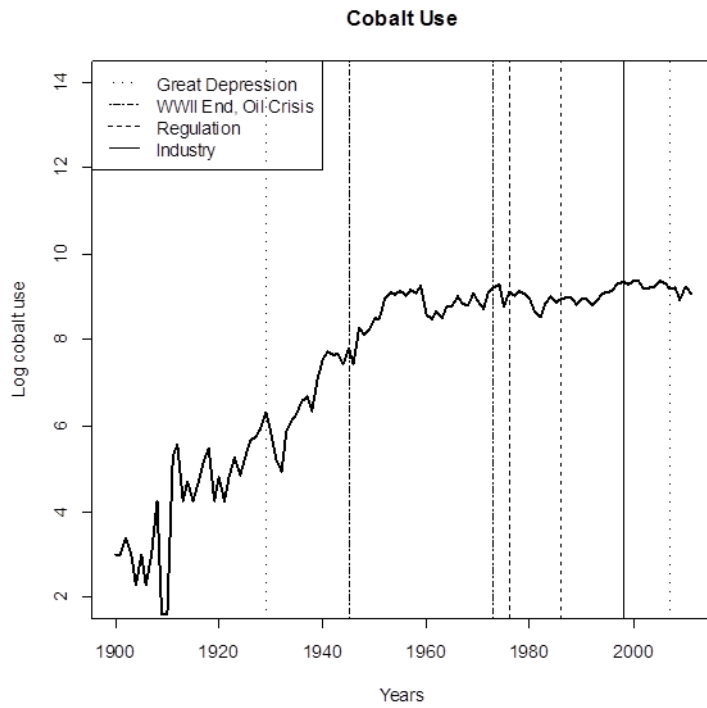


Figure 3 Panel C

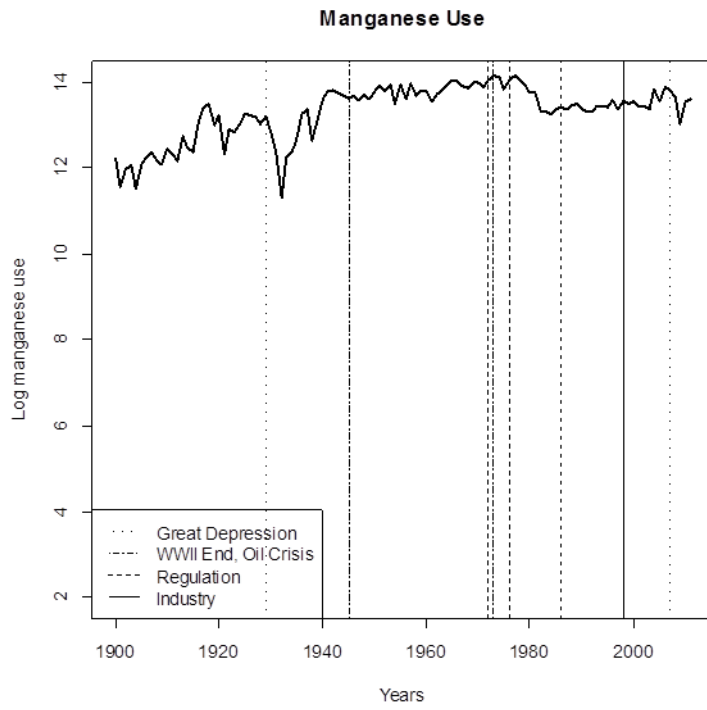


Figure 3 Panel D

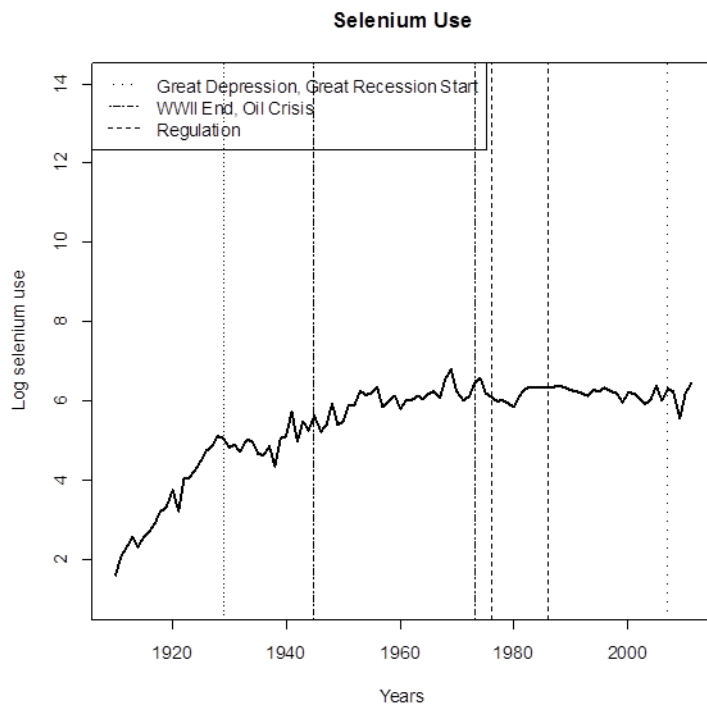
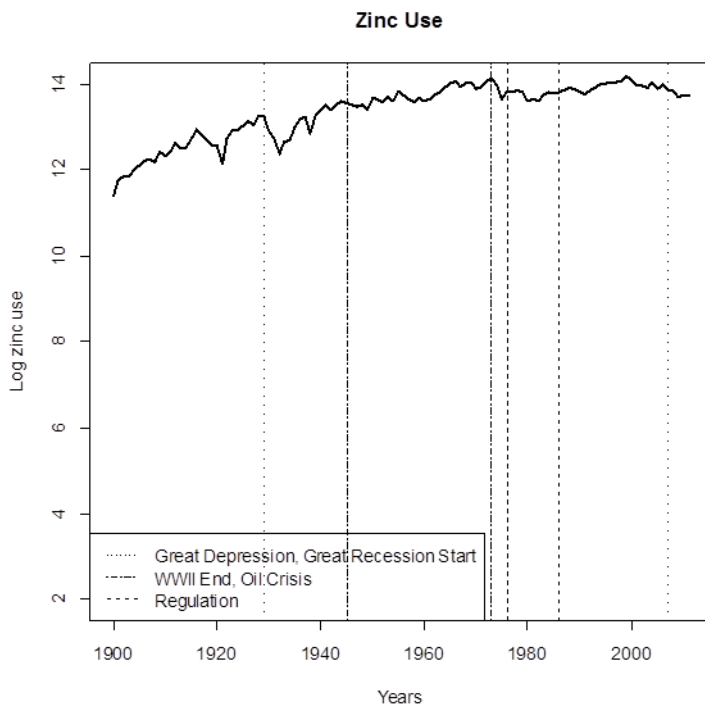


Figure 3 Panel E



Additionally, a third category of toxic chemical use time paths can be identified.

Antimony, bromine, and lead appear to be “Growth” or *growth* chemicals by visual inspection.

By visible inspection, their time paths (see Figure 4 Panels A-D) appear to be by and large upward sloping without much, if at all, heeding to economic or institutional shocks. These toxic chemical use series are likely to contain a unit root and exhibit a cointegrating relationship with macroeconomic series, such as GDP growth and/or industrial production.

Figure 4 Panel A

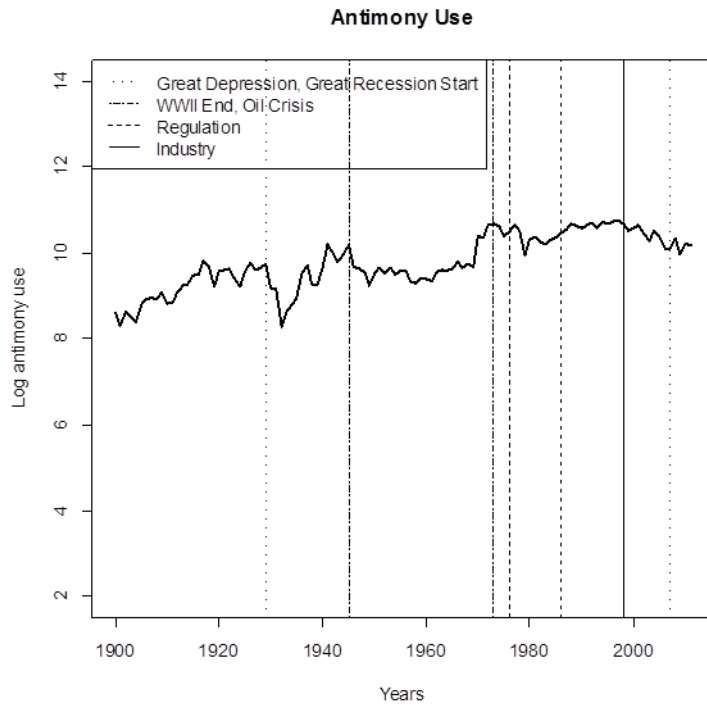


Figure 4 Panel B

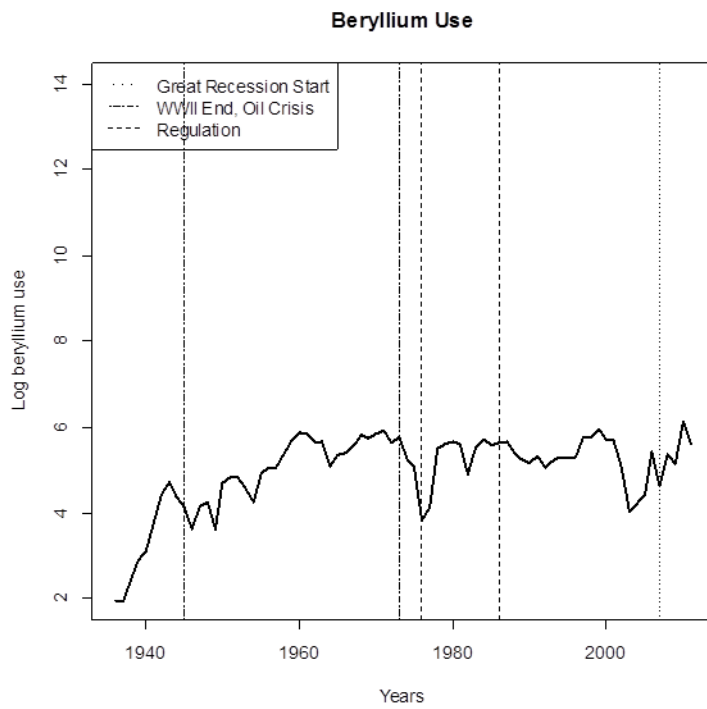


Figure 4 Panel C

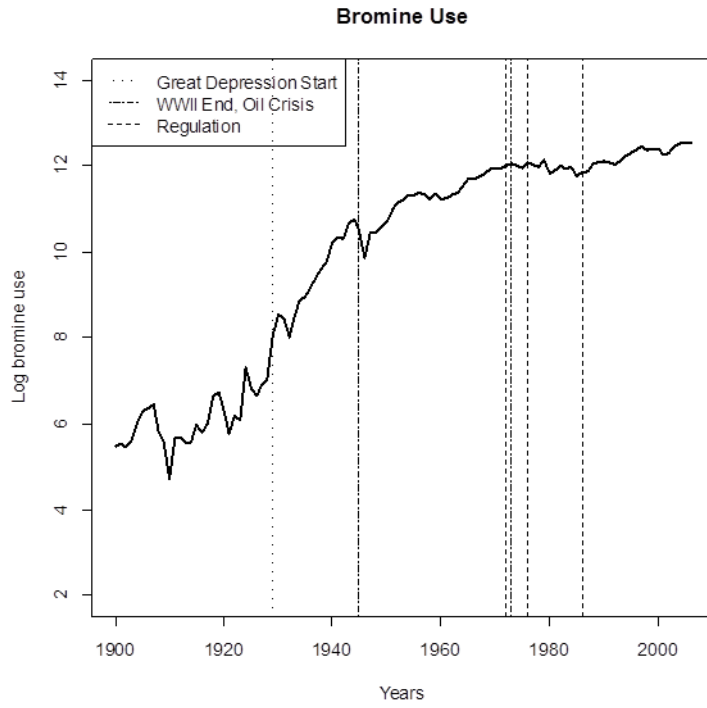
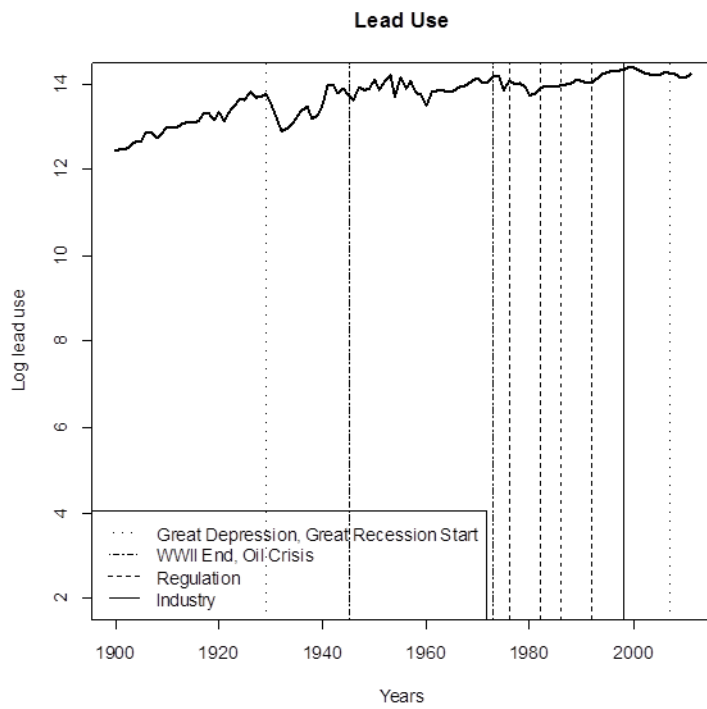


Figure 4 Panel D



Finally, the nature of structural shifts in these toxic chemical use time paths have implications for the time series analyses that follow. While some shifts in the trend of the toxic chemical use series appear gradual and other shifts appear sudden, most changepoints appear by visual inspection to have occurred abruptly, whether the changes are in the mean (“crash”) or the slope (“changing growth”) of the trend function. This suggests that the most appropriate model is likely to be the additive outlier (AO) model, which corresponds to sudden changes, rather than the innovation outlier (IO) model, which corresponds to gradual changes.¹⁵³ As such, for this paper’s empirical analysis, I employ Carrion-i-Silvestre, Kim, and Perron’s unit root tests allowing for multiple breaks, which are based on additive outlier (AO) models as defined in Perron (1989). Related, the Kejriwal and Perron’s sequential procedure to determine the number of structural breaks while invariant to I(O) or I(1) noise component allows for both shifts in the mean and the slope in the trend (“mixed change”).

5. EMPIRICAL METHODS

My approach to identifying the major economic and institutional drivers of toxic chemical use is to estimate structural breaks, test for the presence of unit roots, and search for evidence of cointegrating relationships among chemicals regulated under the same laws and between chemical use and national accounts and industrial production. In particular, I apply the following three-step process to analyzing aggregate toxic chemical use, toxic chemical use by individual chemicals, and toxic chemical use by individual chemical sectors: (1) estimate

¹⁵³ By definition, an additive outlier is an outlier that affects a single observation. After this disturbance, the series returns to its normal path as if nothing has happened. By contrast, an innovative outlier is an outlier that acts as an addition to the error or noise component at a particular point in the time series. It is the type of outliers that affects the subsequent observations starting from its position or an initial shock that propagates in subsequent observations.

structural breaks by testing for shifts in trend with estimated break dates that have the same test statistics distribution whether the data are DS or TS; (2) administer a formal test of non-stationarity with a test for a unit root that allow for multiple structural breaks under the null and the alternative hypotheses conditional on zero or one or more breaks from (1); and (3) test for evidence of cointegrating relationships allowing for structural shift among chemicals regulated under the same laws and between chemical use and national accounts and industrial production.¹⁵⁴

5.1 Multiple Structural Breaks

As laid out in the introduction, a well-known problem in time series econometrics is the identification problem between structural changes and unit roots. A practical consequence of the identification problem is that there is a bias toward not rejecting the presence of a unit root null when structural breaks are ignored (Amsler & Lee, 1995; Perron, 1989). That being said, distributions of traditional statistical tests for shifts in trend depend on whether the data is DS or TS. Recent advances in time series econometrics have circumvented this problem of circularity (Harvey et al., 2009; M. Kejriwal & Lopez, 2010; Perron & Yabu, 2009a). This paper employs Kejriwal and Perron's (2010, henceforth KP) sequential procedure to determine the number of breaks while allowing for estimated break dates to have the same distribution whether the noise component of the data is integrated or stationary.

¹⁵⁴ I administer the LST test which permits a structural shift in *all* cases to allow for the fact that even if an individual chemical use series or end-use series does not have a changepoint, a linear combination of the chemical use series or end-use series could contain a structural break.

For the ease of exposition, I first present the model for one break (Perron & Yabu, 2009a) and then extend it to the multiple breaks case (Mohitosh Kejriwal & Perron, 2010). Consider the following data generating process for a scalar random variable y_t :

$$\begin{aligned}
y_t &= \mu_0 + \mu_1 DU_t + \beta_0 t + \beta_1 DT_t + u_t = x_t' \Psi + u_t \\
DU_t &= 1(t > T_B), \quad DT_t = 1(t > T_1)(t - T_1) \\
u_t &= \rho u_{t-1} + v_t, \quad v_t \sim iid(0, \sigma_v^2) \\
x_t &= (1, DU_t, t, DT_t)', \quad \Psi = (\mu_0, \mu_1, \beta_0, \beta_1)' \\
T_1 &= \text{break date}, \quad \lambda_1 = T_1 / T = \text{break fraction}
\end{aligned} \tag{1}$$

T_1 is the true break date, which occurs at some fraction λ of the time period T . The unknown parameters in (1) are μ_1 , β_0 , and β_1 . This is a general model that allows for structural change in both intercept and slope, i.e., a “mixed” model: DU_t is an indicator variable that specifies when there is a change in the intercept. DT_t is an indicator variable that specifies when there is a change in the slope. In the context of industrial toxic chemicals, shifts in trends could be gradual or abrupt, depending on the nature of the political economic or institutional shocks that affect toxic chemical use. For example, abrupt changes could be induced by sudden and unexpected catastrophic event, such as an industrial chemical spill that prompts immediate institutional response to ban the use of a certain chemical. By contrast, there could be a gradual decline in the use of toxic chemicals for non-growth chemicals and end-use industry sectors.

For the noise component of the model, u_t , I focus on the AR(1) case (although a more generalized error structure could be utilized). The parameter ρ lies between -1 and 1, such that u_t can be stationary or have a unit root. v_t is an iid process with mean 0 and variance σ^2 .

The null hypothesis for the one break test is no structural change: $H_0 = \mu_1 = \beta_1 = 0$. To test for a single break with a generic breakdate (since it is unknown), Perron and Yabu (2009b) estimates the parameters of the model by Generalized Least Squares with a super-efficient estimate of ρ .¹⁵⁵ This modified estimate of ρ is based on a bias-corrected estimate of ρ (using a procedure developed by Roy and Fuller 2001) because the OLS estimate suffers from a serious downward bias especially when rho is close to 1.

To test the null of no structural change, in the case when the breakdate is known, the Wald statistics based on the estimated ρ —it is called the Robust Quasi-Feasible GLS Wald Statistics—is administered. In practice, when the break date is unknown (which is the assumption made in this paper), Perron and Yabu (2009a) proposes using the exp function over the set of permissible break dates. The authors show that when using the exp-functional, asymptotic critical values (limit distributions) in the I(1) and I(0) cases are very close, so that using the larger of the two can be expected to provide tests with the correct size for both stationary and integrated errors:

¹⁵⁵ The super-efficient estimate of ρ is as follows: $\hat{\rho}_s = \begin{cases} \hat{\rho}, & \text{if } T^\delta |\hat{\rho} - 1| > d \\ 1, & \text{if } T^\delta |\hat{\rho} - 1| \leq d \end{cases}$ for $\delta \in (0,1)$ and

$$d > 0 \text{ where } \hat{\rho} = \frac{\sum_{t=2}^T \hat{u}_t \hat{u}_{t-1}}{\sum_{t=2}^T \hat{u}_{t-2}^2} \text{ and } \{\hat{u}_t\} \text{ are the OLS residuals from the regression of } y_t \text{ on } x_t.$$

Perron and Yabu (2009b) show that: (i) $T^{\frac{1}{2}}(\hat{\rho}_s - \rho) \xrightarrow{d} N(0, 1 - \rho^2)$ when $|\rho| < 1$ and (ii)

$T(\hat{\rho}_s - 1) \xrightarrow{d} 0$ when $\rho = 1$. The key point is that these results remain valid both under the null as well as under the alternative of a structural break.

$$Exp - W_{RQF} = \log \left[T^{-1} \sum_{\Lambda} \exp \left(\frac{1}{2} W_{RQF} (\lambda'_i) \right) \right] \quad (2)$$

Kejriwal and Perron (2010) (henceforth, KP) extends the above Feasible GLS procedure to the multiple breaks with a sequential procedure, which allows one to test the null hypothesis of l change points against the alternative hypothesis of $(l + 1)$ changes. Like the PY one-break test, the KP sequential test allows us to distinguish between one or two breaks and so on while being agnostic to whether a unit root is present. The matrix notation in (3) summarizes the model for m breaks ($m + 1$ regime):

$$\begin{aligned} y_t &= x_t' \Psi + u_t \\ x_t &= (1, DU_{1t}, \dots, DU_{(m+1)t}, t, DT_{1t}, \dots, DT_{(m+1)t})' \\ \Psi &= (\mu_0, \mu_1, \dots, \mu_{m+1}, \beta_0, \beta_1, \dots, \beta_{m+1})' \\ DU_{it} &= 1(t > T_i), \quad DT_{it} = 1(t > T_i)(t - T_i) \\ T_1 &< T_2 < \dots < T_m \end{aligned} \quad , \quad (3)$$

where T_i represents the various true break dates. The sequential procedure to determine m proposed by KP first obtains the estimates of the break dates $T_1 < T_2 < T_3 \dots < T_m$ as the global minimizers of the sum of squared residuals from (3) by OLS using an algorithm based on a dynamic programming approach first introduced in the structural change context by Bai and Perron (1998, 2003). Next, the KP strategy proceeds by testing for the presence of an additional break in each of the $(l+1)$ segments (obtained using the estimated partitions). The exp-functional over all permissible break dates in (2) is extended for the multiple breaks case in (4):

$$\exp - W_{RQF}^i = \log \left[(T_i - T_{i-1})^{-1} \sum_{\tau \in \Lambda_{i,i}} \exp \left(\frac{W_{RQF}(\lambda_{i-1}, \tau, \lambda_i)}{2} \right) \right] \quad (4)$$

Given $\exp - W_{RQF}^i$ for $i = 1, \dots, l + 1$, the sequential test is defined by

$$F_T(l + 1|l) = \max_{1 \leq i \leq l+1} \{ \exp - W_{RQF}^i \}. \quad (5)$$

One concludes in favor of a model with $(l+1)$ breaks if the maximum of the $\exp - W_{RQF}^i$ is sufficiently large. This process is repeated by increasing l sequentially until the test fails to reject the null hypothesis of no additional structural breaks. The estimated number of breaks is then obtained as the number of rejections. The KP sequential test is essentially an application of $(l+1)$ tests of the null hypothesis of no change versus the alternative hypothesis of a single change. KP shows that the estimate of m is consistent (see Theorem 2 in Mohitosh Kejriwal & Perron, 2010).

Once the number of breaks has been determined through the KP sequential method, the actual break dates are determined endogenously by the structural break estimation technique developed by Bai and Perron (1998, 2003) (henceforth, BP).¹⁵⁶ In the BP method, the optimal number of breakpoints is established based on the Bayesian Information Criterion (BIC) selection procedure.

Simulations by KP point to the importance of the choice of the maximal value of the number of breaks in relation to the size of the sample available. KP advises practitioners to

¹⁵⁶ The Bai and Perron method is concerned with assessing deviations from stability in the classical linear regression model, where changes concern divergence from the intercept or the mean of the data. Breakpoint estimates are the global minimizers of the sum of squared residuals determined using an algorithm based on a dynamic programming approach.

allow sufficient number of observations in each segment and to use caution when choosing the maximum number of breaks permissible.¹⁵⁷

5.2 Unit Roots

Testing for stationarity of a time series that have multiple changepoints—as may be the case in the toxic chemical use series given the known succession of political, economic, and institutional shocks—is empirically challenging. The various unit root tests—whether it is the first generation augmented Dicky-Fuller test (1979) or the second generation Zivot-Andrew (1992) test for one break or the third generation Elliot-Muller (2006) test for parameter constancy given an unknown break process—lack the statistical power to disentangle whether the time series is stationary data with structural breaks or nonstationary data with structural break. The underlying problem with all these tests is that these unit root tests do not allow for the possibility of a break under both the null and alternative hypotheses. There is bias toward a non-rejection of the unit root hypothesis even though it is not true, i.e., mistaking a series as stationary when in fact it has a unit root (Amsler & Lee, 1995; Perron, 1989).

Perron (1989, 1990) was the first to propose alternative unit root tests that allow for the possibility of a break under both the null and hypotheses. While Perron's tests have the correct size asymptotically and are consistent whether there is a break or not, the precise timing of a break needs to be known a priori. When the wrong break date is used, there are size distortions

¹⁵⁷ The trimming parameter or percentage between structural break regimes must be specified in order to ensure a reasonable amount of degrees of freedom to calculate an initial error sum of squares in the KP method. There is currently no consensus in the literature regarding the criterion or criteria for determining the minimum regime size, which ultimately dictates maximum number of change points. I have set a maximum of three breaks with a trimming parameter of $\varepsilon = 0.15$ in a sample size of 112 for aggregate toxic chemical use and toxic chemical use by individual chemicals; and a maximum of three breaks with a trimming parameter of $\varepsilon = 0.25$ in a sample size of 30 for toxic chemical use by end-use industry sectors.

and power losses in the case of trending data even in large samples but not in nontrending data (Hecq & Urbain, 1993; Montañés & Olloqui, 1999).

Zivot and Andrews's (1992) (henceforth ZA) provided methods that treat the occurrence of break date as unknown under the alternative hypothesis but not under the null hypothesis. While the ZA test has become a standard unit root test in much of empirical work, the ZA test statistics often diverge or are not invariant to break parameters if the noise component has a unit root and a break occurs in the trend (Harvey, Leybourne, & Newbold, 2001; Nunes, Newbold, & Kuan, 1997).

In recent advances, using developments on structural change problems by Perron and Zhu (2005) and Perron and Yabu (2009a), Kim and Perron (Kim & Perron, 2009) (henceforth KP) developed new test procedures that allow a break in the trend function at unknown time under both the null and alternative hypotheses. Also, when the break is present, the limit distribution of the test is same as in the case of a known break date, thereby allowing increased power while maintaining the correct size. Simulation experiments confirm that it offers an improvement over conventionally used methods in small samples.

This paper utilizes unit root tests in the vein of KP, which is developed by Carrion-i-Silvestre, Kim, and Perron (2009) (henceforth CKP). The CKP unit root tests have several features that are relevant for this study. First, the CKP unit root tests allow for an arbitrary number of changes in both the level and slope of the trend function. Many of the toxic chemical use time series appear to have more than one structural break from visual inspection (see Figures 1-4). Second, the CKP tests adopt a quasi-GLS detrending method advocated by Elliott, Rothenberg, and Stock (1996) that permit tests that have local asymptotic power functions close to the local asymptotic Gaussian power envelope. Third, the CKP unit root tests are part of the

class of M-tests introduced in Stock (1999) and analyzed in Ng and Perron (2001). Finally, unlike the KP tests, the CKP tests are restricted to AO models; this appears to be an appropriate model for analyzing the time series proprieties of the toxic chemical time paths.

The one break and multiple breaks “mixed” models presented in (1) and (3) are the starting point. The GLS-detrended unit root test statistics are based on the use of the quasi-

differenced variables $y_t^{\bar{\rho}}$ and $x_t^{\bar{\rho}}(\lambda^0)$ defined by $y_t^{\bar{\rho}} = y_t, x_t^{\bar{\rho}}(\lambda^0) = x_t(\lambda^0)$, and

$$y_t^{\bar{\rho}} = (1 - \bar{\rho}L)y_t,$$

$$x_t^{\bar{\rho}}(\lambda^0) = (1 - \bar{\rho}L)x_t(\lambda^0)$$

for $t = 2, \dots, T$ with $\bar{\rho} = 1 + \bar{c}/T$ where \bar{c} is a noncentrality parameter. λ^0 represents the

collection of the m break fraction parameters: $\lambda^0 = (\lambda_1^0, \dots, \lambda_m^0)'$. Once the data have been

transformed, the parameters Ψ , associated with the deterministic components, can be estimated

by minimizing the following objective function:

$$S^*(\Psi, \bar{\rho}, \lambda^0) = \sum_{t=1}^T (y_t^{\bar{\rho}} - \Psi x_t^{\bar{\rho}}(\lambda^0))^2. \quad (6)$$

The minimum of this function is denoted by $S(\bar{\rho}, \lambda^0)$.

CKP considers M-class unit root tests for both the known break date case and the unknown break date case. This paper is concerned only with the latter case because I want to

retain as much generality as possible; moreover, it is rarely if ever possible to know the true break dates with certainty.¹⁵⁸

The M-class and Related Unit Root Tests

The following are the M-class of tests, first analyzed in Ng and Perron (2001) allowing for multiple structural breaks, defined by

$$MZ_{\alpha}^{GLS}(\lambda^0) = \left(T^{-1} \tilde{y}_T^2 - s(\lambda^0)^2 \right) \left(2T^{-2} \sum_{t=1}^T \tilde{y}_{t-1}^2 \right)^{-1} \quad (7)$$

$$MSB^{GLS}(\lambda^0) = \left(s(\lambda^0)^{-2} T^{-2} \sum_{t=1}^T \tilde{y}_{t-1}^2 \right)^{-1/2} \quad (8)$$

$$MZ_t^{GLS}(\lambda^0) = \left(T^{-1} \tilde{y}_T^2 - s(\lambda^0)^2 \right) \left(4s(\lambda^0) T^{-2} \sum_{t=1}^T \tilde{y}_{t-1}^2 \right)^{-1/2} \quad (9)$$

with $\tilde{y}_t = y_t - \Psi' x_t(\lambda^0)$, where $\hat{\Psi}$ minimizes (6). $s(\lambda^0)^2$ is an autoregressive estimate of the spectral density at frequency zero of v_t defined by

$$s(\lambda^0) = s_{ek}^2 / \left(1 - \sum_{j=1}^k \hat{b}_j \right)^2, \quad (10)$$

where $s_{ek}^2 = (T-k)^{-1} \sum_{t=k+1}^T \hat{e}_{t,k}^2$ and $\{\hat{b}_j, \hat{e}_{t,k}\}$ obtained from OLS regression

$$\Delta \tilde{y}_t = b_0 \tilde{y}_{t-1} + \sum_{j=1}^k b_j \Delta \tilde{y}_{t-j} + e_{t,k} \quad (11)$$

where \tilde{y}_t is as defined above.

¹⁵⁸ CKP shows that if the breaks are estimated by minimizing the sum of squared residuals from the appropriate GLS regression, the limit distributions of the tests are the same as in the known break date case, provided that breaks are present.

Another r statistic, is the modified feasible point optimal test defined by

$$MP_T^{GLS}(\lambda^0) = \left[c^{-2} T^{-2} \sum_{t=1}^T \tilde{y}_{t-1}^{-2} + (1-\bar{c}) T^{-1} \tilde{y}_T^2 \right] / s(\lambda^0)^2 \quad (12)$$

In the case with unknown break dates, CKP estimates the break dates using a detrended GLS version of a BP type structural break test. They follow an iterative procedure similar to that of Perron and Qu (2006).

CKP proves that in the case with unknown break dates that the use of the particular estimate $\hat{\lambda}$ as determined via the author's detrended GLS version of the BP test allows us to obtain unit root tests with the same limit distribution as in the known break date case.

KP provides simulations showing that the GLS-based unit root tests perform well and is superior to that of alternative methods but that they exhibit important size distortions when no breaks occur. When no break occurs, the asymptotic results do not hold because, under the null hypothesis of a unit root, the estimates of the break fractions have a nondegenerate limit distribution on the interval [0,1] instead of converging to either zero or one. CKP's solution is to perform a pre-test using the PY test. In effect, my empirical strategy follows this same strategy but uses the KP test instead, which allows for multiple breaks instead of one in the PY test. For toxic chemical use series with no breaks I conduct the conventional augmented Dickey Fuller (ADF) test to maximize power, size, and efficiency, as advised by CKP, Kim and Perron (2009), and Harris et al. (2009).

5.3 Cointegration With Structural Shift

Granger (1981) propose the concept of cointegration which recognizes that even though several series all have unit roots, a linear combination could exist which would not. Engle and

Granger (1987) were the first to develop tests and estimation procedures to analyze cointegrating relationships among variables. The idea behind cointegration is to find a linear combination between two I(1)-variables that yield a variable with a lower order of integration via a cointegrating vector. In essence what this means is that if two variables (or more) are non-stationary, there can exist a combination of them which is stationary. This definition leads to interesting interpretations as the variables can then be interpreted economically to share a stable relationship via a common stochastic trend (i.e., a long-run equilibrium) and can be represented in a vector error-correction model (VECM).

Two methods for testing for cointegration have become mainstays in the empirical toolbox. The first one was advocated by Engle and Granger (hereafter EG), who propose a two-step approach, estimating the cointegrating values in the long-run representation and then plugging those estimates in a VECM representation.¹⁵⁹ The related testing procedure, which takes the absence of cointegration as a null hypothesis, consists of determining whether the residuals from the first step are stationary or not. Rejection of the stationarity is then interpreted as the rejection of the null hypothesis of cointegration.

A major drawback of the EG approach is that it allows estimating and testing for only one cointegrating relationship. When the cointegrating vectors are known, estimation of multiple cointegration relationship is trivial as the estimation is simply OLS regression for the VECM and testing can be done using classical Wald tests (Horvath & Watson, 1995). When these vectors are unknown, the reduced-rank approach adopted by Johansen and Juselius (1992) and Johansen (1995) is able to estimate the potential cointegrating vectors and to test for their significance,

¹⁵⁹ This two-step approach has been justified afterwards by the fact that the estimator in the first step is super-consistent, i.e. converging to its true value at rate n instead of usual rate \sqrt{n} (Stock 1988).

allowing for the determination of the number of cointegration relationships. This is operationalized by determining the cointegration rank through the maximal eigenvalue statistic or the trace statistic.

Neither the EG 2-step procedure nor the Johansen method accounts for structural breaks, however. The pitfalls of concluding non-stationarity in the data can also be encountered in the case of a VECM. The flip side would be a wrongly accepted cointegration relation, where some or all underlying series behave like an AR(1)-process with a structural break (Pfaff, 2008). Lutkepohl, Saikkonen and Trenkler (2004) (henceforth LST) proposed a procedure for estimating a VECM in which the structural shift is a simple shift in the level of the process and the break date is estimated first. Next, the deterministic part, including the size of the shift, is estimated, and the data are adjusted accordingly. Third, a Johansen-type test for determining the cointegration rank is then applied to these adjusted series in the LST cointegration test. This paper implements the LST cointegration test, the model of which I present below.

LST assume the $(K \times 1)$ vector process $\{y_t\}$ is generated by a constant, a linear trend, and level shift terms

$$y_t = \mu_0 + \mu_1 t + \delta d_{t\tau} + x_t. \quad (13)$$

where $d_{t\tau}$ is a dummy variable defined by $d_{t\tau} = 0$ for $t < \tau$ and $d_{t\tau} = 1$ for $t \geq \tau$. The shift assumes that the shift point τ is unknown and is expressed as a fixed fraction of the same size,

$$\tau = [T\lambda] \text{ with } 0 < \underline{\lambda} \leq \lambda \leq \bar{\lambda} < 1, \quad (14)$$

where $\underline{\lambda}$ and $\bar{\lambda}$ define real numbers and $[\cdot]$ defines the integer part. The meaning of (14) is that the shift might occur neither at the very beginning nor at the very end of the sample.

Furthermore, it is assumed that the process $\{x_t\}$ can be represented as a VAR(p) and that the components are at most I(1) and cointegrated with rank r .

The estimation of the break point is based on the regressions

$$y_t = \nu_0 + \nu_1 t + \delta d_{t\tau} + A_1 y_{t-1} + \dots + A_p y_{t-p} + \varepsilon_{t\tau} \text{ for } t = p+1, \dots, T, \quad (15)$$

where A_i with $i = 1, \dots, p$ assign the $(K \times K)$ coefficient matrices and ε_t is the spherical K -dimensional error process. Other exogenous regressors, like seasonal dummy variables, can also be included in (15).

The estimator for the break point $\hat{\tau}$ is then defined as

$$\hat{\tau} = \arg \min_{\tau \in \mathfrak{S}} \det \left(\sum_{t=p+1}^T \hat{\varepsilon}_{t\tau} \hat{\varepsilon}'_{t\tau} \right), \quad (16)$$

Where $\mathfrak{S} = [T\underline{\lambda}, T\bar{\lambda}]$ and $\hat{\varepsilon}_{t\tau}$ are the least-squares residuals of (15). The integer count of the interval $\mathfrak{S} = [T\underline{\lambda}, T\bar{\lambda}]$ determines how many regressions have to be run with the corresponding step dummy variables $d_{t\tau}$ and how many times the determinant of the product moment matrices of $\hat{\varepsilon}_{t\tau}$ have to be calculated. The minimal one is the one that selects the most likely break point.

Once the break point $\hat{\tau}$ is estimated, the data are adjusted according to

$$\hat{x}_t = y_t - \hat{\mu}_0 - \hat{\mu}_1 t - \hat{\delta} d_{t\hat{\tau}}. \quad (17)$$

I implement the LST cointegration test in the R software using the `ca.jolst()` function

from the `urca` package. In `ca.jolst()`, the test statistic $LR(r) = T \sum_{j=r+1}^N \ln(1 + \hat{\lambda}_j)$ has been

implemented with critical values from Trenkler (2003) instead of the test statistic as proposed in Lutkepohl, Saikkonen and Trenkler (2004).

6. RESULTS AND DISCUSSION

I organize the results into subsections according to the level of analysis: 1) Aggregate toxic chemical use; 2) Toxic chemical use by individual chemicals; and 3) Toxic chemical use by end-use industry sectors. In each of these subsections, I report results from the structural change, unit root, and cointegration analyses. I end the section with a summary and discussion of the empirical results.

6.1 Aggregate Toxic Chemical Use

Table 5 Panels A and B report the result for the BP and KP structural break tests on aggregate toxic chemical use (*ltoxicsall*). Both structural break tests allow for shifts in intercept and slope of the trend (mixed model); the trimming parameter ε has been set to 0.15, which is a common value in the related literature.¹⁶⁰

According to the BP test, which chooses the optimal number of breakpoints by the minimum BIC, there are three structural breaks in the aggregate toxic chemical series between 1900 and 2011. These shifts coincide with the Great Depression, the end of World War II, and the economic downturn in the early 1980s. Once one accounts for I(0) or I(1) in the error component, however, there is no structural break in the series according to the KP test; the $F_T(1|0)$ statistics to determine if there is at least one break is 0.3. One there cannot reject the null hypothesis that there is no break; as such, the KP sequential testing procedure stops here. Since the KP test is an improvement over the BP method for estimating structural change (see section 4.1), I conclude that there is no structural break in the mean or the slope of *ltoxicsall*.

¹⁶⁰ When the trimming parameter is set to 0.25, the result from KP structural break test does not change. BP predicts two instead of three breaks; the breaks are 1929 and 1957, respectively.

Table 5
Panel A
Bai and Perron (2003)
Structural Break Test, Mixed Model

y_t	Minimum BIC	#Breaks	Estimated Break Years	95% Confident Intervals	ε
<i>ltoxicsall</i>	-66.178	3	1930	(1928, 1931)	0.15
			1946	(1945, 1948)	
			1979	(1978, 1982)	

Note: The minimum BIC chooses m=3 breaks. ε represents the trimming parameter.

Panel B
Kejriwal and Perron (2010)
Structural Break Test, Mixed Model

y_t	$Exp - W_{ROF}$	# Breaks	ε
<i>ltoxicsall</i>	0.3	0	0.15

Significant at the 5% level; *Significant at the 1% level

Note: 5% and 1% critical values for the sequential test $F_t(1|0)$ is 3.63 and 5.28, respectively (Kejriwal and Perron 2010, Table 1). ε represents the trimming parameter.

When no break occurs, the proper test for nonstationarity (i.e., null hypothesis of an unit root) is to simply apply a standard ADF test (Carrion-i-Silvestre et al., 2009). Table 6 presents the test statistics for the ADF test. I allow for an intercept and trend to be added to the test regression and for the number of lags for an endogenous variable to be added to be three. The ADF statistics are -2.026, 2.984, and 3.549, which are below the critical values for the test statistics; we cannot reject the null hypothesis that there is presence of a unit root test in the aggregate toxic chemical series.

Table 6
Augmented Dickey Fuller Unit Root Test

Test regression: $\Delta y_t = \mu + \beta t + \alpha y_{t-1} + \phi \Delta y_{t-1} + \gamma \Delta y_{t-2} + \theta \Delta y_{t-3} + e_t$

y_t	ADF statistics	k
<i>ltoxicsall</i>	-2.026	3

Significant at the 5% level; *Significant at the 1% level

Note: 5% critical values for the ADF statistics is -3.43. k represents the number of lags for an endogenous variable to be added.

Given that *ltoxicsall* contains a unit root, the next step is to determine whether a cointegration relationship exists between aggregate toxics chemical and national accounts and industrial production series respectively.¹⁶¹ Results for the inference on cointegration rank for aggregate toxic chemical series and national accounts and industrial production for aggregate toxic chemical use, allowing for structural shift are reported in various panels of Table 7. If one allows for a structural shift in the data, the hypothesis of one cointegration relationship between *ltoxicsall* and the log of industrial production (*lip*), real GDP (*lrgdp*), real investments in research and development (*lrrd*), real investment in research and development by the private sector (*lrrdprivate*), respectively, cannot be rejected for a significance level of 5% or less. See Table 7 Panels A, B, C, and E for these affirmative results toward cointegrating relationships.

¹⁶¹ All the national accounts and industrial production series contain unit roots according to the CKP test. Results for the unit root tests are reported in the Appendix.

Table 7
Lutkepohl, Saikkonen, and Trenkler (2004)
Inference on Cointegration Rank, Allow Structural Shift

Panel A

Aggregate Toxic Chemical Use and Industrial Production

Rank	Trace Statistics	10%	5%	1%
r≤1	7.99**	5.42	6.79	10.04
r=0	21.81***	13.78	15.83	19.85

Panel B

Aggregate Toxic Chemical Use and Real GDP

Rank	Trace Statistics	10%	5%	1%
r≤1	5.25	5.42	6.79	10.04
r=0	19.73**	13.78	15.83	19.85

Panel C

Aggregate Toxic Chemical Use and Real Investments in R&D

Rank	Trace Statistics	10%	5%	1%
r≤1	5.02	5.42	6.79	10.04
r=0	16.09**	13.78	15.83	19.85

Panel D

Aggregate Toxic Chemical Use and Real Investments in R&D, Government

Rank	Trace Statistics	10%	5%	1%
r≤1	3.56	5.42	6.79	10.04
r=0	10.56	13.78	15.83	19.85

Panel E

Aggregate Toxic Chemical Use and Real Investments in R&D, Private Sector

Rank	Trace Statistics	10%	5%	1%
r≤1	7.87**	5.42	6.79	10.04
r=0	17.96**	13.78	15.83	19.85

Panel F

Aggregate Toxic Chemical Use and Real Investments in R&D, Chemicals

Rank	Trace Statistics	10%	5%	1%
r≤1	1.58	5.42	6.79	10.04
r=0	7.98	13.78	15.83	19.85

Panel G

Aggregate Toxic Chemical Use and Real Investments in R&D, Computer & Electronics

Rank	Trace Statistics	10%	5%	1%
r≤1	5.42	5.42	6.79	10.04
r=0	15.46	13.78	15.83	19.85

In sum, according to the BP method, estimated structural breaks in aggregate toxic chemical use correspond to the built-up and slowdown related to WWII and the slowdown associated with economic recessions rather than environmental regulations. When the preferred KP changepoint procedure, which is invariant to an I(1) or I(O) noise component, is employed, however, results show that there is no structural change in *ltoxicsall*. Moreover, aggregate toxic chemical use is nonstationary. Finally, the primary drivers of long-run changes in the trend of the time series appear to be economic factors rather than institutional factors related to environmental governance; results from tests on the presence of cointegration relations between aggregate toxic chemical use and national accounts and industrial production are statistically significant at the 5% level or less.

6.2 Toxic Chemical Use By Individual Chemicals

Table 8 Panels A and B present the results of the BP and KP structural break test from a mixed model on individual toxic chemical use series. In both analyses, the trimming parameter ε has been set to 0.15 following empirical convention except in two cases. ε has been set to 0.25 for testing for structural change in *lcobalt* and *lselenium* because when the trimming parameter for the two toxic chemical use series is set to 0.15, the respective 95% confidence intervals span the entire range of the time series; this suggests that the breakdates are far from precisely estimated for these toxic chemicals when $\varepsilon = 0.15$.¹⁶² The KP test allows up to three

¹⁶² KP find by simulations that there is tendency to overestimate the true number of breaks for the mixed model, which result in low power and/or size distortions. As such, the authors advise that practitioners allow sufficient number of observations in each segment and choose the maximum number of breaks permissible accordingly.

breaks while in the BP test the number of breaks is limited only by the number of observations in each segment.

Table 8

Panel A
Bai and Perron (2003)
Structural Break Test, Mixed Model

y_t	Minimum BIC	#Breaks	Estimated Break Years
<i>larsenic</i>	50.11	3	1922, 1945, 1995
<i>lasbestos</i>	186.14	2	1915, 1974
<i>lcadmium</i>	137.93	3	1915, 1940, 1976
<i>lmercury</i>	-12.561	3	1940, 1961, 1985
<i>lchromium</i>	80.678	2	1939, 19631
<i>lcobalt</i>	178.86	1	1959
<i>lmanganese</i>	56.736	3	1930, 1946, 1981
<i>lselenium</i>	14.955	2	1929, 1952
<i>lzinc</i>	-56.673	4	1929, 1945, 1974, 1994
<i>lantimony</i>	21.113	4	1929, 1945, 1969, 1987
<i>lberyllium</i>	133.46	1	1961
<i>lbromine</i>	73.354	3	1923, 1944, 1979
<i>llead</i>	-91.765	3	1930, 1953, 1993

Note: The trimming parameter, $\varepsilon = 0.15$.

Panel B
Kejriwal and Perron (2010)
Structural Break Test, Mixed Model

y_t	$F(1 0)$	$F(2 1)$	$F(3 2)$	# Breaks	Estimated Break Year ¹	95% CI	ε
<i>larsenic</i>	2.22**	38.06**	3.99**	3	1922 1945 1995	(1920, 1924) (1944, 1947) (1933, 1996)	0.15
<i>lasbestos</i>	4.79**	10.59**	107.74**	3	1915 1940 1976	(1914, 1917) (1939, 1942) (1975, 1977)	0.15
<i>lcadmium</i>	2.88**	19.51**	49.83**	3	1925 1942 1986	(1923, 1926) (1941, 1943) (1984, 1987)	0.15
<i>lmercury</i>	34.35**	13.43**	5.73**	3	1940 1961 1985	(1938, 1944) (1958, 1962) (1984, 1986)	0.15
<i>lchromium</i>	68.80**	1.32		1	1965	(1964, 1966)	0.15
<i>lcobalt</i>	113.86**	-0.42		1	1959	(1958, 1960)	0.25
<i>lmanganese</i>	2.91**	1.50		1	1979	(1978, 1986)	0.15
<i>lselenium</i>	1.85**	55.06**	44.63**	3	1934 1959 1984	(1933, 1937) (1958, 1961) (1966, 1992)	0.25
<i>lzinc</i>	13.9**	1.64		1	1973	(1972, 1974)	0.15
<i>lantimony</i>	-0.2			0			0.15
<i>lberyllium</i>	0.2			0			0.15
<i>lbromine</i>	0.3			0			0.15

**Significant at the 5% level

Note: The KP test allows for a maximum of three breaks. 5% critical values for $F(1|0)$, $F(2|1)$, and $F(3|2)$ are 1.67, 2.22, and 2.56, respectively (Kejriwal and Perron 2010, Table 1). ε represents the trimming parameter. The break dates are estimated by the BP method in the R software using the *strucchange* package.

The largest difference between the results of the BP and KP tests is that the *growth* toxic chemicals, namely antimony, beryllium, bromine, and lead, exhibit no structural change in their use paths according to the KP test. By contrast, the BP method estimates between one to four structural shifts in these series (e.g., there are four structural shifts in *lantimony* and one structural shift in *lberyllium*). Other differences in the estimated structural breaks between the two tests occur mostly in the *kinked growth* category of toxic chemicals. For example, while the BP method estimates four changepoints in *lzinc*, only one is detected by the KP sequential procedure. By and large, the BP test tends to detect more structural changes than the KP test. This is not surprising since the BP test does not account for the fact that the noise component of the data can be I(0) or I(1).

The rest of the analysis proceeds with the estimated structural breaks by the KP sequential method. Figures 5 and 6 plot the time path along with the estimated structural breaks by the KP sequential procedure for the *EKC* and *kinked growth* chemicals, respectively. A fitted line has been estimated for each chemical use time series given the number of breaks using the BP method. 95% confidence intervals bound each of the estimated breakdates. Figure 7 shows the time path of the *growth* chemicals, although the KP sequential method detects no structural breaks for these series.

For each of the *EKC* chemicals (except for mercury), the first three decades of the 20th Century appear to be a period of tremendous growth in use, particularly for cadmium, which relative to the other chemicals was not readily used at large quantities in 1900. This growth culminated in structural changes in 1922 and 1925, respectively, for arsenic and cadmium, at which point the upward trend continued with shift up in the mean of the consumptive use series for both chemicals to slightly lower slopes in the trend. For asbestos use, there was a structural shift in 1915 from a steeper slope to a flatter slope in the trend. These changepoints coincided with a period of much commercial development and technological change in the U.S.

For all three chemical use series, their second regime lasted until the start or the end of WWII. Asbestos use ramped up further for the war efforts and remained there until the regulatory era. A structural shift in 1945 at the end of WWII signaled a third regime for the arsenic use trend. Cadmium trend growth reached its peak in 1942 and essentially remained there until the mid-1980s.

Unlike the other *EKC* chemicals, mercury use did not experience rapid growth in the first few decades of the 20th Century. The estimated structural change in 1940 (a “shift up” to about the same slope as the previous regime) coincided with the economic ramp up associated with WWII. Another structural change in 1961—a slight “shift up” to a flatter slope—demarcated the next regime for mercury use.

The third and last estimated structural break for the trends in *lasbestos*, *lcadmium*, and *lmercury* occur during the regulatory era and coincided with the passage of major federal environmental legislations. Asbestos use which had been a much targeted toxic substance by the federal government experienced a structural break (a steep downward shift in the slope of the trend) in 1976, the year the 1976 Toxics Substance Control Act was passed by Congress. A year

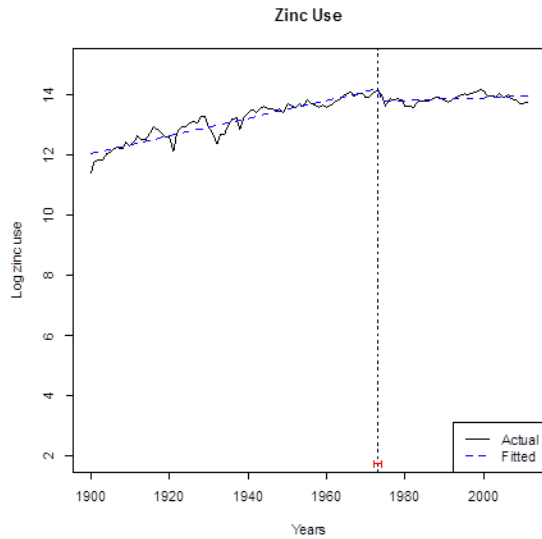
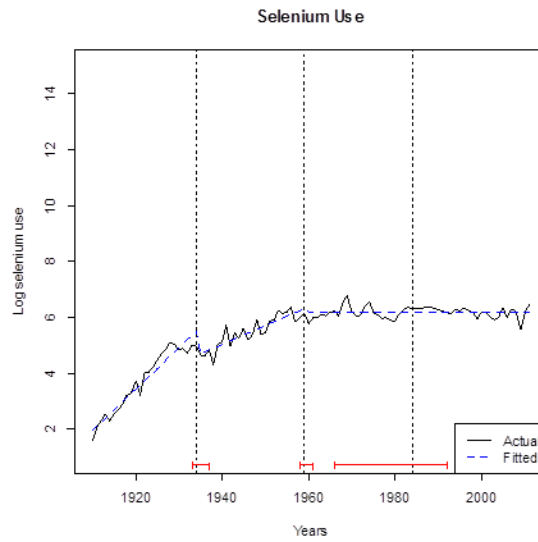
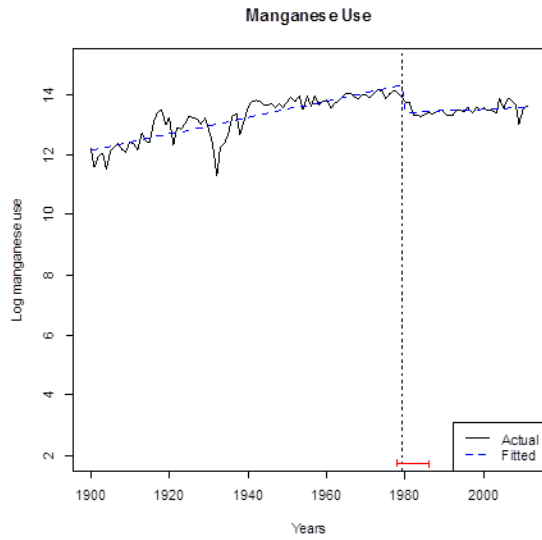
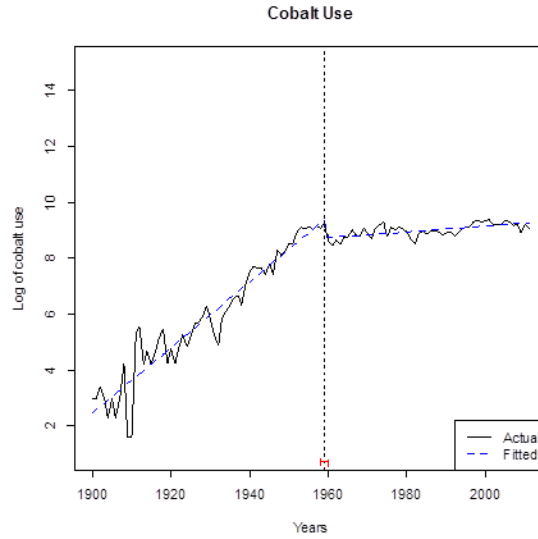
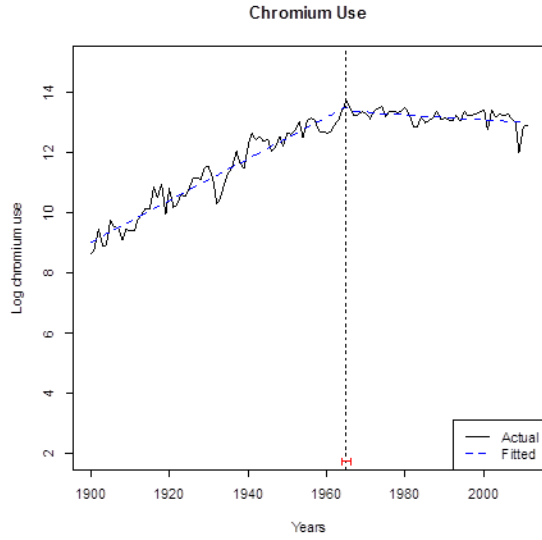
later in 1977, the CPSC banned consumer products containing inhalable asbestos, such as artificial fireplace ash containing asbestos. 1977 is within the 95% confidence band around the estimated break.

A third estimated structural shift occurred in 1985 and 1986, respectively, for mercury use and cadmium use. Both breaks matched the passage of the Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986, which created the Toxics Release Inventory (TRI). This changepoint established a fourth regime of downward sloping trend, which had not reversed, in both of the mercury and cadmium use series.

Finally, for arsenic use, an estimated break in the trend occurred in 1995, two years after the agricultural industry, which is the second largest user of arsenic, banned the use of arsenic acid, an agricultural pesticide that had been commonly used as a cotton desiccant. 1995 is within the 95% confidence region of the estimated break.

Figure 6 plots the time paths of the *kinked growth* chemicals, along with the estimated breaks by the KP sequential procedure. Four of the five toxic chemical use series, namely *lchromium*, *lcobalt*, *lmanaganese*, and *lzinc* all possessed a single break that demarcated two regimes: the first regime was an upward sloping trend and the second was a regime generally characterized by a trend of nearly flat, steady horizontal growth. For *lcobalt* and *lchromium*, the estimated changepoint occurred in 1959 and 1965, respectively. Both dates occurred before the start of the regulatory era, although the modern environmental movement was gaining momentum at the time with the 1962 publication of Rachel Caron's *Silent Spring*. Moreover, the federal government had begun laying out broad environmental goals. Chromium and cobalt have been considered strategic materials by the federal government and a part of the Defense Logistic Agency's strategic materials stockpile program.

Figure 6
Kejriwal and Perron (2010)
Estimated Multiple Structural Breaks
Kinked Growth Chemicals



Upward trends in zinc and manganese experienced a changepoint in 1973 and 1979, respectively. Both both chemicals, the broken trends were demarcated by the said structural breaks in a kink-like fashion; the second regimes that immediately followed the estimated changepoints were characterized by steady horizontal growth. There appeared to have been no abatement per se in the consumptive use of these toxic chemicals (although the pace of growth was flat), which had many commercial applications (see Table 2). The estimated break in the zinc use trend occurred in 1973, a year after major amendments in FIFRA, the U.S. pesticide rule; 1973 is within the tight 95% confidence region of the estimated changepoint.

Manganese's single estimated break occurred in 1979; it is not precisely estimated with a 95% confidence region that spans eight years (1978-1986). Within these eight years, several notable events ensued in the political economy: two recessions (1980 and 1981-82) and the establishment of the TRI by the EPA. It is thus difficult to attribute the estimated changepoint to regulation or to the economy. While the second regime was characterized by a slightly flatter slope in the trend, manganese use by and large continued unabated. This is not surprising since manganese remains an essential ingredient in steel and iron production; there are no satisfactory substitutes.

The only *kinked growth* chemical that experienced multiple structural breaks was selenium. The first estimated break, 1934 (95% CI: 1933-1937), corresponded with the general slowdown associated with the Great Depression (1929-1933). The next changepoint (1959) occurred during the era of intense environmental activities preceding the founding of the EPA and the advent of major environmental legislations. The final estimated break was in 1984; the trend thereafter was a “shift down” from the previous regime. This break is imprecisely estimated—the 95% confidence interval spans 1966 to 1992, which was a period of major

postwar economic growth, the advent of all major environmental legislations, an oil crisis, and five recessions (1969-70, 1973-75, 1980, 1981-82, and 1990-91).¹⁶³

Unit Roots

Once it has been determined whether structural breaks exist in the toxic chemical use series, I apply the appropriate unit root test to the individual toxic chemical use series based on the number of estimated breaks. For zero-break series, namely the *growth* chemicals, I administer the ADF unit root test. For multiple-breaks toxic chemical use series, I administer the CKP test, which allows for multiple breaks in the null and the alternative hypotheses. Results are reported in Table 9 Panels A and B.

Table 9

Panel A
Augmented Dickey Fuller Unit Root Test

Test regression: $\Delta y_t = \mu + \beta t + \alpha y_{t-1} + \phi \Delta y_{t-1} + \gamma \Delta y_{t-2} + \theta \Delta y_{t-3} + e_t$

y_t	ADF statistics	k
<i>lantimony</i>	-3.02	3
<i>lberyllium</i>	-3.54**	3
<i>lbromine</i>	-0.66	3
<i>llead</i>	-3.37	3

Significant at the 5% level; *Significant at the 1% level

Note: 1%, 5%, and 10% critical values for the ADF statistics are -3.99, -3.43, and -3.13. k represents the number of lags for an endogenous variable to be added.

¹⁶³ U.S. expansions and contractions dates are from the NBER: <http://www.nber.org/cycles.html> (Retrieved September 20, 2012)

Panel B
Carrion-i-Silvestre, Kim, and Perron (2009)
GLS-Based Unit Root Tests

y_t	MPT	MZA	MSB	MZT
<i>larsenic</i>	6.92	-37.78**	0.11	-4.34**
<i>lasbestos</i>	6.47	-44.95**	0.11	-4.74**
<i>lcadmium</i>	6.67	-36.29**	0.12	-4.26**
<i>lmercury</i>	16.10**	-16.36	0.17**	-2.74
<i>lchromium</i>	18.62**	-8.86	0.22**	-1.99
<i>lcobalt</i>	21.69**	-5.71	0.28**	-1.60
<i>lmanganese</i>	7.39**	-22.50	0.15**	-3.34
<i>lselenium</i>	9.67**	-24.64	0.14**	-3.51
<i>lzinc</i>	8.26**	-33.00	0.12**	-4.05

**Significant at the 5% level

Note: The CKP test allows for a maximum of five breaks. 5% critical values are reported in Tables 2A-2D of Carrion-i-Silvestre, Kim, Perron (2009).

In Table 9 Panel A, the ADF unit root test reveals that for chemical use series without breaks, antimony, bromine, and lead each have a unit root. Beryllium is the only break-free chemical use series without a unit root.

Table 9 Panel B presents the results from the CKP unit root tests which allow for multiple changepoints in the toxic chemical use series. The unit root test results are based on the number of breaks determined by the KP method (Table 7 Panel B). According to the various M-class tests and the modified feasible point optimal test, arsenic use, cadmium use, and asbestos use series each contain a unit root. By contrast, the following multiple-breaks chemical use series are stationary: mercury, chromium, cobalt, manganese, selenium, and zinc. The time paths of all

kinked growth chemicals are stationary, while only one *EKC* chemical time path is stationary, namely mercury use.

Cointegration

Altogether six out of the thirteen elemental toxic chemical use series analyzed in this paper contain a unit root. These toxic chemical use series are further analyzed for evidence of cointegrating relationships among chemicals regulated under the same laws and between individual chemical use series and national accounts and industrial production, respectively.

To test for evidence of cointegrating relationships among chemicals regulated under the same laws, I consider the difference-stationary *EKC* chemicals and *growth* chemicals separately and then all possible pairs of *EKC* and *growth* chemicals together. Table 10 Panel A reports the results on the inference on cointegration rank for the *EKC* chemicals allowing for structural shift. The hypothesis of two cointegration relationships among *larsenic*, *lasbestos*, and *lcadmium* cannot be rejected for a significant level of 5%. The hypothesis of three cointegration relations cannot be rejected at the 10% confidence level. While *lcadmium* shares a cointegration vector with *lasbestos* and *larsenic*, respectively, the hypothesis of no cointegration cannot be rejected for *larsenic* and *lasbestos*.

Table 10
Lutkepohl, Saikkonen, and Trenkler (2004)
Inference on Cointegration Rank, Allow Structural Shift

Panel A				
<i>EKC</i> Chemicals: <i>larsenic</i> , <i>lasbestos</i> , <i>lcadmium</i>				
Rank	Trace Statistics	10%	5%	1%
$r \leq 2$	6.42*	5.42	6.79	10.4
$r \leq 1$	18.56**	13.78	15.83	19.85
$r = 0$	39.77***	25.93	28.45	33.76

EKC Chemicals: larsenic, lcadmium

Rank	Trace Statistics	10%	5%	1%
$r \leq 1$	6.38*	5.42	6.79	10.4
$r \leq 0$	18.89**	13.78	15.83	19.85

EKC Chemicals: lasbestos, lcadmium

Rank	Trace Statistics	10%	5%	1%
$r \leq 1$	5.55*	5.42	6.79	10.4
$r \leq 0$	25.50***	13.78	15.83	19.85

EKC Chemicals: larsenic, lasbestos

Rank	Trace Statistics	10%	5%	1%
$r \leq 1$	2.75	5.42	6.79	10.4
$r \leq 0$	11.43	13.78	15.83	19.85

Panel B

Growth Chemicals: lantimony, lbromine, llead

Rank	Trace Statistics	10%	5%	1%
$r \leq 2$	7.50**	5.42	6.79	10.4
$r \leq 1$	16.27**	13.78	15.83	19.85
$r = 0$	30.48**	25.93	28.45	33.76

Growth Chemicals: lantimony, lbromine

Rank	Trace Statistics	10%	5%	1%
$r \leq 1$	7.26**	5.42	6.79	10.4
$r \leq 0$	19.57**	13.78	15.83	19.85

Growth Chemicals: lantimony, llead

Rank	Trace Statistics	10%	5%	1%
$r \leq 1$	12.89***	5.42	6.79	10.4
$r \leq 0$	32.58***	13.78	15.83	19.85

Growth Chemicals: lbromine, llead

Rank	Trace Statistics	10%	5%	1%
$r \leq 1$	7.87**	5.42	6.79	10.4
$r \leq 0$	20.19***	13.78	15.83	19.85

Panel C

EKC and Growth Chemicals: larsenic, lantimony

Rank	Trace Statistics	10%	5%	1%
$r \leq 1$	6.63*	5.42	6.79	10.4
$r = 0$	25.13**	13.78	15.83	19.85

EKC and Growth Chemicals: larsenic, lbromine

Rank	Trace Statistics	10%	5%	1%
r _{≤1}	5.08	5.42	6.79	10.4
r _{≤0}	22.00**	13.78	15.83	19.85

EKC and Growth Chemicals: larsenic, llead

Rank	Trace Statistics	10%	5%	1%
r _{≤1}	7.93**	5.42	6.79	10.4
r _{≤0}	20.36***	13.78	15.83	19.85

EKC and Growth Chemicals: lcadmium, lantimony

Rank	Trace Statistics	10%	5%	1%
r _{≤1}	6.62	5.42	6.79	10.4
r _{≤0}	18.26**	13.78	15.83	19.85

EKC and Growth Chemicals: lcadmium, lbromine

Rank	Trace Statistics	10%	5%	1%
r _{≤1}	5.07	5.42	6.79	10.4
r _{≤0}	18.74**	13.78	15.83	19.85

EKC and Growth Chemicals: lcadmium, llead

Rank	Trace Statistics	10%	5%	1%
r _{≤1}	8.67**	5.42	6.79	10.4
r _{≤0}	22.15**	13.78	15.83	19.85

EKC and Growth Chemicals: lasbestos, lantimony

Rank	Trace Statistics	10%	5%	1%
r _{≤1}	2.89	5.42	6.79	10.4
r _{≤0}	19.50**	13.78	15.83	19.85

EKC and Growth Chemicals: lasbestos, lbromine

Rank	Trace Statistics	10%	5%	1%
r _{≤1}	1.32	5.42	6.79	10.4
r _{≤0}	13.50*	13.78	15.83	19.85

EKC and Growth Chemicals: lasbestos, llead

Rank	Trace Statistics	10%	5%	1%
r _{≤1}	3.13	5.42	6.79	10.4
r _{≤0}	16.21**	13.78	15.83	19.85

Moreover, Table 10 Panel B shows that for the *growth* chemicals, the LST test rejects $r \leq 2$ cointegration vector for *lantimony*, *lbromine*, and *llead* at the 5% significance level. No cointegration relationship exists for any combinations of the growth chemical use series.

Table 10 Panel C shows the results of the LST test on all possible combinations of the *EKC* and *growth* chemicals. All pairs of toxic chemicals with the exception of one pair, namely *lbromine* and *lasbestos*, share at least one cointegration relation in its time path.

Taken together, there is evidence of cointegration relationships among chemicals regulated under the same laws, whether they are *EKC* or *growth* chemicals, suggesting that DS chemicals that are regulated under the same laws share a common trend, which imply that there are common economic and institutional drivers.

Another conjecture is that toxic chemicals that are key ingredients in commercial products will share a long-run equilibrium with macroeconomic indicators. Table 11 reports the results on a test to determine whether a cointegration relationship exists between the nonstationary chemical use and national accounts and industrial production series, respectively. I administer the LST cointegration test, which allows for a structural shift in the toxic chemical use series. For *EKC* chemicals, arsenic, cadmium, and asbestos use are each cointegrated with real GDP; arsenic and cadmium use are also cointegrated with industrial production while asbestos use is not. Arsenic use is cointegrated with private sector investments in R&D. Cadmium and asbestos use are both cointegrated with the chemical sector's investments in R&D.

Table 11
Lutkepohl, Saikkonen, and Trenkler (2004)
Inference on Cointegration Rank, Allow Structural Shift

Panel A
Toxic Chemical Use and Industrial Production

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
<i>larsenic</i>	17.55**	4.36
<i>lasbestos</i>	11.15	2.92
<i>lcadmium</i>	23.78***	8.15**
<i>lmercury</i>	N/A	N/A
<i>lchromium</i>	N/A	N/A
<i>lcobalt</i>	N/A	N/A
<i>lmanganese</i>	N/A	N/A
<i>lselenium</i>	N/A	N/A
<i>lzinc</i>	N/A	N/A
<i>lantimony</i>	19.37**	4.82
<i>lberyllium</i>	N/A	N/A
<i>lbromine</i>	16.66**	4.84
<i>llead</i>	14.48*	4.32

Panel B
Toxic Chemical Use and Real GDP

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
<i>larsenic</i>	23.33**	6.77*
<i>lasbestos</i>	28.70***	2.44
<i>lcadmium</i>	30.91***	7.71**
<i>lmercury</i>	N/A	N/A
<i>lchromium</i>	N/A	N/A
<i>lcobalt</i>	N/A	N/A
<i>lmanganese</i>	N/A	N/A
<i>lselenium</i>	N/A	N/A
<i>lzinc</i>	N/A	N/A
<i>lantimony</i>	28.91***	7.44**
<i>lberyllium</i>	N/A	N/A
<i>lbromine</i>	34.65***	12.46**
<i>llead</i>	31.24***	11.99***

Panel C
Toxic Chemical Use and Real Investments in R&D

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
<i>larsenic</i>	13.72	3.75
<i>lasbestos</i>	12.58	2.59
<i>lcadmium</i>	17.07**	2.75
<i>lmercury</i>	N/A	N/A
<i>lchromium</i>	N/A	N/A
<i>lcobalt</i>	N/A	N/A
<i>lmanganese</i>	N/A	N/A
<i>lselenium</i>	N/A	N/A
<i>lzinc</i>	N/A	N/A
<i>lantimony</i>	10.50	3.95
<i>lberyllium</i>	N/A	N/A
<i>lbromine</i>	15.48*	6.93**
<i>llead</i>	18.04**	3.87

Panel D
Toxic Chemical Use and Real Investments in R&D, Government

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
<i>larsenic</i>	13.11	4.30
<i>lasbestos</i>	15.49	4.95
<i>lcadmium</i>	15.06*	1.19
<i>lmercury</i>	N/A	N/A
<i>lchromium</i>	N/A	N/A
<i>lcobalt</i>	N/A	N/A
<i>lmanganese</i>	N/A	N/A
<i>lselenium</i>	N/A	N/A
<i>lzinc</i>	N/A	N/A
<i>lantimony</i>	11.95	2.02
<i>lberyllium</i>	N/A	N/A
<i>lbromine</i>	14.98*	3.55
<i>llead</i>	17.00**	3.05

Panel E
Toxic Chemical Use and Real Investments in R&D, Private Sector

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
<i>larsenic</i>	15.97**	4.93
<i>lasbestos</i>	12.33	3.20
<i>lcadmium</i>	18.10**	5.54*
<i>lmercury</i>	N/A	N/A
<i>lchromium</i>	N/A	N/A
<i>lcobalt</i>	N/A	N/A
<i>lmanganese</i>	N/A	N/A
<i>lselenium</i>	N/A	N/A
<i>lzinc</i>	N/A	N/A
<i>lantimony</i>	10.53	4.23
<i>lberyllium</i>	N/A	N/A
<i>lbromine</i>	15.81*	6.54*
<i>llead</i>	17.48**	6.85**

Panel F
Toxic Chemical Use and Real Investments in R&D, Chemicals

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
<i>larsenic</i>	13.44	3.48
<i>lasbestos</i>	19.21**	7.54**
<i>lcadmium</i>	15.84**	0.26
<i>lmercury</i>	N/A	N/A
<i>lchromium</i>	N/A	N/A
<i>lcobalt</i>	N/A	N/A
<i>lmanganese</i>	N/A	N/A
<i>lselenium</i>	N/A	N/A
<i>lzinc</i>	N/A	N/A
<i>lantimony</i>	10.74	2.59
<i>lberyllium</i>	N/A	N/A
<i>lbromine</i>	17.83**	8.15**
<i>llead</i>	15.10	2.14

Panel G
Toxic Chemical Use and Real Investments in R&D, Electronics & Electrics

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
<i>larsenic</i>	13.74	4.30
<i>lasbestos</i>	10.38	3.47
<i>lcadmium</i>	15.53*	4.06
<i>lmercury</i>	N/A	N/A
<i>lchromium</i>	N/A	N/A
<i>lcobalt</i>	17.29**	4.85
<i>lmanganese</i>	N/A	N/A
<i>lselenium</i>	N/A	N/A
<i>lzinc</i>	N/A	N/A
<i>lantimony</i>	11.13	4.05
<i>lberyllium</i>	N/A	N/A
<i>lbromine</i>	13.48	6.15
<i>llead</i>	16.44**	4.55

*Significant at the 10% level; **Significant at the 5% level; ***Significant at the 1% level
 Note: For $r=0$, 1%, 5% and 10% critical values for the trace statistics is 19.85, 15.83, and 13.78, respectively. For $r \leq 1$, 1%, 5% and 10% critical values for the trace statistics is 5.42, 6.79, 10.04 respectively

For the *kinked growth* chemicals, cobalt is the only chemical containing a unit root. It is cointegrated with real GDP and private sector investments in R&D—in particular, investments in R&D by the electronics sector. Finally, for the *growth* chemicals, antimony, bromine, and lead use are cointegrated with real GDP; antimony and bromine are cointegrated also with industrial production. Moreover, lead use is cointegrated with investments in total R&D investments and R&D investments by the electronics sector. Finally, bromine use is cointegrated with R&D investments by the chemical sector.

6.3 Toxic Chemical Use By End-use Industry Sectors

This section presents the results on the analyses on structural breaks, unit roots, and cointegration for toxic chemical use by individual end-use industry sectors. Table 12 presents the estimated structural changes for the end-use industry sectors by individual chemicals. Half

of the table presents results based on the BP test and the other half presents results based on the KP test. Again, the latter test allows us to distinguish between one versus two breaks, and two versus three breaks while being agnostic to whether a unit root is present. The trimming parameter, ε , is set to 0.25. I discuss only the results from the KP test, which is my preferred method for estimating structural breaks because the KP sequential procedure is valid whether the noise components are I(0) or I(1).

On the whole, more than two-thirds of the toxic chemical end-use sector series have zero structural breaks during the period 1975-2003. Moreover, for the end-use sector series that recorded one or two estimated structural shifts the break estimates are generally imprecisely estimated; the 95% confidence regions are considerably wide, covering several years in both directions. These results are consistent with the fact that for toxic chemical use by individual chemicals (see section 5.2) the regulatory era (post-1970) was by-and-large characterized by either downward sloping trends (*EKC* chemicals), horizontal growth trends (*Kinked growth* chemicals), or upward sloping trends (*growth* chemicals) with fewer perturbations in the time paths relative to the first half of the 20th Century.

For three of the *EKC* chemicals—*asbestos*, *cadmium*, and *mercury*—their end-use series have generally been characterized by downward sloping trends with the exception of the *cadmium-using battery* sector where a horizontal growth trend persisted throughout period 1975-2003. The structural breaks in these series demarcated changes in the slope but not the direction of the trends: 1984 (*asbestos* use in roofing products), 1985 (*mercury* use in electronics), 1986 (*mercury* use in chemicals), 1992 (*mercury* use in electronics), and 1995 (*asbestos* use in friction products). The first three structural shifts coincided with the establishment of the EPA's TRI as well as technological changes in the *mercury-using* sectors.

Table 12
Toxic Chemical Use By Individual Chemical Industry Sector
Structural Break Tests, Mixed Model

End-Use Sectors	Bai and Perron (2003)			Kejriwal and Perron (2010)				
	Minimum BIC	#Breaks	Estimated Break Year	$F(1 0)$	$F(2 1)$	#Breaks	Estimated Break Year	95% CI
Arsenic								
<i>Pressure-treated Wood</i>	17.00	2	1981	2.74**	205.62**	2	1981	(1980, 1982)
			1997				1997	(1995, 1998)
<i>Agriculture</i>	9.58	1	1993	-0.45		0		
<i>Glass</i>	1.70	1	1993	17.28**		1	1993	(1992, 1999)
<i>Electronics</i>	26.31	0		-0.37		0		
Asbestos								
<i>Friction products</i>		3	1983	13.54**		1	1995	(1994, 1995)
			1989					
			1995					
<i>Packing products</i>	29.04	0		-0.28		0		
<i>Roofing products</i>	44.93	1	1984	2.89**		1	1984	(1983, 1989)
Cadmium								

<i>Batteries</i>	34.22	1	1996	-0.36		0		
<i>Coating</i>	27.39	2	1988	0.05		0		
			1955					
<i>Paint Pigments</i>	36.25	2	1981	-0.09		0		
			1996					
<i>Plastics</i>	28.60	2	1989	-0.29		0		
			1995					
Mercury								
<i>Chemicals</i>	24.71	1	1986	1.83**	0.14	1	1986	(1978, 1987)
<i>Electronics</i>	11.55	2	1985	9.86**	5.87**	2	1985	(1984, 1986)
			1992				1992	(1991, 1994)
<i>Instruments</i>	-11.68	0		-0.23		0		
Chromium								
<i>Metal</i>	-8.06	1	1981	-0.43		0		
<i>Other Applications*</i>	-7.71	1	1981	14.02**		1	1981	(1978, 1982)
Cobalt								
<i>Cement</i>	0.22	1	1981	3.74**		1	1981	(1980, 1982)
<i>Chemicals</i>	-30.93	2	1982	-0.52		0		
			1996					

<i>Magnetic Alloys</i>	11.23	1	1993	-0.33		0		
<i>Steel</i>	18.29	2	1986	-0.30		0		
			1996					
<i>Superalloys</i>				-0.15		0		
Manganese								
<i>Steel</i>	-40.40	2	1981	-0.07		0		
			1992					
<i>Cast Iron</i>	-9.38	1	1985	1.46		0		
<i>Alloys</i>	-14.67	1	1983	-0.45		0		
<i>Batteries</i>	-19.61	2	1983	0.90		0		
			1996					
<i>Chemicals</i>	-26.81	1	1981	0.00		0		
Selenium								
<i>Glass</i>	-5.74	0		-0.51		0		
<i>Chemicals</i>	-11.97	1	1987	16.85**	61.54**	2	1987	(1986, 1989)
							1995	(1982, 1996)
<i>Electronics</i>	4.70	2	1981	4.81**		1	1995	(1994, 1995)
			1996					
<i>Other Applications</i>	3.91	2	1987	-0.54		0		

			1995					
Zinc								
<i>Galvanizing</i>	-48.95	1	1996	-0.36		0		
<i>Brass</i>	-24.82	1	1983	3.51**		1	1983	(1982, 1986)
<i>Alloys</i>	-36.14	3	1982	-0.46		0		
			1989					
			1996					
<i>Other Applications</i>	7.46	0		-0.57		0		
Antimony								
<i>Glass</i>	12.47	2	1981	-0.46		0		
			1993					
<i>Chemicals</i>	7.20	1	1983	0.23		0		
<i>Flame Retardants</i>	-4.34	1	1989	32.78**	466.80**	2	1981	(1980, 2014)
							1990	(1990, 1991)
<i>Transportation and Batteries</i>	4.96	2	1981	0.04		0		
			1993					
<i>Other Applications</i>	32.91	2	1986	-0.36		0		
			1993					
Beryllium								

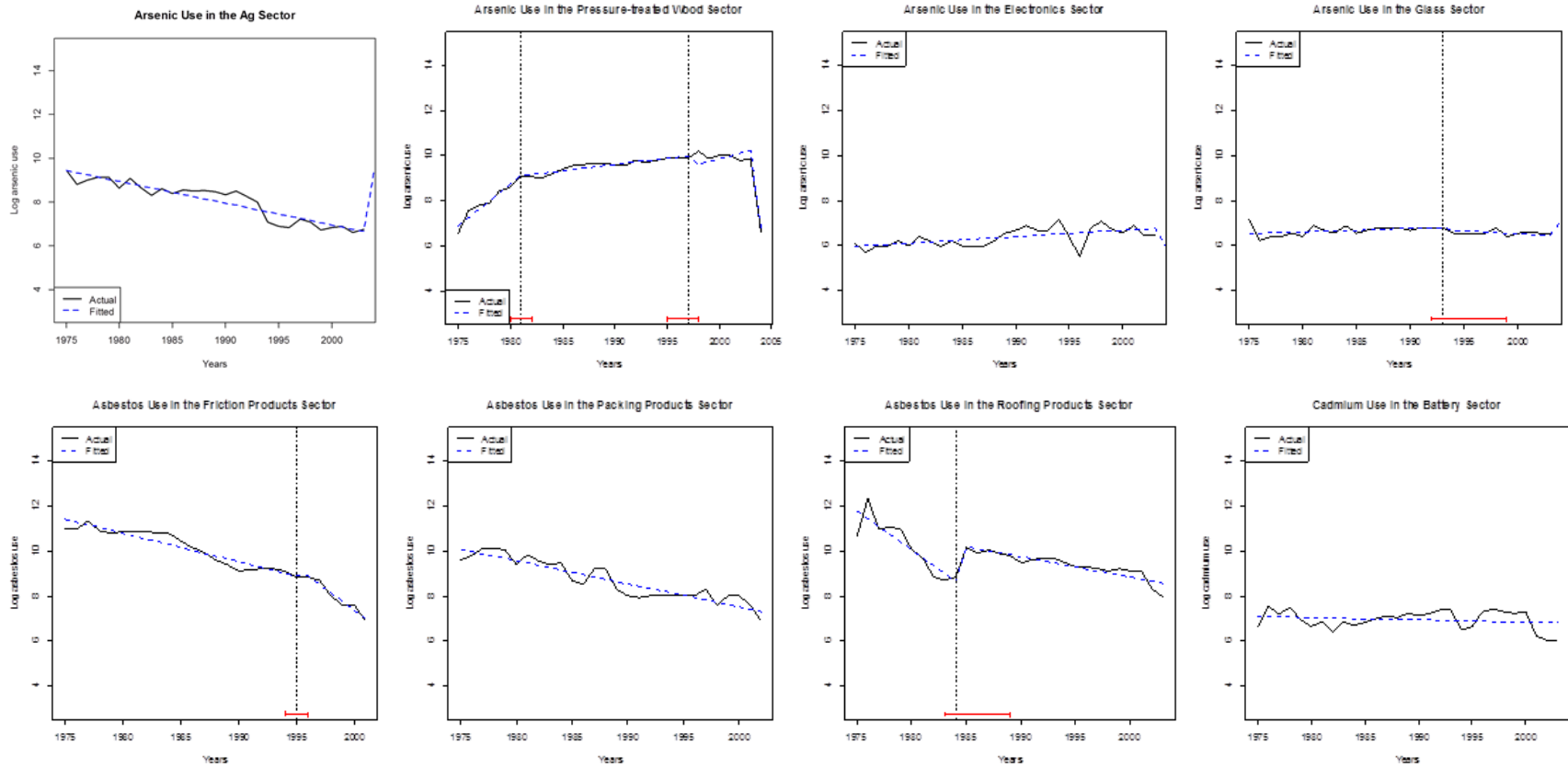
<i>Aerospace</i>	36.52	1	1981	2.69**	1	1981	(1980, 1987)
<i>Electrical</i>	43.15	1	1987	-0.58	0		
<i>Electronics</i>	36.38	0		-0.62	0		
<i>Other Applications</i>	54.10	2	1988	-0.46	0		
			1996				
Bromine	N/A						
Lead							
<i>Ammunition</i>	-55.81	2	1982	-0.18	0		
			1995				
<i>Brass</i>	-13.13		1983	1.07	0		
			1992				
<i>Glass & Paint Pigments</i>	-34.58	0		1.17	0		
<i>Gasoline</i>	-4.86	1	1984	21.86	1	1984	(1983, 1986)
<i>Lead Sheet</i>	7.78	0		-0.45	0		
<i>Solder</i>	-5.61	0		1.41	0		
<i>Batteries</i>	-41.80	1	1994	-0.34	0		
<i>Other Applications</i>	-29.96	1	1994	1.16	0		

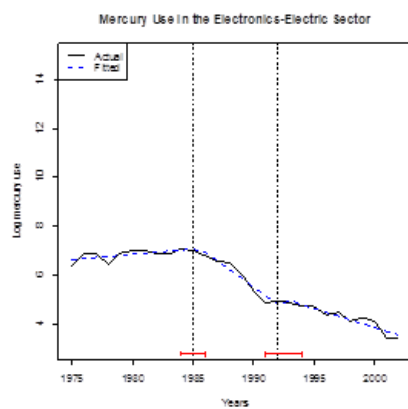
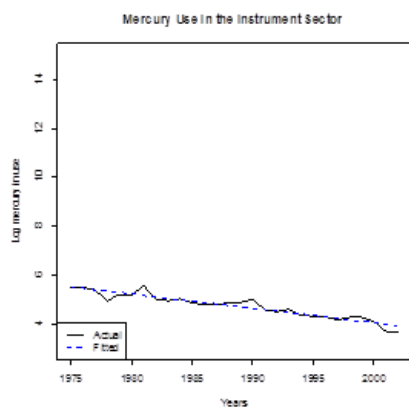
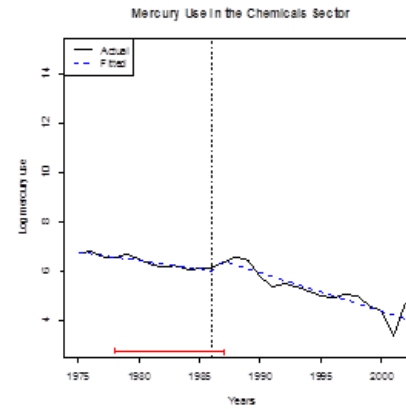
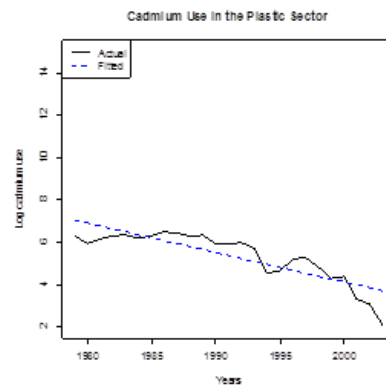
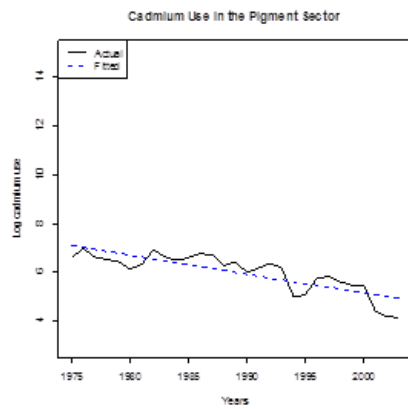
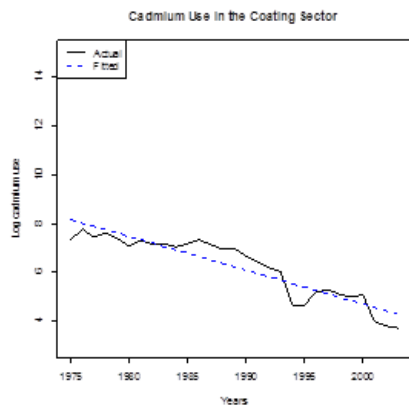
Over the past several decades there have been much technological change in the mercury-using sectors. The chlor-alkali industry, which was the largest user of mercury began in the 1980s to substitute away from a mercury-intensive technology for manufacturing chlorine to a technology that eliminated the use of the toxic chemical input (Chlorine Institute, 2009). Furthermore, mercury is no longer used in batteries and paints manufactured in the U.S. (“USGS Minerals Information,” 2012).

Among all toxic chemicals, asbestos has been the most regulated by the EPA. As such, it is not surprising to see downward trends for all asbestos-using end use sectors and for the estimated structural shifts to occur in the mid-1980s (for roofing products) and mid-1990s (for friction products). Regulatory activities that pertained to asbestos included the EPA’s TRI (1986) and various versions the EPA’s asbestos regulatory phase-out and restrictions (1989, 1993); the EPA’s final rule on most asbestos products was overturned by the appeals courts but many asbestos-containing products remained banned, including many friction products and some roofing products (U.S. EPA, 2012).

Among the arsenic-using sectors, there were little deviations from steady horizontal growth trends for the glass and electronics sectors. The 1993 estimated break for the glass sector was imprecisely estimated and the change in slope between the first and second regimes was statistically significant but very small (from 0.01 to -0.02, not shown). Most of the action was in the pressure-treated wood sector where the 1981 structural shift to a flatter slope in trend corresponded with the 1981-82 recession. Another structural break in the mid-to-late 1990s signaled a third regime that started off as a relatively flat trend only to fall sharply toward the end of the series. The dramatic decline in 2003 in the arsenic use trend was not captured by the KP test, however, because it occurred at the tail-end of the time path.

Figure 7
Kejriwal and Perron (2010) Estimated Multiple Structural Breaks
Toxic Chemical Use By Individual Chemical Industry Sectors, *EKC* Chemicals



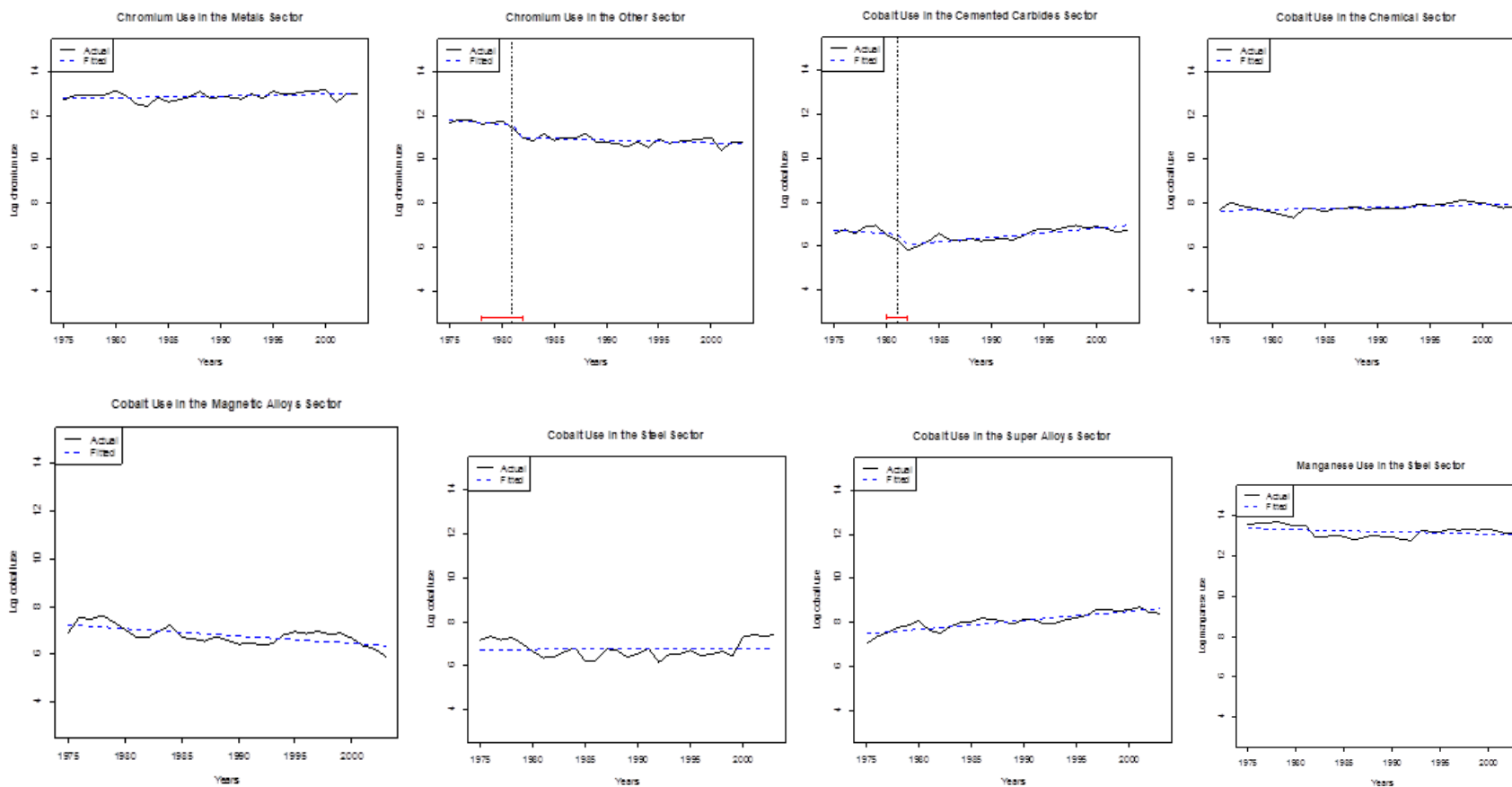


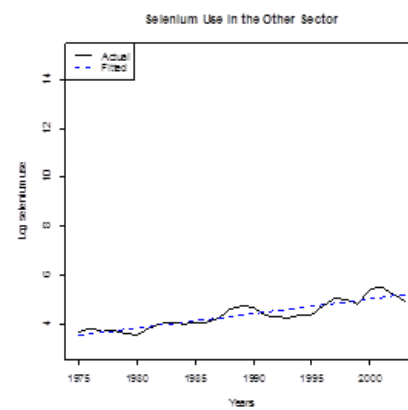
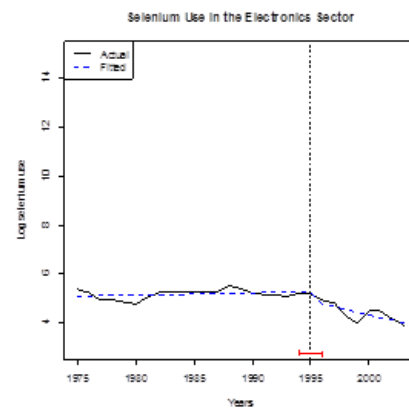
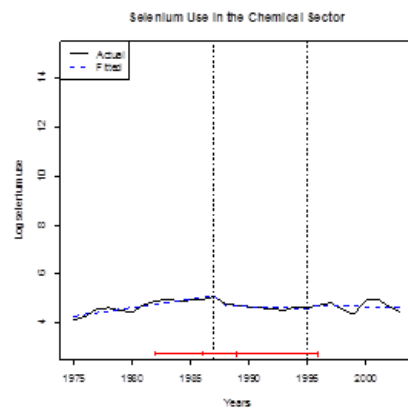
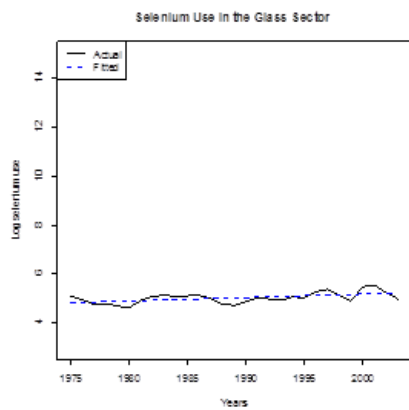
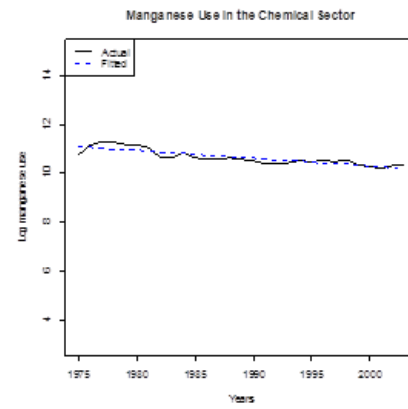
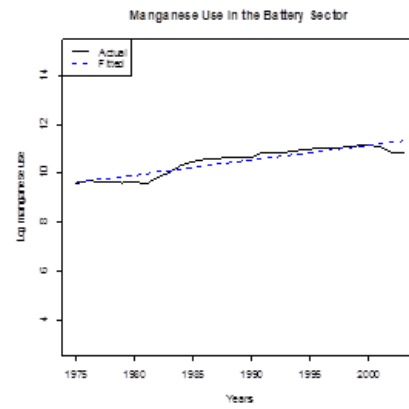
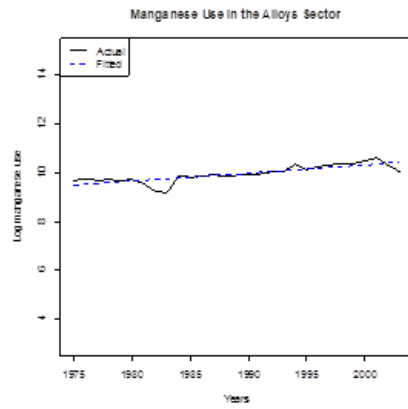
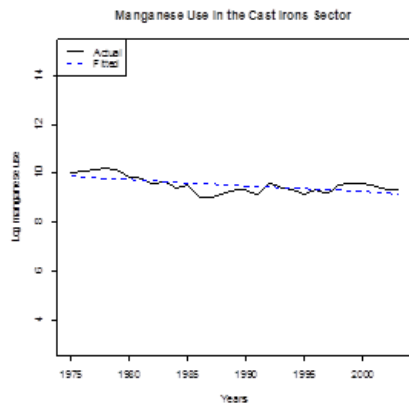
There were few structural shifts recorded in the end-use sectors of the *kinked growth* chemicals. Several of the estimated breaks corresponded with economic downturns or ramp ups. The estimated break of 1981 for chromium-using other applications sector and the cobalt-using cement sector coincided with the 1981-82 recession. The 1983 for the zinc-using brass sector corresponded to the post-1981-82 recession recovery of economic activities.

For the selenium-using chemicals sector, the 1987 breakdate coincided with the EPA's establishment of the TRI. The chemicals sector trended down sometime between 1985 and 1989. A second break demarcating the beginning of a third regime occurred in 1995 for selenium use in the electronics sector. This second estimated break represented a shift down in the use time trend.

The second break in selenium-using chemical sector is imprecisely estimated—the confidence band of 1982 to 1992 includes 12 years of trend; two economic downturns likely kept the growth trends flat through the second regime into the third regime. See Figure 8 for plots of the consumptive time paths of these end-use sectors.

Figure 8
Kejriwal and Perron (2010) Estimated Multiple Structural Breaks
Toxic Chemical Use by Individual Chemical Industry Sectors, *Kinked Growth* Chemicals





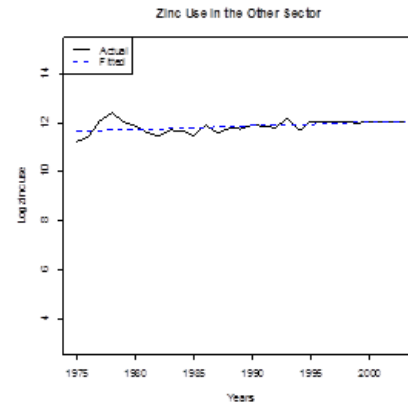
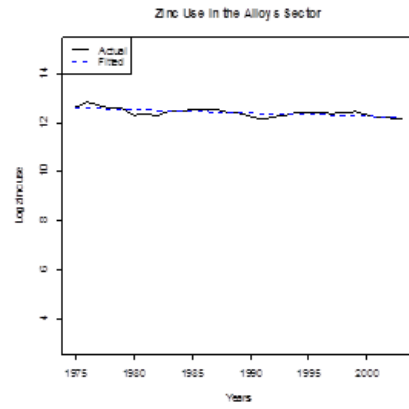
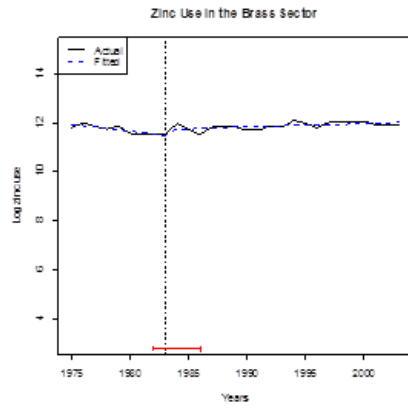
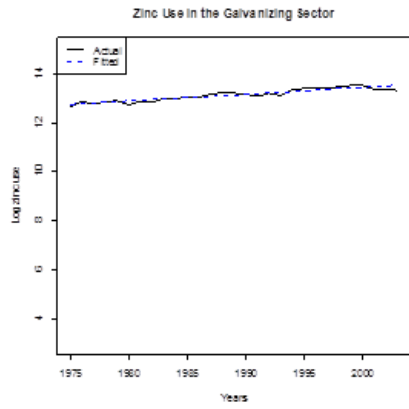
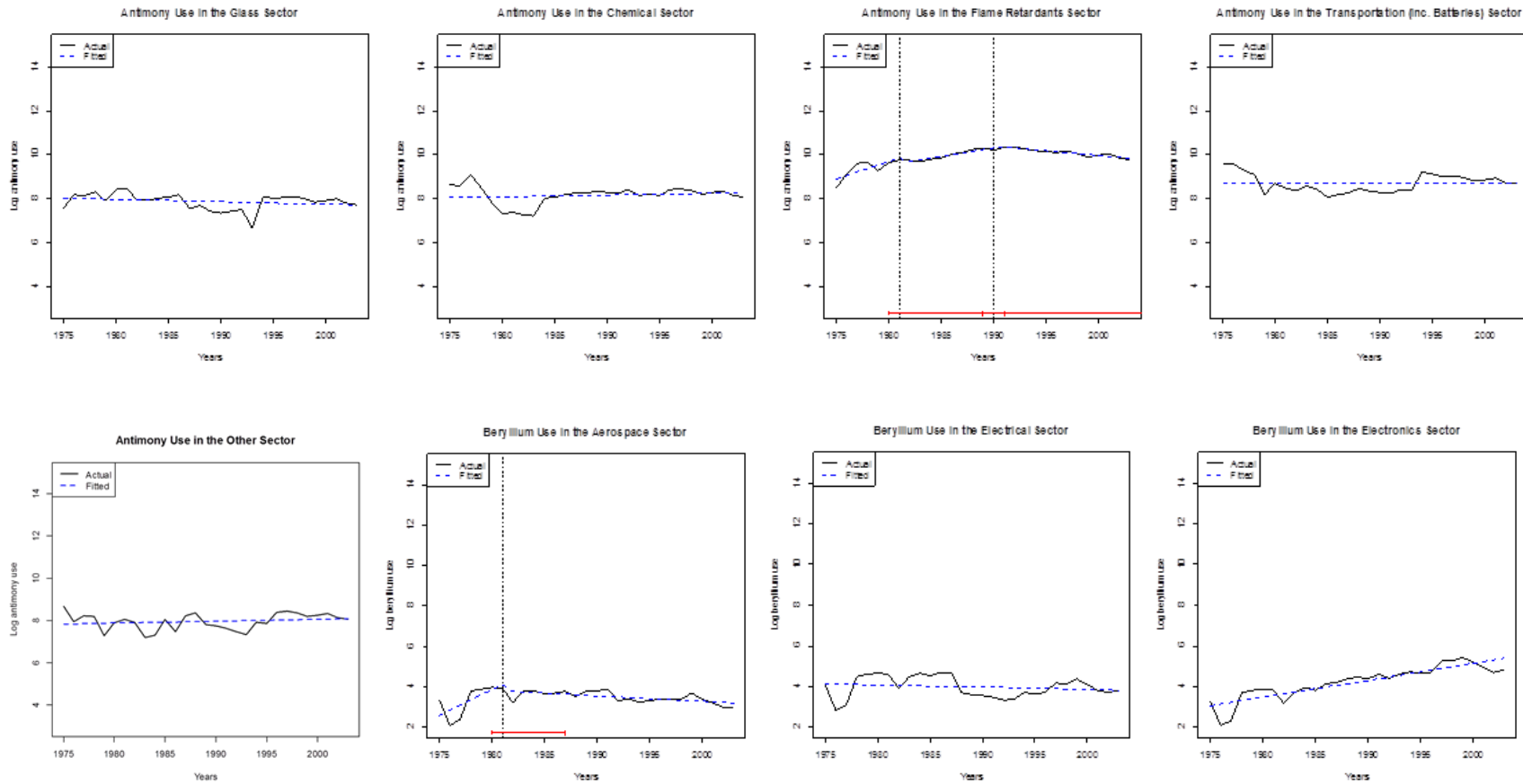
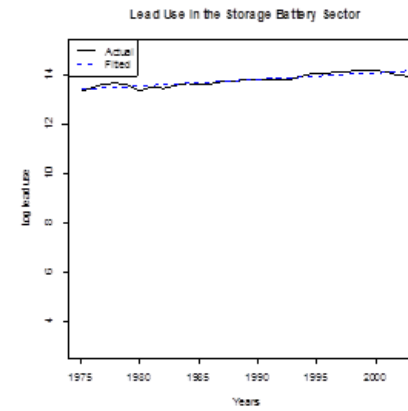
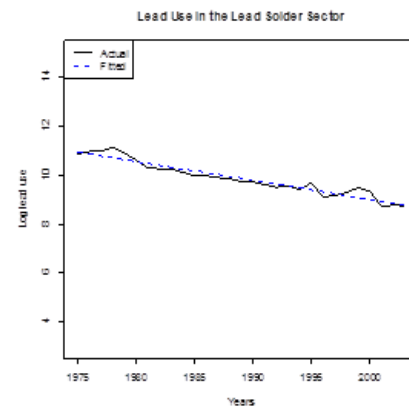
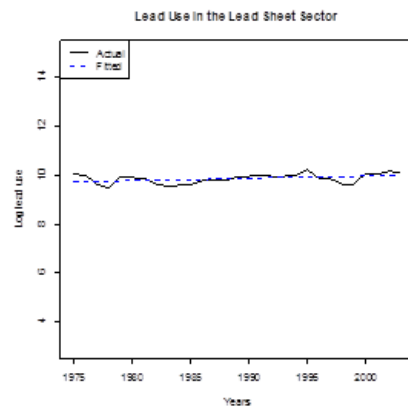
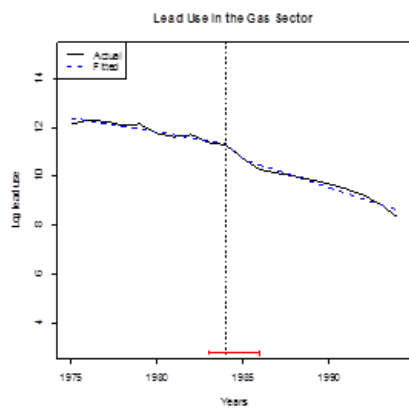
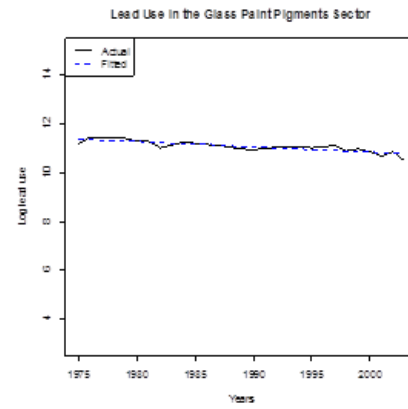
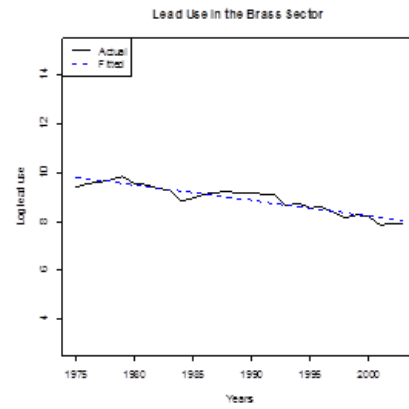
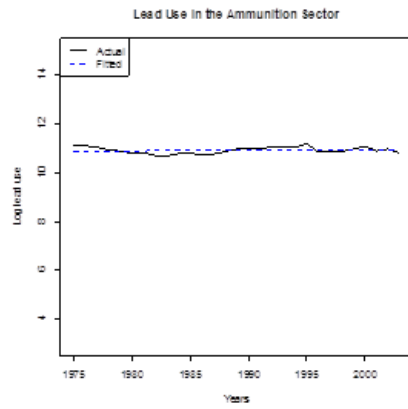
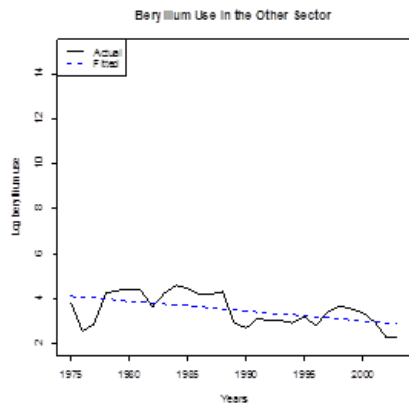


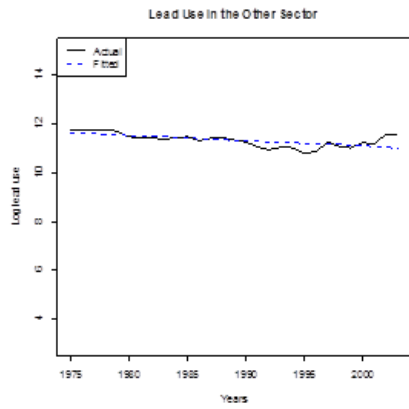
Figure 9 plots the consumptive time path of the end-use sectors for the *growth* chemical use series. A majority of these series recorded no structural shifts according to the KP test. In fact, most of these time paths retained their horizontal growth trends (antimony, lead-using sectors) or downward growth trends (beryllium-using and lead-using sectors) throughout the time series with the exception of beryllium use in the electronics sector. For the latter, the growth of the electronics sector globally was likely a major factor for the rise in beryllium use since the U.S. is one of only three suppliers worldwide in beryllium ores used in semiconductor manufacturing (“USGS Minerals Information,” 2012).

Only three end-use sector series, namely, the antimony-using flame retardant, beryllium-using aerospace, and the lead-using gasoline sectors deviated from their respective time trends. That being said, these three breakdates were not precisely estimated. In particular, the 1981 estimated break for the antimony-using flame retardant sector has a confidence band that extends from 1980 to beyond the time series (2014). For the beryllium-using aerospace sector, the shift down in the trend of beryllium use after the 1981 breakdate could have been a result of an economic downturn and/or the advent of the EPA’s TRI.

Figure 9
Kejriwal and Perron (2010) Estimated Multiple Structural Breaks
Toxic Chemical Use by Individual Chemical Industry Sectors, *Growth* Chemicals







By contrast, the 1984 structural shift toward a lower trend in the lead-using gasoline sector corresponded fairly straightforwardly with the 1982-1987 leaded gasoline phase down by the EPA; the confidence band was tight. A lead trading program, which was developed in the 1980s by the federal government, gave gasoline refiners greater flexibility in meeting emission standards at a time when the lead-content of gasoline was reduced to 10 percent from its previous level. In 1982, EPA authorized inter-refinery trading of lead credits, a major purpose of which was to lessen the financial burden on smaller refineries, which were believed to have significantly higher compliance costs. If refiners produced gasoline with a lower lead content than was required, they earned lead credits.

In 1985, EPA initiated a program allowing refineries to bank lead credits, and subsequently firms made extensive use of this option. In each year of the program, more than 60 percent of the lead added to gasoline was associated with traded lead credits (Hahn and Hester 1989), until the program was terminated at the end of 1987, when the lead phasedown was completed. Overall, the lead program was considered by policymakers as successful in meeting its environmental targets, although it may have produced some temporary geographic shifts in use patterns (Anderson, R., Hoffmann, & Rusin, 1990).

Unit Roots

I use the information from the structural break tests to test for the presence of a unit root in the end-use sector series. A majority of the end-use sector series have zero breaks according to the KP test. As such, I administer the ADF unit root test in these cases. In the end-use series that have at least one break I administer the CKP unit root test. Table 13 reports the test statistics from these unit root tests conditional on the presence or absence of breaks. On the whole, these tests do not provide evidence against the stochastic trend/unit root hypothesis.

Table 13
Toxic Chemical Use By Individual Chemical Industry Sector
Unit Root Tests

End-Use Sectors	#Breaks	Augmented Dickey Fuller	Carrioni-Silvestre, Kim, and Perron (2009)			
			KP	MPT	MZA	MSB
Arsenic						
<i>Pressure-treated Wood</i>	2		14.36**	-13.50	0.19**	-2.54
<i>Agriculture</i>	0	-2.00				
<i>Glass</i>	1		11.04**	-13.36	0.19**	-2.58
<i>Electronics</i>	0	-2.52				
Asbestos						
<i>Friction products</i>	1		20.24**	-7.41	0.22**	-1.64
<i>Packing products</i>	0	-1.90				
<i>Roofing products</i>	1		11.83**	-9.70	0.23**	-2.20
Cadmium						
<i>Batteries</i>	0	-2.17				
<i>Coating</i>	0	-1.59				
<i>Paint Pigments</i>	0	-1.05				

<i>Plastics</i>	0	0.17				
Mercury						
<i>Chemicals</i>	1		12.27**	-13.43	0.18**	-2.43
<i>Electronics</i>	2		18.68**	-12.52	0.20**	-2.46
<i>Instruments</i>	0	-2.12				
Chromium						
<i>Metal</i>	0	-2.35				
<i>Other Applications</i>	1		11.73**	-13.72	0.19**	-2.61
Cobalt						
<i>Cement</i>	1		13.46**	-11.09	0.21**	-2.34
<i>Chemicals</i>	0	-3.71**				
<i>Magnetic Alloys</i>	0	-2.19				
<i>Steel</i>	0	-0.88				
<i>Superalloys</i>	0	-3.23				
Manganese						
<i>Steel</i>	0	-2.27				
<i>Cast Iron</i>	0	-1.80				
<i>Alloys</i>	0	2.68				

<i>Batteries</i>	0	-0.68				
<i>Chemicals</i>	0	-2.12				
Selenium						
<i>Glass</i>	0	-2.47				
<i>Chemicals</i>	2		4.06	-49.46**	0.10	-4.96**
<i>Electronics</i>	1		14.13**	-8.74	0.23**	-2.07
<i>Other Applications</i>	0	-2.86				
Zinc						
<i>Galvanizing</i>	0	-2.80				
<i>Brass</i>	1		7.57**	-22.30	0.15**	-3.01
<i>Alloys</i>	0	-4.40**				
<i>Other</i>	0	-4.34**				
Antimony						
<i>Glass</i>	0	-1.62				
<i>Chemicals</i>	0	-4.09**				
<i>Flame Retardants</i>	2		28.4**	-3.92	0.30**	-1.19
<i>Transportation and Batteries</i>	0	-3.34				
<i>Other Applications</i>	0	-3.23				

Beryllium						
<i>Aerospace</i>	1		9.32**	-13.82	0.19**	-2.59
<i>Electrical</i>	0	-2.46				
<i>Electronics</i>	0	-3.09				
<i>Other Applications</i>	0	-2.58				
Bromine		N/A				
Lead						
<i>Ammunition</i>	0	-2.11				
<i>Brass</i>	0	-1.99				
<i>Glass & Paint Pigments</i>	0	-2.87				
<i>Gasoline</i>	1		16.92**	-9.79	0.13	-1.27
<i>Lead Sheet</i>	0	-2.19				
<i>Solder</i>	0	-2.20				
<i>Batteries</i>	0	-2.67				
<i>Other Applications</i>	0	-0.28				

Note: 1%, 5%, and 10% critical values for the ADF statistics are -4.15, -3.50, and -3.18. The lag of the endogenous variable to be added, $k = 3$.

Only a small number of end-use series are stationary and they generally do not correspond to the stationarity of the respective individual chemical use series. According to the results in section 5.2, the *kinked growth* chemical time paths are all stationary (see Table 9 Panel B). Yet, in none of the end-use sector series of the *kinked growth* chemicals could we reject the unit root null. Yet, only four out of the twenty-one end-use sector series in this category—namely, cobalt use in the cement and chemical sectors, and zinc use in the manufacturing of alloys and other applications—are stationary, i.e., do not contain a unit root.

Other stationary end-use sector series are arsenic use in the pressure-treated wood and glass sectors and asbestos use in friction products and roofing products in the *EKC* chemicals category; and antimony use in chemical manufacturing in the *growth* chemicals category.

The fact that a majority of the end-use sector chemical use series contain a unit root suggest that the potential effects of policy interventions aimed at individual end-use sectors are less predictable given any new trend in the series are more likely to drift in a random walk fashion rather than hold close to a new trend associated with a policy change.

Cointegration

Table 13 shows that a majority of the end-use sector series contain a unit root. The time paths of these end-use sectors are further analyzed for evidence of cointegrating relationships among sectors that use the same chemicals. Furthermore, inference on cointegration ranks is made between individual end-use sector series and national accounts and industrial production.

Table 14 presents the results of the LST cointegration test for end-use sectors that use the same chemicals. In a majority of the cases, the end-use sectors that use the same chemicals are not cointegrated: We cannot reject that $r=0$ or that there is no cointegrating vector at the 5% significance level for these end-use sector time paths. Only in the arsenic-using industry sectors

are there evidence, at the 5% significance level, that there is at least one cointegrating relation in these time paths. Mercury-using and selenium-using industry sectors share one cointegrating relation, respectively, at the 10% significance level. In a majority of the cases, no lesser combinations of the end-use sectors share cointegration relations when the respective larger sets of the end-use sectors that use the same chemicals are not cointegrated.

The next set of analysis examines whether chemicals with unit roots are likely to be cointegrated with national accounts and industrial production. Table 15 presents the results of the LST cointegration tests on individual end-use sectors and industrial production, real GDP, real investments in R&D by government, real investments in R&D by the private sector, real investments in R&D in chemicals, and real investments in R&D in electronics and electrics. Overall, evidence from the LST cointegration tests suggest that chemical use at the industry sector level are largely driven by changes in U.S. GDP and industrial production rather than by changes in real investments in R&D. That being said, a couple more end-use sector series are cointegrated with R&D investments by the private sector than the government.

Of the various national accounts and industrial production, evidence is heavily weighted towards real GDP as the macroeconomic variable most often cointegrated with chemical use at the industry sector level. 21 of the 41 end-use sector series share at least one cointegrating rank/vector with real GDP at the 5% significance level; in fact, several of these series yield trace statistics that are significant at the 1% level. If we count the series with trace statistics that pass the 10% significance threshold, there are 10 more end-use sector series that share a cointegrating relation with real GDP. Together, the results indicate that about 75% of all chemical use series at the industry sector level are driven in the long-run by changes in the trend of real GDP.

Table 14
Lutkepohl, Saikkonen, and Trenkler (2004)
Inference on Cointegration Rank, Allow Structural Shift
End-Sector Chemical Use Series by Individual Chemicals

y_t	Trace Statistics				
	$r = 0$	$r \leq 1$	$r \leq 2$	$r \geq 3$	$r \leq 4$
Arsenic-using sectors <i>Agriculture, Electronics</i> ¹	17.20**	5.97*			
Asbestos-using sectors <i>Packing</i>	N/A	N/A	N/A	N/A	N/A
Cadmium-using sectors <i>Batteries, Coating, Paint, Plastics</i> ²	27.24	15.30	5.70	0.46	
Mercury-using sectors <i>Chemical, Electronics, Instruments</i>	27.81*	15.85**	4.21		
Chromium-using sectors <i>Metal, Other Applications</i>	8.80	1.31			
Cobalt-using sectors <i>Magnetic Alloys, Steel, Superalloys</i>	24.80	11.81	3.68		
Manganese-using sectors <i>Steel, Cast Iron, Alloys, Batteries, Chemicals</i>	52.10	37.50	24.49	15.12*	6.53*
Selenium-using sectors <i>Glass, Chemicals, Electronics, Other Applications</i>	42.58*	24.94	13.57*	2.99	
Zinc-using sectors <i>Galvanizing, Brass</i>	13.49	3.86			
Antimony-using sectors <i>Glass, Flame Retardants, Transportations and Batteries, Other Applications</i>	37.45	22.74	12.42	3.37	
Beryllium-using sectors <i>Aerospace, Electrical, Electronics, Other Applications</i>	34.12	20.27	9.61	0.80	
Bromine-using sectors	N/A	N/A	N/A	N/A	N/A

Lead-using sectors

<i>Ammunition, Brass, Glass & Paint Pigments,</i>	35.29	21.44	9.71	2.88
<i>Lead Sheet</i>				
<i>Solder, Batteries, Other Applications</i>	22.09	10.06	1.46	

¹ Data series analyzed 1975-2003.

² No combinations of the cadmium-using sectors are cointegrated.

Table 15
Lutkepohl, Saikkonen, and Trenkler (2004)
Inference on Cointegration Rank, Allow Structural Shift

Panel A		
End-Sector Chemical Use Series and Industrial Production		
y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
Arsenic-using sectors		
<i>Agriculture</i>	12.05	4.15
<i>Electronic</i>	17.23**	5.81*
Asbestos-using sectors		
<i>Packing</i>	15.81*	4.44
Cadmium-using sectors		
<i>Batteries</i>	16.14**	6.86**
<i>Coating</i>	13.49	4.83
<i>Paint</i>	147.61*	5.27
<i>Plastics</i>	11.11	5.03
Mercury-using sectors		
<i>Chemical</i>	9.61	1.14
<i>Electronics</i>	9.71	2.68
<i>Instruments</i>	17.47**	8.14**
Chromium-using sectors		
<i>Metal</i>	16.01**	5.45*
<i>Other Applications</i>	11.02	3.79
Cobalt-using sectors		
<i>Magnetic Alloys</i>	16.31**	4.13
<i>Steel</i>	14.25*	6.18*
<i>Superalloys</i>	18.16**	7.36**
Manganese-using sectors		
<i>Steel</i>	11.15	4.55
<i>Cast Iron</i>	8.46	1.92
<i>Alloys</i>	13.65	4.36
<i>Chemicals</i>	13.43	3.44
<i>Batteries</i>	11.88	3.33
Selenium-using sectors		
<i>Glass</i>	18.83**	7.84**
<i>Chemicals</i>	15.31*	6.95**
<i>Electronics</i>	14.00	3.78
<i>Other Applications</i>	17.46**	7.47**
Zinc-using sectors		
<i>Galvanizing</i>	10.05	3.47
<i>Brass</i>	18.60**	7.96**
Antimony-using sectors		
<i>Glass</i>	15.63*	4.28

<i>Flame Retardants</i>	12.76	4.19
<i>Transportations and Batteries</i>	11.39	4.64
<i>Other Applications</i>	14.33*	5.44*
Beryllium-using sectors		
<i>Aerospace</i>	14.99*	3.77
<i>Electrical</i>	18.78**	8.26**
<i>Electronics</i>	19.56**	7.13**
<i>Other Applications</i>	15.10*	4.31
Bromine-using sectors		
Lead-using sectors		
<i>Ammunition</i>	14.41*	6.12*
<i>Brass</i>	17.76**	8.68**
<i>Glass & Paint Pigments</i>	14.37	4.16
<i>Lead Sheet</i>	18.98**	7.56**
<i>Solder</i>	15.70*	5.64*
<i>Batteries</i>	15.24*	4.28*
<i>Other Applications</i>	9.15	2.86

Panel B
End-Sector Chemical Use Series and Real GDP

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
Arsenic-using sectors		
<i>Agriculture</i>	14.26*	4.43
<i>Electronic</i>	21.28***	8.95**
Asbestos-using sectors		
<i>Packing</i>	18.73**	8.70**
Cadmium-using sectors		
<i>Batteries</i>	14.38*	5.85*
<i>Coating</i>	17.01**	6.27*
<i>Paint</i>	17.64**	6.71*
<i>Plastics</i>	12.05	3.33
Mercury-using sectors		
<i>Chemical</i>	20.28***	9.06**
<i>Electronics</i>	14.52*	2.94
<i>Instruments</i>	19.76**	7.29**
Chromium-using sectors		
<i>Metal</i>	14.43*	6.82**
<i>Other Applications</i>	13.03	4.78
Cobalt-using sectors		
<i>Magnetic Alloys</i>	10.17	3.40
<i>Steel</i>	14.16*	5.99*
<i>Superalloys</i>	17.00**	5.96*
Manganese-using sectors		

<i>Steel</i>	14.39*	4.61
<i>Cast Iron</i>	19.28**	6.88**
<i>Alloys</i>	16.89**	7.94**
<i>Chemicals</i>	15.41*	7.21**
<i>Batteries</i>	13.44	3.75
Selenium-using sectors		
<i>Glass</i>	19.41**	7.24**
<i>Chemicals</i>	18.11**	5.88*
<i>Electronics</i>	12.80	4.22
<i>Other Applications</i>	18.71**	6.58*
Zinc-using sectors		
<i>Galvanizing</i>	12.73	3.25
<i>Brass</i>	20.16**	9.02**
Antimony-using sectors		
<i>Glass</i>	19.05**	8.57**
<i>Flame Retardants</i>	17.01**	4.80
<i>Transportations and Batteries</i>	12.80	4.28
<i>Other Applications</i>	14.36*	6.11*
Beryllium-using sectors		
<i>Aerospace</i>	18.93**	5.59*
<i>Electrical</i>	20.86***	7.87**
<i>Electronics</i>	19.90***	6.23*
<i>Other Applications</i>	15.94**	3.52
Bromine-using sectors	N/A	N/A
Lead-using sectors		
<i>Ammunition</i>	18.35**	7.00**
<i>Brass</i>	16.86**	6.37*
<i>Glass & Paint Pigments</i>	14.11*	5.69*
<i>Lead Sheet</i>	17.75**	6.24*
<i>Solder</i>	15.30*	6.69*
<i>Batteries</i>	13.13	4.74
<i>Other Applications</i>	12.97	4.02

Panel C
End-Sector Chemical Use Series and Real Investments in R&D

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
Arsenic-using sectors		
<i>Agriculture</i>	12.44	4.45
<i>Electronic</i>	14.74*	4.21
Asbestos-using sectors		
<i>Packing</i>	16.65**	7.49**
Cadmium-using sectors		
<i>Batteries</i>	10.69	3.67

<i>Coating</i>	10.35	4.32
<i>Paint</i>	16.29**	5.38
<i>Plastics</i>	9.75	3.87
Mercury-using sectors		
<i>Chemical</i>	10.25	4.91
<i>Electronics</i>	11.48	5.02
<i>Instruments</i>	12.96	4.03
Chromium-using sectors		
<i>Metal</i>	15.17*	5.10
<i>Other Applications</i>	13.40	5.36
Cobalt-using sectors		
<i>Magnetic Alloys</i>	3.53	10.75
<i>Steel</i>	11.05	4.16
<i>Superalloys</i>	14.93*	5.24
Manganese-using sectors		
<i>Steel</i>	14.35*	4.01
<i>Cast Iron</i>	10.86	4.16
<i>Alloys</i>	12.88	3.80
<i>Chemicals</i>	14.61*	4.44
<i>Batteries</i>	8.75	2.13
Selenium-using sectors		
<i>Glass</i>	14.55*	4.02
<i>Chemicals</i>	16.75**	3.68
<i>Electronics</i>	14.12*	5.24
<i>Other Applications</i>	16.34**	6.34*
Zinc-using sectors		
<i>Galvanizing</i>	7.35	2.64
<i>Brass</i>	12.36	3.63
Antimony-using sectors		
<i>Glass</i>	13.11	4.34
<i>Flame Retardants</i>	13.69	2.67
<i>Transportations and Batteries</i>	13.54	3.87
<i>Other Applications</i>	11.68	3.78
Beryllium-using sectors		
<i>Aerospace</i>	15.18*	3.87
<i>Electrical</i>	15.21*	5.22
<i>Electronics</i>	16.4**	3.8
<i>Other Applications</i>	18.89**	7.97**
Bromine-using sectors	N/A	N/A
Lead-using sectors		
<i>Ammunition</i>	15.20*	4.31
<i>Brass</i>	12.62	2.48
<i>Glass & Paint Pigments</i>	10.05	2.68
<i>Lead Sheet</i>	15.85**	4.91
<i>Solder</i>	14.49*	4.99

<i>Batteries</i>	10.85	3.10
<i>Other Applications</i>	7.75	0.92

Panel D
End-Sector Chemical Use Series and Real Investments in R&D, Government

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
Arsenic-using sectors		
<i>Agriculture</i>	11.06	3.60
<i>Electronic</i>	13.73	3.29
Asbestos-using sectors		
<i>Packing</i>	15.90**	7.29**
Cadmium-using sectors		
<i>Batteries</i>	13.76	5.47
<i>Coating</i>	9.83	3.42
<i>Paint</i>	16.73**	6.09*
<i>Plastics</i>	10.72	4.42
Mercury-using sectors		
<i>Chemical</i>	10.44	4.78
<i>Electronics</i>	12.47	5.72*
<i>Instruments</i>	13.27	4.51
Chromium-using sectors		
<i>Metal</i>	16.75**	5.92*
<i>Other Applications</i>	12.91	6.35*
Cobalt-using sectors		
<i>Magnetic Alloys</i>	10.92	3.26
<i>Steel</i>	11.76	4.44
<i>Superalloys</i>	17.61**	7.67**
Manganese-using sectors		
<i>Steel</i>	12.89	4.72
<i>Cast Iron</i>	10.99	4.65
<i>Alloys</i>	12.83	3.42
<i>Chemicals</i>	13.92*	3.69
<i>Batteries</i>	9.46	3.03
Selenium-using sectors		
<i>Glass</i>	15.18*	5.22
<i>Chemicals</i>	16.32**	2.87
<i>Electronics</i>	13.56	5.59
<i>Other Applications</i>	16.15**	6.20*
Zinc-using sectors		
<i>Galvanizing</i>	10.75	4.40
<i>Brass</i>	14.14*	4.38
Antimony-using sectors		
<i>Glass</i>	12.16	3.86
<i>Flame Retardants</i>	13.60	2.04

<i>Transportations and Batteries</i>	12.84	3.08
<i>Other Applications</i>	15.50*	6.24*
Beryllium-using sectors		
<i>Aerospace</i>	14.09*	2.67
<i>Electrical</i>	19.09**	7.83**
<i>Electronics</i>	14.51*	2.58
<i>Other Applications</i>	17.32**	6.01*
Bromine-using sectors	N/A	N/A
Lead-using sectors		
<i>Ammunition</i>	13.65	3.85
<i>Brass</i>	11.50	2.04
<i>Glass & Paint Pigments</i>	10.00	2.08
<i>Lead Sheet</i>	15.27*	4.27
<i>Solder</i>	15.94**	6.83**
<i>Batteries</i>	10.94	2.48
<i>Other Applications</i>	9.71	1.66

Panel E
End-Sector Chemical Use Series and Real Investments in R&D, Private Sector

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
Arsenic-using sectors		
<i>Agriculture</i>	15.07*	5.22
<i>Electronic</i>	15.48*	5.20
Asbestos-using sectors		
<i>Packing</i>	16.95**	7.74**
Cadmium-using sectors		
<i>Batteries</i>	12.20	5.58*
<i>Coating</i>	10.67	3.49
<i>Paint</i>	15.40*	4.03
<i>Plastics</i>	8.51	4.04
Mercury-using sectors		
<i>Chemical</i>	10.24	2.28
<i>Electronics</i>	12.47	2.83
<i>Instruments</i>	11.61	4.93
Chromium-using sectors		
<i>Metal</i>	14.64*	5.62*
<i>Other Applications</i>	10.50	4.36
Cobalt-using sectors		
<i>Magnetic Alloys</i>	9.00	3.73
<i>Steel</i>	12.59	4.59
<i>Superalloys</i>	15.11*	6.25*
Manganese-using sectors		
<i>Steel</i>	17.18**	5.13

<i>Cast Iron</i>	13.44	3.22
<i>Alloys</i>	14.97*	5.47*
<i>Chemicals</i>	11.79	4.57
<i>Batteries</i>	10.14	2.93
Selenium-using sectors		
<i>Glass</i>	15.12*	5.18
<i>Chemicals</i>	19.39**	5.12
<i>Electronics</i>	13.48	5.77*
<i>Other Applications</i>	14.91*	5.42*
Zinc-using sectors		
<i>Galvanizing</i>	9.62	4.36
<i>Brass</i>	13.11	4.43
Antimony-using sectors		
<i>Glass</i>	12.95	5.18
<i>Flame Retardants</i>	9.53	3.53
<i>Transportations and Batteries</i>	11.49	4.78
<i>Other Applications</i>	12.38	5.08
Beryllium-using sectors		
<i>Aerospace</i>	18.09**	6.37*
<i>Electrical</i>	17.94**	6.58*
<i>Electronics</i>	17.23**	5.99*
<i>Other Applications</i>	18.04**	7.55**
Bromine-using sectors	N/A	N/A
Lead-using sectors		
<i>Ammunition</i>	15.20*	4.31
<i>Brass</i>	12.62	2.48
<i>Glass & Paint Pigments</i>	10.05	2.68
<i>Lead Sheet</i>	15.85**	4.91
<i>Solder</i>	14.49*	4.99
<i>Batteries</i>	10.85	3.10
<i>Other Applications</i>	7.75	0.92

Panel F
End-Sector Chemical Use Series and Real Investments in R&D, Chemicals

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
Arsenic-using sectors		
<i>Agriculture</i>	11.50	3.74
<i>Electronic</i>	14.01	2.93
Asbestos-using sectors		
<i>Packing</i>	16.44*	6.45**
Cadmium-using sectors		
<i>Batteries</i>	12.06	5.27*
<i>Coating</i>	12.51	6.16*

<i>Paint</i>	13.71	5.52*
<i>Plastics</i>	12.55	5.07
Mercury-using sectors		
<i>Chemical</i>	12.88	2.92
<i>Electronics</i>	12.78	5.10
<i>Instruments</i>	14.39*	6.06*
<hr/>		
Chromium-using sectors		
<i>Metal</i>	13.95*	5.04
<i>Other Applications</i>	12.71	5.80*
Cobalt-using sectors		
<i>Magnetic Alloys</i>	9.74	3.40
<i>Steel</i>	10.58	3.66
<i>Superalloys</i>	14.40*	4.48
Manganese-using sectors		
<i>Steel</i>	16.29**	5.38
<i>Cast Iron</i>	14.22*	5.79*
<i>Alloys</i>	14.34*	5.18
<i>Chemicals</i>	13.10	2.88
<i>Batteries</i>	11.16	2.58
Selenium-using sectors		
<i>Glass</i>	16.00**	4.76
<i>Chemicals</i>	17.23**	5.97*
<i>Electronics</i>	13.34	5.98*
<i>Other Applications</i>	16.22**	5.81*
Zinc-using sectors		
<i>Galvanizing</i>	9.26	3.67
<i>Brass</i>	13.75	5.48*
<hr/>		
Antimony-using sectors		
<i>Glass</i>	11.52	3.90
<i>Flame Retardants</i>	14.54*	3.05
<i>Transportations and Batteries</i>	11.21	2.89
<i>Other Applications</i>	13.60	5.36
Beryllium-using sectors		
<i>Aerospace</i>	18.89**	5.97*
<i>Electrical</i>	16.96**	7.42**
<i>Electronics</i>	18.55**	6.05*
<i>Other Applications</i>	16.87**	7.18**
Bromine-using sectors		
Lead-using sectors		
<i>Ammunition</i>	16.69**	5.64*
<i>Brass</i>	13.00	2.71
<i>Glass & Paint Pigments</i>	11.01	3.863
<i>Lead Sheet</i>	15.48*	6.96**
<i>Solder</i>	16.89**	6.50*
<i>Batteries</i>	13.04	4.84

<i>Other Applications</i>	10.39	2.70
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Panel G

End-Sector Chemical Use Series and Real Investments in R&D, Electronics and Electrics

y_t	Trace Statistics	
	$r = 0$	$r \leq 1$
Arsenic-using sectors		
<i>Agriculture</i>	13.60	3.05
<i>Electronic</i>	13.56	3.62
Asbestos-using sectors		
<i>Packing</i>	18.07**	4.72
Cadmium-using sectors		
<i>Batteries</i>	12.06	5.27
<i>Coating</i>	13.71	5.52*
<i>Paint</i>	14.90*	3.83
<i>Plastics</i>	7.89	3.53
Mercury-using sectors		
<i>Chemical</i>	12.78	5.10
<i>Electronics</i>	13.99	3.83
<i>Instruments</i>	13.69	4.56
Chromium-using sectors		
<i>Metal</i>	12.09	4.07
<i>Other Applications</i>	11.41	4.03
Cobalt-using sectors		
<i>Magnetic Alloys</i>	11.22	3.41
<i>Steel</i>	13.12	4.47
<i>Superalloys</i>	13.90*	4.36
Manganese-using sectors		
<i>Steel</i>	14.96*	4.04
<i>Cast Iron</i>	10.24	2.38
<i>Alloys</i>	13.19	4.70
<i>Chemicals</i>	14.00**	4.40
<i>Batteries</i>	6.13	1.30
Selenium-using sectors		
<i>Glass</i>	11.91	3.19
<i>Chemicals</i>	14.75*	3.85
<i>Electronics</i>	10.40	4.66
<i>Other Applications</i>	12.34	3.62
Zinc-using sectors		
<i>Galvanizing</i>	9.54	4.26
<i>Brass</i>	14.60*	4.68
Antimony-using sectors		
<i>Glass</i>	9.76	2.89
<i>Flame Retardants</i>	10.68	3.43

<i>Transportations and Batteries</i>	11.91	3.45
<i>Other Applications</i>	11.82	3.50
Beryllium-using sectors		
<i>Aerospace</i>	16.57**	4.06
<i>Electrical</i>	14.87*	3.25
<i>Electronics</i>	15.01*	3.47
<i>Other Applications</i>	14.35*	3.50
Bromine-using sectors		
Lead-using sectors		
<i>Ammunition</i>	13.81*	3.78
<i>Brass</i>	12.56	1.99
<i>Glass & Paint Pigments</i>	14.67*	6.22*
<i>Lead Sheet</i>	12.69	2.97
<i>Solder</i>	15.64*	5.02
<i>Batteries</i>	10.86	3.87
<i>Other Applications</i>	7.35	1.56

*Significant at the 10% level; **Significant at the 5% level; ***Significant at the 1% level
 Note: For $r=0$, 1%, 5% and 10% critical values for the trace statistics is 19.85, 15.83, and 13.78, respectively. For $r \leq 1$, 1%, 5% and 10% critical values for the trace statistics is 5.42, 6.79, 10.04 respectively

More than half of the end-use sector series are cointegrated with industrial production (with at least cointegration rank=1) when we accept the 10% significance threshold. If we impose a stricter criterion for hypothesis testing, 13 of out the 41 end-use sector series share at least one cointegrating relation with industrial production at the 5% significance level.

By contrast, relatively fewer end-use sector series are cointegrated with real investments in R&D regardless whether the investments are made by the government or the private sector. That being said, there are several more time paths at the industry sector level that share a common trend with private sector investments than government investments in R&D (18 versus 16 cointegrating relations, respectively). In the long-run trend, seven more end-use sector series are cointegrated with R&D expenditures in chemicals than with R&D investments in electronics and electrics. Results suggest that the time paths of the electronics sector (namely, arsenic-using

electronics, mercury-using electronics, and selenium-using electronics) are not more likely to be cointegrated with real investments in R&D in electronics and electrics than other end-use sectors.

Several of the end-use sectors stand out in their persistence in rejecting the null hypothesis of no cointegration across the national accounts and industrial production series. First, the beryllium-using sectors, namely aerospace, electrics, electronics, and other applications, share at least one cointegrating relation with industrial production, real GDP, and the various R&D investment series, respectively, at the 10% significance level or in several cases at 5% or 1% significance level (namely, real GDP and R&D outlays in chemicals). Second, to a lesser extent the selenium-using sectors also share a common long-run trend with the national accounts and industrial production series. Moreover, the lead-using lead sheet and solder industry sectors are also persistent in rejecting the null of zero cointegration rank.

In sum, the LST tests indicate that real GDP and industrial production, and R&D investments to a lesser degree, are common drivers of long-run changes in the trend of chemical use at the industry sector level across toxic chemicals. Of all the end-use series, the time paths of the beryllium-using, selenium-using sectors, and two lead-using sectors share in common the fact that they are cointegrated with *all* the national accounts and industrial production series. This is not a surprising finding for lead use because we already know from earlier results at the individual chemical level that lead is cointegrated with industrial production and all the national accounts except for R&D investments in chemicals. By contrast, at the individual chemical level beryllium and selenium are both stationary series. Of note, however, is that several sectors that use beryllium and selenium as inputs in the manufacturing of commercial products have been steady drivers of GDP growth over the past several decades. For example, between 1987 and 2011, for both the computer and electronic products and chemical products sectors value added

as a percentage of GDP has remained steady at about 2%, respectively, even while the share of the manufacturing sector as a percentage of GDP has fallen from 17% in 1987 to 12% in 2011.

6.4 Discussion of Results

I examine the trend behavior of thirteen elemental toxic chemicals and that of their end-use industry sectors using recently developed methods for estimating structural breaks that are valid for DS and TS data, testing for the existence of unit roots that allow for structural breaks in the null and the alternative hypotheses, and establishing cointegrating relations that allow for a structural shift. I answer three questions. First, which of the government regulations—the command and control regulations (1972 FIFRA, 1976 TCSA) or the information-based regulation (1986 TRI)—have had an effect on toxic chemical use? Second, how effective have the various voluntary programs been in reducing toxic chemical use? Third, given the economic significance of these toxic chemicals as inputs into the manufacturing of commercial products, what has had more effect on the long-run time path of these toxic chemicals—political economic and institutional factors (e.g., government regulations) or macroeconomic factors (e.g., real GDP, industrial production)? I discuss the results from sections 6.1-6.3 with these questions and the hypotheses from section 3 in mind.

Public Policy Efficacy

The existence of a reduction in the mean and/or slope of the trend in toxic chemical use around the timing of various federal environmental legislations and voluntary programs provide strong evidence of the effectiveness of public policy. Relevant angles for analysis include whether policies are most effective when addressing aggregate pollution, when addressing one pollutant at a time, or when addressing pollutants in the context of the industry sectors that use them as inputs.

First, the conjecture is that TSCA and FIFRA, which are command-and-control regulations, and TRI, which is an information-based regulation, may be more effective when addressing aggregate pollution rather than any one chemical. It turns out, however, results from the preferred KP changepoint procedure, which is invariant to DS or TS data, show that there is no structural change in aggregate chemical use. When we consider the thirteen toxic chemicals together, no economic or institutional factors appear to have induced a structural shift in the mean or the slope of the aggregate chemical use time path. I speculate this may be because the aggregate chemical use data are driven to a large extent by the heavily used *growth* toxic chemicals—antimony, beryllium, bromine, and lead—in commercial products, all of which have changepoint-free trends.

That being said, a different depiction of public policy efficacy emerges when we consider the use trends of individual chemicals one at a time. For a majority of the individual chemical use series, structural changes occurred around the time of economic booms and busts, WWII, environmental regulations, and industry developments. Even so, there is variation across the thirteen toxic chemicals under study. I have grouped these differences by the plots of their time paths (see Figures 4-6 and Table 7 Panel B).¹⁶⁴ First, the time paths of *growth* chemicals (namely, antimony, beryllium, bromine, and lead) yield *no* structural breaks according to the KP structural change test. The mean and slope of these toxic chemical use trends have risen unabated.

For the *EKC* chemicals (arsenic, asbestos, cadmium, and mercury) three structural shifts in the mean and slope of the use trends demarcate four regimes. The first regime, which

¹⁶⁴ Again, the *EKC*, *kinked growth*, and *growth* categories are meant to be analytical categories only. These categories do not drive the empirical analysis or results.

represents the first several decades of the 20th Century, was a period of much commercial development and technological growth. The second regime, which is characterized by slower but still upward sloping growth leading up to WWII, is preceded by estimated changepoints in the mid-1910s to early 1920s for arsenic use, asbestos use, and cadmium use, respectively. The second structural change for each of the time paths of these toxic chemicals was either right before or at the end of WWII. By contrast, mercury use did not experience its first structural break until 1940, which coincided with the buildup of WWII.

The post-WWII era was a period of steady horizontal growth trend for all *EKC* chemicals until the next structural change, at which time the time paths of these toxic chemicals trended downward without ever returning to its previous trend. The third estimated structural shift for asbestos was in 1976, which corresponded with the enactment of the 1976 TSCA by the federal government. Incidentally, asbestos is the only toxic chemical among the thirteen toxic chemicals analyzed in which the EPA has *promulgated* formal rulemaking under the TSCA. For mercury and cadmium use, a structural break occurred in 1985 and 1986, respectively; these changepoints corresponded with the passage of the 1986 TRI by Congress.

Third, four of the five *kinked growth* toxic chemical use series, namely chromium use, cobalt use, manganese use, and zinc use possess a single break that demarcated two regimes: the first regime is an upward sloping trend and the second is a regime generally characterized by a trend of nearly flat, steady horizontal growth. For cobalt and chromium, the estimated changepoint occurred in 1959 and 1965, respectively. Both dates occurred before the start of the regulatory era, although the modern environmental movement was gaining momentum at the time with the 1962 publication of Rachel Caron's *Silent Spring*. Moreover, at the time the federal government had begun laying out broad environmental goals.

Upward trends in zinc and manganese experienced a changepoint in 1973 and 1979, respectively. The estimated break in the zinc use trend occurred in 1973, a year after major amendments in FIFRA, which is the mainstay pesticide rule. Manganese use's single estimated break occurred in 1979, although the confidence region spans eight years (1978-1986). Two recessions (1980 and 1981-82) and the establishment of the TRI by the EPA occurred during these eight years. It is thus difficult to attribute the estimated changepoint to regulation or to the economy.

The only *kinked growth* chemical that experienced multiple structural breaks was selenium. The first estimated break, 1934 corresponds with the general slowdown associated with the Great Depression (1929-1933). The next changepoint (1959) occurred during the era of intense environmental activities, which preceded the founding of the EPA and the advent of major environmental legislations. The final estimated break was in 1984 with a very large confidence interval that spans 1966 to 1992, which was a period of major postwar economic growth, the advent of all major environmental legislations, an oil crisis, and five recessions (1969-70, 1973-75, 1980, 1981-82, and 1990-91). Further disaggregated data and microeconometrics techniques and systematic policy process tracing would be needed to disentangle the causal impact of these various events and factors on chemical use.

Finally, on the whole, more than two-thirds of the toxic chemical end-use sector series have zero structural breaks during the time period (roughly 1975-2003) in which the industry sector data are available (see Figures 8-10 and Table 13). An important caveat is that due to the availability of the relatively short end-use sector time series, I cannot evaluate the effectiveness of the 1972 FIFRA and the 1976 TSCA, nor consider the factors that have affected toxic chemical use since 2003.

For the end-use sector series that recorded one or two estimated structural shifts the break estimates are generally imprecisely estimated with large confidence bands. The imprecision in the break estimations leads to the difficulty of identifying the effectiveness of public policy from the impact of the business cycle. With that said, the results are on balance consistent with the fact that for toxic chemical use by individual chemicals the regulatory era (post-1970) was by and large characterized by either downward sloping trends (*EKC* chemicals), horizontal growth trends (*Kinked growth* chemicals), or upward sloping trends (*growth* chemicals) with fewer perturbations in the time paths relative to the first half of the 20th Century.

For three of the *EKC* chemicals—*asbestos*, *cadmium*, and *mercury*—their end-use series have generally been characterized by downward sloping trends with the exception of the *cadmium-using battery* sector where a horizontal growth trend persisted throughout the period 1975-2003. These structural breaks occur in 1984 (*asbestos use in roofing products*), 1985 (*mercury use in electronics*), 1986 (*mercury use in chemicals*), 1992 (*mercury use in electronics*), and 1995 (*asbestos use in friction products*). The first three estimated shifts coincided with the establishment of the EPA's TRI as well as technological changes in the 1980s in the *mercury-using* sectors. Regulatory activities that pertained to *asbestos* included the EPA's TRI (1986) and various versions of the EPA's *asbestos* regulatory phase-out and restrictions that occurred in 1989 and 1993.

Among the *arsenic-using* sectors, there were little deviations from steady horizontal growth trends for the *glass* and *electronics* sectors. Most of the action was in the *pressure-treated wood* sector where the 1981 structural shift to a flatter slope in trend corresponded with the 1981-82 recession. Another structural break in the mid-to-late 1990s signaled a third regime that started off as a relatively flat trend only to fall sharply at the end of the trend. The dramatic

decline in 2003 in the arsenic use trend was not captured by the KP test, however, because it occurred at the tail-end of the time path.

The few estimated breaks in the *kinked growth* chemical use series corresponded with economic downturns or ramp-ups. First, the estimated break of 1981 for chromium-using other applications sector and the cobalt-using cement sector coincides with the 1981-82 recession. The 1983 break for the zinc-using brass sector corresponded with the post 1981-82 recession ramp-up in economic activities.

Second, for the manganese and selenium end-use sectors—other applications and chemicals, respectively—the 1986 and 1987 breakdates coincided with the EPA’s establishment of the TRI. Both end-use sector series trended down sometime between 1985 and 1989. A second break demarcating the beginning of a third regime occurred in 1993 for the manganese-using other applications sector. Within a similar confidence region is a structural shift for selenium use in the electronics sector. Both of these changepoints represented a shift down in the trend.

Third, the second break in selenium-using chemicals sector is imprecisely estimated—the confidence band 1982 to 1992 spans twelve years; two economic downturns likely have kept the trend flat through the second regime into the third regime.

Aside from the abovementioned end-use series, a majority of the end-use series of the *kinked growth* chemicals had no structural shifts according to the KP test. In fact, most of these time paths retained their horizontal growth trends (antimony-using and lead-using sectors) or downward growth trends (beryllium-using and lead-using sectors) throughout the time series with the exception of the beryllium use in the electronics sector. For the latter, the growth of the electronics sector globally is likely a major factor for beryllium use since the U.S. is one of only

three suppliers worldwide of beryllium ores used in semiconductor manufacturing (USGS website).

Finally, only three end-use sector series of the *growth* chemicals, namely, the antimony-using flame retardant, beryllium-using aerospace, and the lead-using gasoline sectors deviated from their respective time trends. That being said, these three breakdates were not precisely estimated. In particular, the 1981 estimated break for the antimony-using flame retardant sector has a confidence band that extends from 1980 to beyond the time series (2014). For the beryllium-using aerospace sector, the shift down in the trend of beryllium use after the 1981 breakdate could have been a result of an economic downturn and/or the advent of the EPA's TRI. By contrast, the 1984 structural shift toward a lower trend in the lead-using gasoline sector corresponds fairly straightforwardly with the 1982-1987 leaded gasoline phase down.

In sum, no economic or institutional factors appear to have induced a structural shift in aggregate chemical use. By contrast, for a majority of the individual chemical use series, structural changes occurred around the time of economic booms and busts, WWII, environmental regulations, and industry developments. The two command-and-control regulations—1972 FIFRA and 1976 TSCA—appeared to have had a policy impact on zinc use and asbestos use, respectively. On the other hand, the 1986 TRI, which is an information-based regulation, has had impact on the consumptive use trends of multiple toxic chemicals and/or the industry sectors that use these chemicals as key inputs in their manufacturing process: asbestos, cadmium, mercury, manganese, and selenium. Industry developments in arsenic use (the 1993 industry ban on arsenic acid) and mercury use (technological developments in the 1980s) have had an effect on the time paths of these said chemicals. Finally, the structural change results cannot preclude

the impact of economic booms and busts and build-ups related to WWII on the chemical use trend of several of the toxic chemicals and end-use sectors.

Long-run Impact and Drivers

The distinction between stationary and stochastic/non-stationary processes and the identification of the long-run drivers of toxic chemical use are important for assessing the potential long-run impact of environmental policy. Specifically, the fact that a series is $I(0)$ or $I(1)$ can reveal whether a government intervention is likely to be effective or not in the long-run. A stationary series with break (i.e., a broken trend) indicate that a policy is probably going to be effective because the series/variable will hold tightly rather than meander from the new trend induced by the policy shock. By contrast, a unit root series with break suggests that the series/variable will not clasp the new trend but rather drift in a random walk fashion.

To test for the presence of a unit root, I administer what research has shown as the efficient unit root test given the existence (or not) of structural breaks. For zero-break series, I administer the ADF unit root test. For multiple-breaks series, I administer the CKP test. Results indicate that aggregate toxic chemical use contains a unit root (see Table 5). This suggests that in aggregate the consumptive use of the toxic chemicals analyzed in this paper is not easily perturbed by external shocks, policy shocks or otherwise. Rather, aggregate toxic chemical use in the long-run will likely drift in a random walk-like fashion as opposed to being restrained by policy interventions.

By contrast, when the consumptive use of toxic chemicals is considered separately by individual toxic chemicals over half of them (7 out of 13) are TS (see Table 8). That being said, all but one *growth* chemical (i.e., beryllium) contains a unit root. Antimony, beryllium, bromine, and lead use all have stochastic trends. Moreover, the time paths of all *kinked growth* chemicals

are stationary, while only one *EKC* chemical time path is stationary, namely mercury use. These results suggest that the only toxic chemicals likely to be restrained by public policy in the long-run are the *kinked growth* chemicals—namely, chromium, cobalt, manganese, selenium, and zinc.

On the whole, the CKP tests administered to the end-use series do not provide evidence against the stochastic trend/unit root hypothesis. In fact, a majority of the toxic chemical use series at the industry sector level contains a unit root (see Table 12). The stochastic nature of the end-use toxic chemical series suggest that the effects of policy interventions aimed at individual end-use sectors are less predictable given that any new trend in the series are likely to drift in a random walk fashion.

One of the corollaries of my hypotheses is that chemical use series containing a unit root are more likely to be cointegrated with national accounts and industrial production, and thus are by implication less likely to be cointegrated with toxic chemical use series that are regulated under the same laws. The logic is that chemical use cannot easily be both restrained by policy interventions and subjected to the ebb and flow of the business cycle. To determine the validity of this conjecture, I administer the LKT test, which is an inference on the cointegration rank allowing for a structural shift in the toxic chemical use series at various levels of disaggregation.

Results show that for aggregate toxic chemical use *and* for a majority of the end-use toxic chemical series that contain a unit root, the primary drivers of long-run changes in the trend appear to be economic factors rather than political economic and institutional factors related to environmental governance. The null hypothesis of one cointegration relationship between aggregate chemical use and industrial production, real GDP, real investments in R&D, and real

investment in R&D by the private sector, cannot be rejected for at least a significance level of 5%.

For toxic chemical use at the industry sector level, in a majority of the cases, the end-use sectors that use the same chemicals are not cointegrated (see Table 13). Only in the arsenic-using sectors is there evidence at the 5% significance level that there is at least one cointegrating relation among the time paths of the end-use sectors that use arsenic. Mercury-using and selenium-using sectors share one cointegrating relation, respectively, at the 10% significance level. In a majority of the cases, no lesser combinations of the end-use sectors yield cointegration relations when the larger sets of the end-use sectors that use the same chemicals are not cointegrated.

Results from the LST tests indicate that real GDP and industrial production, and R&D investments to a lesser degree, are common drivers of long-run changes in the trend of chemical use at the industry sector level across toxic chemicals. There appears not to be notable variation across the end-use series of the *EKC*, *kinked growth*, and *growth* chemicals with respect to this finding. Of all the end-use series, Beryllium-using and selenium-using sectors (aerospace, electrics, electronics, glass, chemicals), and two lead-using sectors (lead sheets, solder) share in common the fact that they are cointegrated with *all* the national accounts and industrial production series. This is not a surprising finding for lead use because results from the analysis of individual chemical use data show that lead is cointegrated with industrial production and all the national accounts except for R&D investments in chemicals. On the other hand, at the individual chemical level beryllium and selenium are both stationary series. Thus, this is new result we discover in the disaggregated data. These end-use sectors have been consistent drivers of GDP growth.

Unlike aggregate chemical use and end-sector series, results from the LST tests show that at the individual chemical level there is evidence of cointegration relationships among chemicals regulated under the same laws whether they are *EKC* or *growth* chemicals (Table 10).¹⁶⁵ This result holds when all possible combinations of the *EKC* and *growth* chemicals are tested for cointegration (Table 10 Panel C). This suggests that the DS chemicals that are regulated under the same laws share a common trend, which implies that there are common economic and institutional drivers at the individual chemical level.

Moreover, these same chemicals are by and large cointegrated with industrial production and/or national accounts, which is contrary to the logical implication of the corollaries. There is, however, variation among the chemicals with respect to which of the national accounts and/or industrial production they share a cointegrating relation. The bottom-line is that there is evidence that the chemical use series that are DS share a long-run equilibrium with economic *as well as* political economic and institutional factors.

In sum, there is evidence that that aggregate toxic chemical use is DS, and thus in the long-run will likely drift in a random walk-like fashion as opposed to being restrained by policy interventions. By contrast, when we consider toxic chemical use separately by individual chemicals 7 out of the 13 chemical use series are TS. The following chemical use series are more likely to be restrained by public policy in the long-run: chromium, cobalt, manganese, selenium, and zinc (these four are *kinked growth* chemicals), beryllium (*growth* chemical), and mercury (*EKC* chemical). That being said, there is little evidence against the stochastic trend/unit root hypothesis in the analysis of toxic chemical use at the industry sector level.

¹⁶⁵ Recall from section 6.2, the *kinked growth* chemicals are all stationary series. Thus, these chemical use series are not part of the cointegration analysis.

The test for cointegrating relation administered on toxic chemical use at all levels of aggregation/disaggregation reveals that at all the various levels of analysis toxic chemical use shares a long-run equilibrium with macroeconomic variables. At the same time, there is evidence that the time paths of individual chemicals are cointegrated among chemicals regulated under the same laws whether they are *EKC* or *growth* chemicals.

6. CONCLUSION AND POLICY IMPLICATIONS

This paper demonstrates the utility of employing advanced time series econometrics to investigate whether major U.S. federal environmental regulations have had an effect on the aggregate toxic chemical use and chemical use at the individual chemical and industry sector levels, and what the time series properties of the data reveal about policy efficacy over the long-run. Specifically, I ask the three questions: Which of the government regulations—the command and control regulations (1972 FIFRA, 1976 TCSA) or the information-based regulation (1986 TRI)—have had an effect on toxic chemical use? How effective have the government and industry-sponsored voluntary programs been in reducing toxic chemical use? Moreover, given the economic significance of these toxic chemicals as inputs into the manufacturing of commercial products, what have had more effect on the long-run time path of these toxic chemicals—political, economic, and institutional factors (e.g., government regulations) or macroeconomic factors (e.g., GDP, industrial production)?

My empirical strategy is threefold: First, I employ Kejriwal and Perron's sequential procedure for multiple structural breaks in the trend that have the same distribution whether the data are DS or TS. Next, I administer Carrion-i-Silvestre, Kim, and Perron's (2009) GLS-based unit root tests with multiple breaks under both the null and the alternative hypotheses. In the cases where there are no breaks detected, I administer the standard Augmented Dickey-Fuller

test to maximize efficiency and power of the tests. Finally, I test for evidence of cointegrating relationships allowing for structural shift among DS chemicals regulated under the same laws and between chemical use and national accounts and industrial production.

No economic or institutional factors appear to have induced a structural shift in aggregate chemical use. By contrast, for a majority of the individual chemical use series, structural changes occurred around the time of economic booms and busts, WWII, environmental regulations, and industry developments. The 1986 TRI, which is an information-based regulation, has had impact on the consumptive use of more individual chemicals and chemical use in end-use sectors than the 1972 FIFRA and the 1976 TSCA, which are two command-and-control regulations. Moreover, given the large confidence bands around several of the structural break estimates, the results cannot preclude the impact of economic booms and busts and build-ups related to WWII on the time paths of several of the individual toxic chemicals and end-use sectors. Finally, there is no evidence that government-sponsored voluntary programs have had any effect. However, results show that two industry voluntary initiatives in the form of bilateral voluntary agreements with the EPA—the agricultural sector’s voluntary ban of arsenic acid and the voluntary stewardship program by the chlor-alkali industry—have had an impact on the trend of arsenic use and mercury use, respectively. These toxic chemicals are the number one and two most poisonous substances according the EPA (refer to column three of Table 1).

With respect to the unit root hypothesis, evidence suggests that aggregate toxic chemical use is DS. By contrast, when we consider toxic chemical use separately by individual chemicals 7 out of the 13 chemical use series are TS. The majority of the TS series are the *kinked growth* chemicals, i.e., toxic chemicals that have experienced an upward trend before a kink-like turning

point that transition the series to a horizontal growth trend. Moreover, there is little evidence against the stochastic trend/unit root hypothesis in toxic chemical use at the industry sector level.

The test for cointegrating relations administered on toxic chemical use at all levels of aggregation/disaggregation reveals that at the three levels of analysis toxic chemical use share a long-run equilibrium with macroeconomic variables. At the same time, there is evidence that the time paths of the individual DS chemicals are cointegrated among chemicals that are regulated under the same laws.

Several policy implications can be drawn from this paper's empirical findings. First, while command-and-control policies have continued as the mainstay public policy for managing toxic chemical uses in the U.S., it is an information disclosure policy—the 1986 Toxic Release Inventory—that appears to have had a permanent effect on the consumptive use of more toxic chemicals. This suggests that the government's role is broader, more collaborative, and more dynamic than conventionally accepted. The role of public agencies is not just to set and enforce standards, but to establish an information-rich context for private citizens, interest groups, and firms to solve environmental problems. This is in line with what Fung and O'Rourke (2000) term as “populist maximin regulation”: the government's role is to set up a mechanism for information disclosure by firms such that maximum attention on minimum performers is reinforced by public pressures. In response to a dynamic range of public pressures, minimum performers will be compelled without coercive force by government to adopt more effective environmental practices.

Second, the fact that two industry self-regulation initiatives to reduce two of the most poisonous chemicals have had an impact on chemical use in these end-use sectors suggest that industry sponsored voluntary agreements could be effective in reducing toxic chemical use or

other types of pollutants. This confirms the findings of existing research that show that bilateral voluntary agreements have fared considerably better than other types of voluntary programs in their efficacy (T. Arimura et al., 2008; Darnall & Kim, 2012; Dasgupta et al., 2000; Glachant & Muizon, 2007; Hsueh, 2012c; Krarup & Millock, 2007; Morgenstern & Pizer, 2007; Potoski & Prakash, 2005). This is likely because voluntary agreements, such as the mercury and arsenic voluntary agreements found to have had a negative effect on toxic chemical use, generally combine *ex ante* interactions with industry and other stakeholders with *ex post* legal sanctions for noncompliance. Related, policymakers are well advised to monitor sectoral developments and growth, including technological advances and opportunities for encouraging voluntary agreements.

That being said, regulators should primarily set public policy at the individual chemical level rather than target chemical use by end-use industry sectors or set umbrella rules that pertain to aggregate chemical use. This implication is particularly pertinent in recent policy debates on whether the existing regulatory framework of the EPA's chemical-by-chemical approach is more or less effective/efficient than the recently enacted European approach (i.e., the European Union's Registration, Evaluation and Authorization of Chemicals) for regulating potentially poisonous chemicals in the face of rapid technological change and high transaction costs.

APPENDIX

Table A
National Accounts and Industrial Production
Structural Break and Unit Root Tests

Structural Breaks					Unit Roots				
Kejriwal and Perron (2010)*					Augmented Dickey Fuller	Carrion-i-Silvestre, Kim, and Perron (2009)			
y_t	$F(1 0)$	$F(2 1)$	$F(3 2)$	# Breaks		MPT	MZA	MSB	MZT
<i>lrgdp</i>	-0.09			0	-2.67				
<i>lrrd</i>	0.13			0	-1.47				
<i>lrrdprivate</i>	-0.14			0	-1.70				
<i>lrrdgovt</i>	-0.32			0	-2.12				
<i>lrrdchem</i>	10.26	128.04	+INF	3		2.99	-84.45**	0.08	-6.46**
<i>lrrdelectronics</i>	-0.27			0	-2.72				
<i>lip</i>	1.00			0	2.00				

**Significant at the 5% level

Note: In the KP test, the trimming parameter, $\varepsilon = 0.15$ for *lrgdp* and *lip* (n=8, n=93, respectively), and $\varepsilon = 0.25$ for the *lrrd*, *lrrdprivate*, *lrrdgovt*, *lrrdchem*, *lrrdelectronics*, *lip* (n=49).

CHAPTER 5. CONCLUSION

This dissertation underscores the importance of understanding how economics and politics interact and how institutions play a mediating role in determining policy efficacy in the new era of environmental management where government is no longer synonymous with governance. Rather, the roles of the private sector as well as other stakeholders are increasingly salient for understanding how policies become part of the political agenda, how policies are formed, and why certain policies are effective and while others are not.

This dissertation attempts to build macro-micro linkages on both the theoretical and empirical fronts. On the theoretical front, I take a systemic approach: I delineate a new economy stream by building on Kingdon's multiple streams (MS) framework, which has largely emphasized the dynamics of politics and policymaking over market-making in agenda setting and policy formation. The elements that make up the new economy stream are built on micro-foundations. I open the "black box" of business to consider what motivating and demotivating factors explain the compliance-related decision-making processes of businesses and industries in partaking in bilateral voluntary agreements, one type of voluntary environmental programs that research has shown to be relatively effective for pollution control and abatement. In doing so, I contend that the incentives of the marketplace and the economy interplay with politics and existing institutions to explain the viability of voluntary governance in solving complex environmental problems. Firm and industry specific variables take on policy significance and relevance when placed in the larger political economy in which they reside.

Moreover, this dissertation highlights the role of NGO activists and other stakeholders, as well as the government's role in encouraging and at times pressuring for beyond-compliance activities by businesses. This research is consistent with prior work that show that voluntary

environmental programs are often developed and adopted in the shadow of public law or the threat of the government's imposition of more stringent rules (Buthe, 2010a; Cashore et al., 2011; Mayer & Gereffi, 2010; Potoski & Prakash, 2005). As such, which roles the government and external stakeholders play have implications for compliance and efficacy. The bilateral voluntary agreements to reduce mercury and arsenic use analyzed in this dissertation combine *ex ante* interactions with industry and other stakeholders with *ex post* legal sanctions for noncompliance. This supports Buthe's (2010b) hypothesis that when governments explicitly delegate public authority to a private rule-maker, and when such delegation is accompanied by commitments to monitoring and enforcement by government agencies, this should result in higher levels of compliance.

Empirically, this dissertation utilizes advanced time series, alongside microeconomic techniques and systematic qualitative methods to study a topic area that has largely been dominated by microeconomic and micropolitical analyses. State-of-the-art techniques for structural break estimation, impulse response analysis, unit root tests, and cointegration analysis are employed by the dissertation to analyze policy efficacy and political economic dynamics in the toxic chemical policy domain.

The toxic chemical policy domain is characterized by unique circumstances that plague the natural resource and environmental policy more generally. First, the reality of nonexperimental data warrants the use of methodological techniques that verify whether the exogenously determined factors—namely, the variables and measures that the researchers hypothesize are the causal drivers of policy change—correspond with the actual or endogenous change points in the data. Second, the lack of disaggregated data for toxic chemical use series beyond the national and industry sector levels (in some cases only the national level data exist)

means that many microeconomic methods cannot be practically utilized. When this is the case, it is important to have statistical techniques in the empirical toolbox, with which to identify macroeconomic and macropolitical factors (and perhaps meso-level analytical drivers) rather than focus on micro/facility-level analysis. Third, the time dynamics of the toxic chemical use data and industrial pollution data more generally have been seldom studied. Yet, an understanding of the stochastic properties of the historical data intimate information about regulatory efficacy in the short and long-run policy horizon.

The dissertation's process tracing, which is made possible by the systematic surveys of major stakeholders, documents the causal mechanisms involving complex interactions of political, economic, and institutional factors that have led to the formation of the bilateral voluntary agreements to reduce mercury and arsenic use. While the systematic qualitative analysis is not meant to give quantitative measures of causal effects, it does help build an argument for the significance of the two voluntary agreements in controlling toxic chemical use. The bottom-line: the employment of systematic qualitative methods along with statistical analyses allow for the mutual validation of the same phenomena, thereby enhancing external and internal validity.

The dissertation is limited on several accounts and leaves room for further research. To begin, this study is limited in its scope: it focuses on a comparative case study of two "successful" cases of bilateral voluntary agreements in toxic chemicals to show the explanatory power of the new economy stream in the augmented MS framework (see Chapter 3). The utility of the augmented MS framework needs to be further tested with additional cases that vary across other dimensions. Research opportunities abound: Future research could exploit variation in policy outcomes. For example, would the augmented MS framework be just as relevant for

explaining “failed” cases of bilateral voluntary agreements, such as when toxic chemical use has not been reduced and/or when other negotiated objectives have not been realized?

Alternatively, future research could consider cases outside of the toxic chemical policy domain, such as private regulation in global climate change policy or cases of novel domestic or international policy across policy domains that involve private actors, markets, and the economy. The more cases that the augmented MS framework is able to explain the more robust the framework is for delineating the political economic conditions under which various forms of alternative governance approaches, including voluntary environmental programs and private regulation more generally might be efficient and effective in achieving key environmental, economic, and social objectives.

Other limitations of the dissertation are paradigmatic and methodological in nature. This study’s empirical methods belong in the conventional, frequentist approach. The frequentist approach postulates deterministic models and treat unknown variables/parameters as fixed but with unknown values, while in the Bayesian paradigm, models (and knowledge in general) are treated as probabilistic and variables/parameters are assigned probabilities.

Evaluation studies in environmental policy, and public policy more generally, are challenged by the fact that nuanced explanations of the causal relationship between government policy, pollution, and environmental outcomes often lead to extreme model uncertainty where the true model is unknown and multiple competing approaches exist. Policy impact studies, including Chapter 2 of this dissertation, are rarely experimental and a wide range of possible control variables must be considered. Yet, the standard hypothesis testing framework assumes that only two models are ever entertained at a time. In fact, each control variable represents a

different model; with p possible variables, the number of candidate models may reach 2^p , which can be enormous (Raftery 1995).

One methodological extension of this study is to employ Bayesian Model Averaging (BMA) to determine which political economy specification is most strongly supported by the data. A nascent technique in environmental economics and policy, BMA is a natural statistical tool to examine the support that competing theories receive from the data, and to address the model uncertainty. Bayesian Model Averaging examines all models, weighs them by their relative quality, and then generates the probability that a candidate variable is related to the dependent variable or outcome variable of interest. BMA could serve as a further robustness check of the proposed model specifications in Chapter 2.

The time series analyses (see Chapter 4) could also be recast in the Bayesian framework. For example, the Bayesian approach treats structural change estimation as a model selection problem of a probabilistic form. The Bayesian analysis of structural change is technically simpler than the frequentist methods, allows finite-sample inferences that are optimal and is the same for stationary or non-stationary data (Raftery, 1995). This is a potential improvement on the frequentist approach because the statistical validity of the Bai and Perron (1998, 2003) and Kejriwal and Perron (2010) structural break tests (see Chapter 4) are based on asymptotic results. Moreover, in the context of environmental policy, prior knowledge about the timing, form, and maximum number of changepoints are taken into account in a probabilistic way in the Bayesian approach (Western & Kleykamp, 2004). Finally, recent advances in the Bayesian methodology

allow for the simultaneous determination of structural breaks and the lag length or trimming parameter (Hultblad & Karlsson, 2008).¹⁶⁶

¹⁶⁶ Lag length or the trimming percentage between structural break regimes must be specified in order to ensure a reasonable amount of degrees of freedom to calculate an initial error sum of squares in the BP and KP methods. There is currently no consensus in the literature regarding the criterion or criteria for determining the minimum regime size, which ultimately dictates maximum number of change points.

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VITA

Lily Hsueh grew up in the San Francisco Bay Area where she earned a Bachelor of Arts degree in Economics at the University of California, Berkeley in 1999. After college, she moved to London where she obtained a Master of Science in Economics from the University College London, University of London in 2001. Between 2001 and 2007, she served as a Senior Analyst in Economic Research at the Federal Reserve Bank of San Francisco. In 2012, she earned a Doctor of Philosophy in Public Policy and Management from the University of Washington where she specialized in environmental and resource economics, public policy, governance, political economy, econometrics, and mixed methods research design. Upon graduation she began a National Research Council Postdoctoral Fellowship at the National Oceanic and Atmospheric Administration in Seattle, Washington.