2013-07-12

Essays in International Trade and the Environment

Cherniwchan, Jevan Michael

Cherniwchan, J. M. (2013). Essays in International Trade and the Environment (Doctoral thesis, University of Calgary, Calgary, Canada). Retrieved from https://prism.ucalgary.ca. doi:10.11575/PRISM/25937

http://hdl.handle.net/11023/808

UNIVERSITY OF CALGARY

Essays in International Trade and the Environment

by

Jevan Michael Cherniwchan

A THESIS
SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF ECONOMICS
CALGARY, ALBERTA
July, 2013

Abstract

This thesis is a collection of three essays on international trade and environmental economics.

Chapter 1 examines the effect of trade policy on pollution. Using a novel dataset, I examine how trade liberalization following the North American Free Trade Agreement (NAFTA) affected the pollution emitted by manufacturing plants in the United States. My empirical approach exploits variation in protection across time, industries and geographic locations to isolate the causal effect of trade liberalization. I find that NAFTA led to significant reductions in the emissions of three common pollutants from affected plants. These changes are primarily due to reductions in emission intensity, as opposed to changes in the scale of plant output. My findings suggest a new channel through which trade affects the environment.

Chapter 2 analyzes the relationship between international trade, economic growth and the environment. In this chapter, I argue the compositional shift from agricultural to industrial production – industrialization – is a central determinant of changes in environmental quality as economies develop. I develop a simple two-sector model of neoclassical growth and the environment in a small open economy to examine how industrialization affects the environment. The model is estimated using sulfur emissions data for 157 countries over the period 1970-2000. The results show the process of industrialization is a significant determinant of observed changes in emissions: a 1% increase in industry's share of total output is associated with an 11.8% increase in the level of emissions per capita.

Chapter 3, coauthored with Eugene Beaulieu, examines Canada's trade policy at the end of the 19th century. Canada's trade policy at this time is commonly viewed as protectionist and extremely costly. We employ the Anderson-Neary Trade

Restrictiveness Index to reexamine this view. Based on product level customs data, we show that Canadian trade policy between 1870 and 1910 was more restrictive than previously understood, but created smaller welfare losses than previously believed. These results are primarily driven by high tariffs on inelastic, non-competing import goods. Although Canada's tariff structure becomes more restrictive over the period, our findings indicate it was not as protectionist or as costly as once thought.

Acknowledgements

This thesis would never have been written without the support and encouragement of many people in my life. My family, friends and numerous faculty have all contributed greatly to my success, and to each I owe many thanks.

First and foremost, I would like to thank my supervisor, Scott Taylor. Scott has been an incredible mentor from the time that I arrived at the University of Calgary. His advice and guidance have been instrumental in my development as an economist and researcher.

I would next like to thank Eugene Beaulieu and Arvind Magesan for serving on my supervisory committee and for providing me with comments and suggestions that greatly improved my research. I also benefited greatly from working with Eugene as a co-author. In addition, I owe a debt of gratitude to the other faculty members in the department for their feedback and comments on my research at various stages, especially Eugene Choo, Curtis Eaton, Francisco Gonzalez, Ken McKenzie, Rob Oxoby, Joanne Roberts and Trevor Tombe. Special thanks also go to Jared Carbone for serving on my candidacy committee and to Joule Bergerson and Carol McAusland for serving as my examiners. I have also benefited from financial support from the Social Sciences and Research Council of Canada and the University of Calgary.

I would also like to thank Karen Chang, Cecilia Garcia and Irving Rosales for their friendship and support since the beginning. I must also thank the various individuals that have indulged me on my many trips for caffeine over the years; in addition to providing me with a captive audience to talk about ideas, these excursions were a constant source of laughs and a much welcome distraction from the everyday.

I am incredibly grateful for the support and encouragement that I received from my parents throughout graduate school. They deserve much of the credit for my success. I also wish to thank my sister for her support; her phone calls and visits always proved to be timely diversions. Thanks also to my friends, particularly Chris and Christine Crawford, Mike Kennedy, and Matt Pedwell, for reminding me that life goes on outside these walls and for forcing me to join in from time to time. Special thanks to Ryan Day for averting my potential homelessness when I first arrived in Calgary, and for his perpetual willingness to go for beers and steaks whenever the opportunity presented itself.

Finally, I want to thank Lauren Mercier for her constant love and support despite great distances. Being apart from her has been the toughest part of this process.

Table of Contents

List of Tables

List of Figures and Illustrations

List of Symbols, Abbreviations and Nomenclature

Symbol	Definition
ACE	Absolute Convergence in Emissions per Capita
AWT	Average Weighted Tariff
CAAA	Clean Air Act Amendments
CCE	Conditional Convergence in Emissions per Capita
CUSTFA	Canada-U.S. Free Trade Agreement
DWL	Deadweight Loss
EKC	Environmental Kuznets Curve
EPA	Environmental Protection Agency
GDP	Gross Domestic Product
GNP	Gross National Product
GSP	Generalized System of Preferences
HS	Harmonized Commodity Description and Coding System
LSDV	Least Squares with Dummy Variables
NAFTA	North American Free Trade Agreement
NETS	National Establishment Time Series
Pb	Lead
PM	Particulate Matter
SIC	Standard Industrial Classification
TRI	Toxic Release Inventory (Chapter 1)
TRI	Trade Restrictiveness Index (Chapter 3)
VOCs	Volatile Organic Compounds

Overview

The three essays that comprise this volume centre on two main themes: the effects of international trade policies and the role played by international trade in determining environmental quality. Chapter 1 examines the effects of trade liberalization on plant pollution emissions. Chapter 2 investigates the effect of industrialization on environmental quality in a small open economy. Chapter 3 examines the effects of Canada's tariff policy on protection and welfare at the end of the 19th century.

The relationship between trade liberalization and the environment has been one of the most debated aspects of globalization for over twenty five years. Yet, surprisingly little is known about how trade affects the behaviour of individual polluters within an economy. In Chapter 1, I provide the first empirical evidence along these lines.

To do so, I examine how one of the most significant episodes of trade liberalization in history, the North American Free Trade Agreement, affected the pollution emitted by U.S. manufacturing plants. I develop a novel research design that exploits variation in protection across time, industries and geographic locations to isolate the causal effect of trade liberalization on plant pollution emissions. In my analysis, I rely on a unique longitudinal dataset on pollution emissions and other plant characteristics. I find that NAFTA reduced the emissions of three common pollutants from affected plants. These changes are primarily due to reductions in emission intensity, as opposed to changes in the scale of plant output. Moreover, these shifts are not due to contemporaneous changes in environmental policy or the reallocation of dirty production to Mexico. These results suggest a new channel through which trade affects the environment: within-plant changes in emission intensity.

In Chapter 2, I examine the role played by industrialization in explaining cross-country differences in pollution emissions. I develop a two-sector model of economic growth and the environment in a small open economy that explains several features of the cross-country pollution data that have not been considered before, and offers new testable predictions. Specifically, the theory predicts cross-country convergence in pollution emissions as economies industrialize. To test this prediction empirically, I utilize a unique panel data set of sulfur emissions from 157 countries over the period 1970-2000. I find that industrialization is a significant determinant of observed changes in sulfur emissions: a 1% increase in industry's share of total output is associated with an 11.8% increase in the level of emissions per capita. This study was published as "Economic Growth, Industrialization and the Environment", Resource and Energy Economics, Vol. 24, No. 4, November 2012, pages 442-467.

Chapter 3, coauthored with Eugene Beaulieu, investigates the restrictiveness of Canadian trade policy between 1870 and 1910. Canadian trade policy during this period is commonly viewed as protectionist, with protection leading to large welfare losses. However, the empirical evidence supporting this view is predominantly based on average tariff measures that may not accurately reflect the true level of protection offered by trade policy. To address this issue, we employ the theoretically consistent Anderson-Neary Trade Restrictiveness Index to construct measures of protection and welfare loss. We compute this index using a unique dataset based on customs level import and tariff statistics. We show that Canadian trade policy from at the end of the 19th century was more restrictive than previously understood, but led to smaller welfare losses than previously believed. We find that most of the increase in protection is explained by higher tariffs on inelastic, non-competing import goods. While Canadian trade policy becomes more restrictive during this period, we find that it is not as protectionist or costly as was once thought.

Chapter 1

Trade Liberalization and the Environment: Evidence from NAFTA and U.S. Manufacturing

1.1 Introduction

Over the past twenty five years, one of the most widely debated aspects of globalization has been the environmental consequences of trade liberalization.[1] While much of this debate is framed in terms of industry responses to trade liberalization, these responses hinge on the behaviour of the individual polluters within each industry. Yet, surprisingly little is known about how trade liberalization affects the pollution emitted by plants.

This is largely due to the lack of disaggregate, plant-level data on emissions and other plant characteristics.[2] To date, research has primarily relied on cross-country variation in pollution levels and trade flows to examine the link between trade and the environment.[3] Consequently, existing studies have focused on the relationship between trade and aggregate pollution levels; these studies find that trade is not necessarily bad for the environment.[4] Even so, the literature often points to the unmeasured responses of individual polluters, such as the adoption of new technologies or the exit of dirty plants, to explain the mechanisms underlying this result.

---

[1] For overviews of the literature on trade and the environment, see Copeland and Taylor (2004) or Karp (2011).

[2] While plant-level emissions data from emissions inventories such as the Toxic Release Inventory in the United States and the National Pollutant Release Inventory in Canada have been publicly available for close to 20 years, it is only recently that these data have started to be matched to data on plant characteristics for plants from multiple industries (e.g. Holladay (2010)).

[3] This is not to say all studies rely on cross-country variation. Some research, such as that of Dean (2002) or Chintrakarn and Millimet (2006), relies on the variation in pollution and trade across states or provinces within a country to study the relationship between trade and the environment.

[4] See, for example, Antweiler et al. (2001), Harbaugh et al. (2002) or Frankel and Rose (2005).

In this paper, I provide the first empirical evidence of how trade liberalization affects the pollution emitted by plants. To do so, I rely on a unique longitudinal dataset constructed from two main sources: the Toxic Release Inventory and the National Establishment Time Series. This dataset contains detailed information on the emissions of volatile organic compounds, particulate matter, lead, and other toxic chemicals from manufacturing plants in the United States (U.S.), as well as other plant characteristics for the years 1991-1998. I employ this data to examine how one of the most significant episodes of trade liberalization in history, the North American Free Trade Agreement (NAFTA), affected the pollution emitted by U.S. manufacturing plants. The empirical challenge is credibly identifying the causal effect of trade liberalization on plant pollution emissions.

My empirical strategy exploits three sources of variation. The first two sources arise from changes in trade policy due to NAFTA. NAFTA came into effect on January 1, 1994 and either eliminated or set a timeline for the elimination of existing bilateral tariffs between the U.S. and Mexico, creating temporal variation in protection.[5] However, not all industries were liberalized; some goods were traded freely between the U.S. and Mexico before the agreement. This means there is variation in protection across industries. The third source of variation stems from the dispersion of production across the United States. Different states face different costs of trading with the Mexican market because of factors such as distance and transportation infrastructure. These costs act as a barrier to trade, meaning that even in the absence of protection from trade policy, some states would trade very little with Mexico. As a result, for any industry, plants that are located in these states are effectively protected from Mexican competition, while plants located elsewhere in the U.S. are not.

Given the cross-industry variation in tariff reductions, variation in the location of

---

[5] The agreement also liberalized bilateral trade between Canada and Mexico, but did not affect trade between the Canada and the United States. Canada-U.S. trade had been liberalized previously as a result of the Canada-U.S. Free Trade Agreement, and was unaffected by NAFTA.

production means the subset of plants in liberalized industries that are not effectively protected from Mexican competition by geography will be the only establishments that are affected, or "treated", by trade liberalization. Hence, identifying NAFTA's effect on pollution emissions amounts to measuring the effect of trade liberalization on these plants. I do so using an empirical approach similar in spirit to differences-in-differences-in-differences.

I start by comparing the average outcomes of treated plants before and after NAFTA. This comparison allows me to control for any unobserved time-invariant plant, industry or state heterogeneity, such as factor intensity, that may affect pollution emissions. Moreover, in the absence of other policy changes or secular changes in outcomes, this difference measures the average causal effect of trade liberalization. In practice, however, this is unlikely to be the case because trade policy is endogenously determined, meaning treated plants receive treatment because of an underlying industry or state trend.[6] Additionally, there may have been concurrent changes in policy at the time of NAFTA. Both of these factors will confound identification of the causal effect.

I exploit the additional variation in protection to control for these shocks. First, the variation in protection across locations allows me to treat the unaffected plants as a comparison group for the affected plants from the same industry. This enables me to control for unobserved time-varying industry heterogeneity such as industry-specific demand shocks or industry-wide changes in environmental regulation. Second, the cross-industry variation in the trade policies faced by plants within a state allows me to control for unobserved time-varying state heterogeneity, such as changes in state environmental policies, in a similar manner. I treat unliberalized plants as a counterfactual for liberalized plants in the same state. Finally, the cross-industry and

---

[6] The endogeneity of U.S. trade policy is documented by Trefler (1993) and Goldberg and Maggi (1999).

cross-location variation also allows me to control for nation-wide shocks that affect pollution emissions, such as changes in aggregate expenditures or nation-wide changes in environmental regulations.

I find that NAFTA had significant effects on the emissions of three common pollutants. Specifically, I find that trade liberalization reduced the emissions of particulate matter (PM), lead (Pb) and toxic chemicals (Toxics) from affected U.S. manufacturing plants. My results show that for the average plant, increased access to the Mexican market following NAFTA reduced PM emissions by close to 18% and Pb emissions by close to 35%, but had little effect on the emissions of VOCs or Toxics. Similarly, my results indicate that reduced protection from Mexican competition decreased Toxic emissions by just over 11%, but did not have a significant effect on the emissions of the other pollutants. My analysis shows that the changes are not due to pre-existing differences in trends across plants or other major shocks that occurred during my period of study.

There are two possible mechanisms driving these results. By definition, trade liberalization can affect the level of pollution emitted at a plant by altering the physical quantity of output produced, or by altering level of pollution emitted per unit of output (the emission intensity of production).[7] To distinguish between the two, I analyze the effect of trade liberalization on the emission intensity of production at each plant.

I find that for an average plant, NAFTA reduced PM emission intensity by close to 18%. Similarly, I find that NAFTA reduced the Pb emission intensity of an average plant by close to 38%. For both pollutants these changes are due to increased access to the Mexican market, suggesting the reductions may be tied to export decisions. I also find that reduced protection from Mexican competition decreased Toxic emission

---

[7] In the terminology of Copeland and Taylor (2003), a change in emissions due to a change in the level of output is a scale effect, while changes in emission intensity may be due to changes in product mix (a composition effect) or production methods (a technique effect).

intensity by close to 15%. Given the magnitude of the changes in emissions levels, these results suggest that the observed reductions in PM, Pb and Toxics are primarily due to decreases in emission intensity, not decreases in output from polluting plants. I also find that NAFTA had little effect on the emission intensity of VOCs, suggesting trade had little effect on pollution from these plants.[8]

These results indicate that for some pollutants, changes in emission intensity following trade liberalization are a primary determinant of pollution emissions. Yet, given that my empirical approach includes aggregate, industry-specific, state-specific trends that capture any significant changes in environmental regulations, the reductions in emission intensity that I observe are not due to contemporaneous changes in environmental policy.

In the context of the literature, this finding is striking. While previous research has suggested that changes in emission intensity are an important determinant of how international trade affects the environment, these changes are usually motivated as a response to income induced changes in environmental policy (e.g. Grossman and Krueger (1991) or Copeland and Taylor (1994)). My results indicate that such changes in environmental policy are not necessary for plants to improve their emission intensities.

From the perspective of many commentators, the finding that NAFTA reduced plant pollution emissions through decreases in emission intensity is unsurprising. Prior to the agreement, it was often predicted that Mexico would become a pollution haven as plants relocated the dirty aspects of their production processes to take advantage of lax environmental regulation. While I do not observe such reallocations directly, I investigate the possibility of pollution havens to the extent that I can with the available data. In particular, I examine if the observed changes in emission in-

---

[8] This finding is consistent with the work of Levinson (2009), who finds that international trade explains little of the reduction in U.S. VOC emissions during the 1987-2001 period.

tensity can be explained by changes in intermediate inputs or product switching, as both would suggest plants are reducing their emission intensities by reallocating dirty production to Mexico. I do not find any evidence that shows this is the case.

Instead, my results can be explained as a consequence of productivity improvements following trade liberalization. In models where pollution depends on plant productivity, such as that of Li and Shi (2012), equilibrium emission intensity is typically decreasing in productivity, meaning an increase in plant productivity will lead to a reduction in the emission intensity of production. Recent research has demonstrated that trade liberalization increases plant productivity, both through the effects of increased import competition (e.g. Pavcnik (2002), Trefler (2004), Amiti and Konings (2007), Fernandes (2007), or Bloom et al. (2011)), and increased access to foreign markets (e.g. Verhoogen (2008), Lileeva and Trefler (2010), or Bustos (2011)). This suggests that the reductions in emission intensity that I observe for PM, Pb, and Toxics may be due to productivity improvements, but data limitations prevent me from examining this channel directly.[9]

This paper is related to a number of recent empirical studies that examine the relationship between trade and the environment at the plant level. These studies primarily focus on the relationship between export behaviour and pollution emissions (e.g. Holladay (2010) and Cui et al. (2012)). My work is more closely related to the work of Gutierrez and Teshima (2011) and Martin (2012), who examine the effect of trade liberalization on pollution from plants. However, this paper differs from their work in one important respect. Neither paper examines pollution emissions directly; the effect of trade liberalization is inferred from changes in ambient pollution concentrations (Gutierrez and Teshima) or from changes in fuel intensity (Martin). Hence, this study provides the first direct evidence of how an episode of trade liberalization

---

[9] My data does not include any information on investment or capital, making it impossible to calculate productivity using standard methods.

affects the pollution emitted by plants.

This paper also contributes to a large literature examining the economic effects of NAFTA. Most of these studies have examined how the agreement affected trade creation and diversion (Romalis, 2007; Caliendo and Parro, 2011) or labor market outcomes (Burfisher et al., 2001; McLaren and Hakobyan, 2010). The environmental effects of NAFTA were first studied in the seminal work of Grossman and Krueger (1991), who examined the potential environmental impacts of the agreement on Mexico. While other studies have since examined the effects of the agreement on pollution (see, for example, Cole (2004), Gamper-Rabindran (2006) or Stern (2007)), my study is the first to examine the causal effect of NAFTA on pollution generated by the production decisions of individual manufacturing plants in the United States.[10]

The rest of this paper proceeds as follows. Section 2 outlines the research design employed in this study. Section 3 discusses the data, while section 4 presents my empirical specification. Section 5 presents the results. Finally, section 6 concludes.

1.2 Identifying Trade Liberalization's Effect on the Environment

The ideal analysis of the relationship between protection and pollution emissions would involve a controlled experiment in which a sample of U.S. manufacturing plants are randomly divided into two groups: treatment and control. In this experiment, the treated group is exposed to foreign competition, while the control group remains protected. With this setup the average causal effect of trade liberalization on the level of pollution emitted by plants is obtained by simply comparing the average emissions from protected and unprotected plants. Randomization would ensure any observed difference in pollution emissions across the treatment and control groups is driven by

---

[10] See Davis and Kahn (2010) for an analysis of how NAFTA affected pollution from consumption.

trade liberalization.

Since this experiment is impossible in practice, economists have had to rely on variation in protection across time and industries to measure the effect of trade liberalization on the outcomes of affected plants. The underlying research design follows the logic of differences-in-differences (DD).[11] In its simplest version, the average outcomes for liberalized, or treated, plants are compared pre- and post-liberalization. This difference is then compared to the difference in average outcomes for unliberalized, or control, plants. The resulting difference-in-differences measures the average effect of changes in protection on the outcome of interest.

With this approach, the difference in average outcomes for the control group serves as the counterfactual for would have happened to the average outcome from liberalized plants in the absence of treatment. Hence, credible inference requires that the treatment and control groups would have followed the same trends in the absence of trade liberalization, conditional on observed characteristics. If the treatment and control groups were to exhibit different trends, DD would capture the average difference in outcomes due to both the difference in treatment and the difference in trends. As a result, the measured effect of a change in protection would be biased.

Identification with DD requires that changes in protection (treatment) are uncorrelated with unobserved time-varying industry characteristics. This means the degree to which an industry is liberalized must be independent of its underlying trend. This condition is rarely satisfied because protection is usually endogenously determined.[12]

There are strong theoretical reasons to believe that the level of protection observed for an industry at any point in time is correlated with the industry's characteristics

---

[11] The main difference between the typical approach employed in the trade literature and the standard DD strategy is that trade economists typically employ a continuous measure of treatment, tariffs, and multiple treatment and control groups.

[12] The exceptions to this are the few instances where trade liberalization is externally imposed and cannot be manipulated by domestic policy makers, such as in the case of India (Goldberg et al., 2010; Khandelwal and Topalova, 2011; Martin, 2012).

(Grossman and Helpman, 1994, 1995).[13] This suggests the changes in protection across industries will be related to the trends in economic and political factors specific to each industry. As a result, employing DD will yield biased results; the estimates will capture differences in outcomes attributable to both differences in protection and differences in industry trends. Previous studies have tried to address this issue by controlling for observable time varying industry characteristics (Bustos, 2011), and employing instrumental variable techniques (Trefler, 2004; Amiti and Konings, 2007). In this study, I take an alternative approach to control for these confounding trends.

1.2.1 NAFTA and Variation in Protection

The starting point for my approach is the observation that protection is determined by both trade policy and trade costs.[14] Both factors affect the competition faced by plants. This suggests there are three possible sources of variation in protection that can be exploited to identify the effect of changes in competition on pollution emissions from plants that are affected by the liberalization.

The first two sources of variation originate from changes in trade policy due to NAFTA. NAFTA came into effect on January 1st, 1994 and liberalized trade between Mexico, the United States, and Canada.[15] This liberalization primarily came in the form of reductions in tariffs between member countries. After the agreement came into effect, there was substantial variation in both the magnitude and speed of tariff reductions across industries in both the U.S. and Mexico. In some industries, such as Concrete Block and Brick Manufacturing (SIC 3271), bilateral tariffs were eliminated immediately. In other cases, such as Electronic Capacitors (SIC 3675), tariffs were

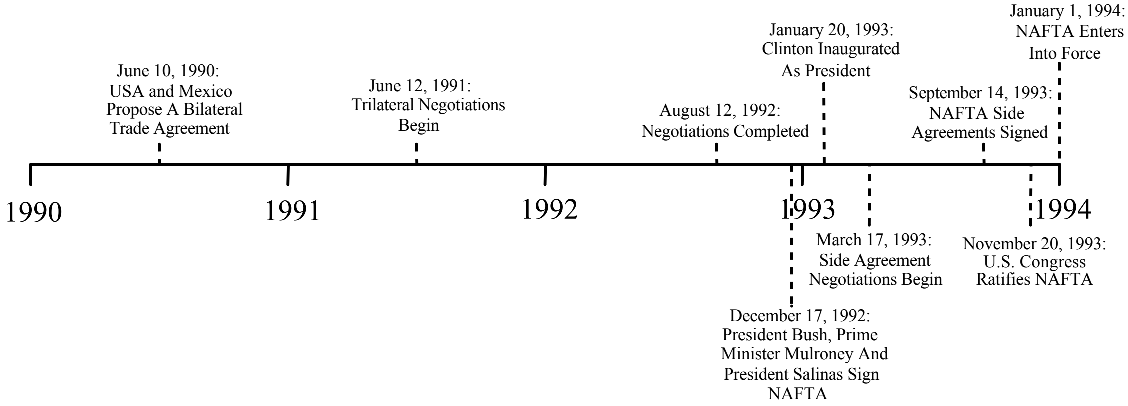
---

[13] The empirical evidence suggests this is particularly true for the U.S. (Trefler, 1993; Goldberg and Maggi, 1999; Gawande and Bandyopadhyay, 2000).

[14] For evidence that the protection provided by trade costs are an important determinant of plant-level outcomes, such as productivity, see Schmitz (2005).

[15] To be precise, the agreement only liberalized bilateral trade between the United States and Mexico and Canada and Mexico. Trade between Canada and the United States had been previously liberalized during the Canada-U.S. Free Trade Agreement and was unaffected by NAFTA.

Figure 1.1: The North American Free Trade Agreement: A Timeline



Notes: Dates taken from Cameron and Tomlin (2000).

eliminated gradually following a set schedule of reductions. However, NAFTA did not affect the tariffs of all industries; some, such as Gaskets, Packing, and Sealing Devices (SIC 3053), were already traded freely prior to the agreement.[16]

A potential drawback to using this variation is the possibility of anticipatory responses by plants prior to NAFTA. As Figure 1.1 shows, trilateral negotiations between the U.S., Mexico, and Canada began in 1991 and the agreement was signed by President Bush, Prime Minister Mulroney and President Salinas 18 months later, nearly one year before NAFTA came into effect. At first glance, this timeline suggests producers had close to 12 months to adjust their production and abatement decisions prior to the agreement, making inference difficult. However, there was a great deal of uncertainty about the future of the agreement throughout this period, particularly after the election of President Bill Clinton in 1992. Clinton required additional side deals on labor and the environment before sending the agreement to Congress. The negotiation of these side agreements created uncertainty over when NAFTA would be

---

[16] As reported by Davis and Kowalczyk (1996), a substantial amount of trade between the U.S. and Mexico was duty free prior to NAFTA. In particular, 14% of U.S. imports from Mexico and 18% of Mexican imports from the U.S. were unaffected by the agreement because they were already freely traded.

ratified (if at all).[17] This uncertainty over the future of NAFTA persisted even after the side agreements were signed in September of 1993, due to political opposition in Congress, and continued until NAFTA was finally ratified on November 20, 1993. Hence, the uncertainty was resolved mere weeks before the agreement came into effect. This means the agreement functioned as a de facto shock, despite its prominence as a policy issue at the time.

The third source of variation in protection arises because of differences in the trade costs faced by plants. Geographic variation in the location of production across the United States means plants within the same industry are faced with different costs of accessing the Mexican market. Like tariffs, these costs act as a barrier to trade, meaning that even in the absence of trade policy, producers in some states are effectively protected while others are not. This variation suggests that there was differential exposure to the Mexican market across the United States prior to NAFTA.[18]

These differences mean that the changes in competition following trade liberalization vary by location. If, for example, plants face prohibitively high trade costs, a reduction in tariffs will not change competition because plants remain protected due to their location. On the other hand, if plants are located where trade is completely costless, they will be fully exposed to the change in competition. Thus, for any industry, only a fraction of plants could be affected by trade liberalization. Given the cross industry variation in tariff reductions, this means the subset of plants in liberalized

---

[17] For example, shortly after Clinton's election, when Democratic campaigner Barry Carter was asked when Clinton would send the NAFTA legislation to Congress, Carter replied, "It will depend on how long it takes to negotiate additional agreements on labor and the environment." (Cameron and Tomlin, 2000).

[18] Geographic variation in exposure to the Mexican market has been at the centre of much of the popular debate about the effects of the agreement. Prior to the agreement it was believed that NAFTA would primarily benefit those states, such as California or Texas, with the closest ties to Mexico (Goldsborough, 1993). Since the agreement, NAFTA has been blamed for Ohio's decline (Leonhardt, 2008), Texas's success (Kumar, 2006), as well as various changes in state employment throughout the U.S. (Bolle, 2000; Scott, 2011).

industries that are exposed to the Mexican market because of their location will be affected (or treated) by trade liberalization. Identifying NAFTA's effect amounts to measuring the effect of trade liberalization on these plants.

Exploiting geographic variation in this manner is not costless. One concern is that there was sorting across locations prior to NAFTA due to the possibility of a trade agreement with Mexico. This would mean that plants located in states with low costs of trade with Mexico are systematically different from plants elsewhere, making it impossible to discern whether differences in outcomes are due to differences in competition, or differences inherent to the plants themselves. It is unlikely that this is the case because U.S. plants primarily serve local domestic markets (Hanson, 2005; Hillberry and Hummels, 2008; Holmes and Stevens, 2012) and the location of these markets is driven by long run trends (Kim, 1995), which suggests location is exogenous.

1.2.2 NAFTA as the Basis of a Research Design

Together, the variation in protection from tariff reductions and differences in trade costs make it possible to develop a research design for identifying the causal impact of changes in competition due to trade liberalization on plant pollution emissions. This design examines the outcomes of plants in liberalized industries located in states that were exposed to trade with Mexico, the plants that were "treated" by NAFTA. To build intuition, I describe the simplest version of my design, where there are two industries (liberalized and unliberalized), and two locations (an exposed state and a protected state). In this case, the treated plants are those in the liberalized industry that are situated in the exposed state.

I start by comparing the average outcomes of treated plants before and after NAFTA. Because these plants are in the same industry and location before and after NAFTA, this comparison allows me to control for any unobserved time-invariant characteristics, such as industry factor intensity or location factor endowments that affect pollution emissions. More importantly, this difference measures the average causal effect of trade liberalization in the absence of concurrent policy changes or secular changes in outcomes. However, it is unlikely that this is the case. As detailed above, there are strong reasons to believe that trade policy is endogenously determined, meaning that the treatment group is treated because of an underlying trend. Moreover, there may have been contemporaneous changes in policy at the time of NAFTA. Isolating the causal effect requires controlling for these shocks. To do so, I exploit the cross-industry and cross-location variation in protection.

The variation in protection across locations allows me to compare the difference in average outcomes for exposed plants with the corresponding difference for unexposed plants from the same industry. Thus, for the liberalized industry, I treat the unexposed plants as a counterfactual for what would have happened to pollution in the industry in the absence of liberalization. This allows me to control for the unobserved time-varying industry heterogeneity that has made identification difficult in previous studies.

The cross-industry variation in the trade policies faced by plants within a state allows me to control for unobserved time-varying state heterogeneity in a similar manner. Hence, for the exposed state, I treat the difference in average outcomes from unliberalized plants as the counterfactual for the average change for liberalized plants in the exposed state. Employing such a counterfactual is important because there is some evidence that state characteristics determine the trade policy preferences of a constituency (see for example, Scheve and Slaughter (2001) or Beaulieu (2002)), meaning that trade policy may be correlated with unobserved state features. Moreover, state legislators may enact policies to offset the effects of trade liberalization within their domain, meaning there may be confounding policy changes within a state.

The cross-industry and cross-location variation in protection also allows me to compare the difference in average outcomes from treated plants with the difference in average outcomes from unexposed plants in the unliberalized industry. Given that these plants are not in the same industry or state as the treated plants, and are not faced by the same changes in policy, they capture the underlying aggregate trend in pollution. This makes it possible to control for nationwide shocks that affect pollution emissions, such as changes in aggregate expenditures due to the recession at the beginning of the 1990's.

1.3 Data and Measurement

1.3.1 Data Overview

My study relies on data from four main sources, which have not been used previously to study how trade liberalization affects plant pollution emissions. These sources are briefly described below.[19]

Emissions Data

The primary data source for this study is the Toxic Release Inventory (TRI) maintained by the U.S. Environmental Protection Agency (EPA). The TRI includes detailed data on the emissions of various toxic chemicals to air, water, ground and other media from plants that are required to report their releases under the Emergence Planning and Community Right to Know Act (EPCRA) of 1986.[20] Plants are required to report their emissions if three conditions are met. In particular, plants

---

[19] Additional details are provided in Appendix A.1.

[20] It is important to note that while these emissions are self-reported, facilities are penalized if they fail to report or misreport their emissions, but do not face penalties for the amount of emissions that they report. For example, the EPA fined Valimet Incorporated of Stockton California $193,996 for failing to report releases between 2001 and 2005. The existence of these penalties means that plants have an incentive to accurately report their emissions.

must report if they: (i) employ at least ten employees, (ii) operate in a TRI-covered industry, and (iii) manufacture, process or use a regulated substance in excess of a designated threshold in a calendar year.

There have been a number of revisions to these requirements since the TRI was first implemented.[21] This means some of the observed changes in emissions are due to changes in reporting requirements, not due to meaningful changes in economic activity.[22] To address this issue, I employ a subset of the data available in the TRI. In particular, I restrict attention to those chemicals that are listed throughout my period of study.

An additional concern is that the releases reported in the TRI come from a variety of sources and production methods. Given my research design, this creates the possibility that simply comparing changes in total emissions across plants would reflect differences in the particular substances produced at each as opposed to meaningful differences due to changes in competitive pressures. To deal with this issue, I also restrict the data to those chemicals that can be classified as volatile organic compounds (VOCs), particulate matter (PM), lead (Pb) or other toxic chemicals (Toxics) and create a separate dataset for each pollutant. This ensures that I am comparing pollutants with similar characteristics throughout my analysis. I employ the classification used by Greenstone (2003) to sort pollutants into these categories.

The TRI contains detailed information on pollution releases to a variety of media. Here, I focus on total emissions of VOCs, PM, Pb and Toxics to air, land, and water.[23]

---

[21] These changes fall into one of three categories: (i) expansion in industry coverage to include sectors outside of manufacturing, (ii) revisions to the thresholds for reporting, and (ii) modifications to the list of chemicals that facilities are required to report.

[22] For example, in 1990, facilities were required to report their emissions if they manufacture or use of nearly 300 chemicals exceeded the reporting thresholds. By 1996, the list of required compounds had grown to include 588 chemicals. Hence, for a plant that reports in both years, an increase in total emissions may be driven by an increase in the quantities of emissions of base year pollutants, an increase in the number of chemicals the facility is required to report, or changes in both factors.

[23] The TRI also includes information on releases to the environment that occur at off-site treatment facilities. I exclude these emissions, because they may include substances that were produced in previous years and stored onsite before being shipped to an off-site treatment facility.

As such I restrict the data to only include plants with positive emissions to at least one of these media throughout my period of study.[24] Moreover, given the focus of the NAFTA debate on pollution from manufacturing, I only consider plants from this sector (4-digit Standard Industrial Classification (SIC) categories 2000-3999).

Plant Characteristics

I match the pollution data from the TRI to proprietary data on plant characteristics from the National Establishment Time Series (NETS). The NETS database is a longitudinal plant database compiled by Walls and Associates from Dunn & Bradstreet's DUNS Marketing Information archives.[25] The NETS data contain information on plant location, sales and employment.[26] I match the NETS data to the pollution data using the facility identification numbers reported in the TRI using a correspondence created by Walls and Associates. I deflate plant sales using the industry deflators from Bartelsman and Gray (1996).

It is important to note that the NETS is not a census of all U.S. plants. This makes it ill-suited for the study of plant entry and exit; if a plant exits the NETS data it has not necessarily terminated operations.[27] As a result, I restrict the data to plants that were in operation throughout my period of study.

International Trade Data

I supplement the data from the TRI and NETS with tariff data for the U.S. from Feenstra et al. (2002) and for Mexico from Romalis (2007). In both cases, the tariff

---

[24] It is possible for plants to meet the reporting requirements and produce zero emissions, however missing values are recorded as zeroes in the TRI data, making it impossible to distinguish zero emissions from missing values. Hence, I am forced to drop all plants with zero reported emissions from the data.

[25] For a detailed discussion of the NETS database, see the appendix of Neumark et al. (2011).

[26] The NETS data also includes information on other plant characteristics, such as foreign ownership and export status, but these characteristics are only reported for the last year each plant is observed in the NETS data, which is typically well after of my period of study.

[27] The data does contain some information on plant start dates and dates of plant closure, but this information is missing in many cases and the non-missing data is unreliable. As Neumark et al. (2011) indicate, only 75% of plants have accurate start date information.

data is classified using the Harmonized System (HS) classification system while the matched TRI and NETS data is classified according to the four digit Standard Industrial Classification (SIC4). I aggregate the tariff data to the SIC4 classification using the concordance from Pierce and Schott (2009). Although it is the best concordance currently available, the Pierce and Schott algorithm does not match tariffs to all industries. To address this issue, I reclassify some of the excluded industries using the correspondence reported in Table 3 of Feenstra et al. (2002) and drop all remaining industries from the data. Finally, I match the data from the TRI and NETS to data on state exports for 1993 from Feenstra (1997).[28]

1.3.2 Descriptive Statistics

I combine the data from each of these sources to construct a dataset for each pollutant. Descriptive statistics for each are reported in Table 1.1.

Three features of the data are worth noting. First, there are large differences in plant characteristics for each pollutant. On average, plants that emit VOCs produce more pollution, and are more emission intensive (measured either in terms of the emissions-sales ratio or emissions per worker) than plants that emit other pollutants. However, plants that emit either PM or Toxics are much larger (both in terms of sales and employment) than plants that emit VOCs and Pb. These features suggest that there are important differences in how each of the pollutants are produced. Moreover, in each case, the distributions of emissions, sales, and employment are highly skewed. This suggests that there are also important differences in the production processes of plants that emit the same pollutant.

Second, the number of industries covered in each sample varies by pollutant. For

---

[28] Data on state exports is also available for 1991 and 1992, however as Feenstra documents, the method used by the U.S. Census Bureau to determine the state of origin for exports during these years does not necessarily reflect the true location of production, but rather the location of wholesalers and other intermediaries. Hence I rely on the export data from 1993.

Table 1.1: Descriptive Statistics: 1991-1998

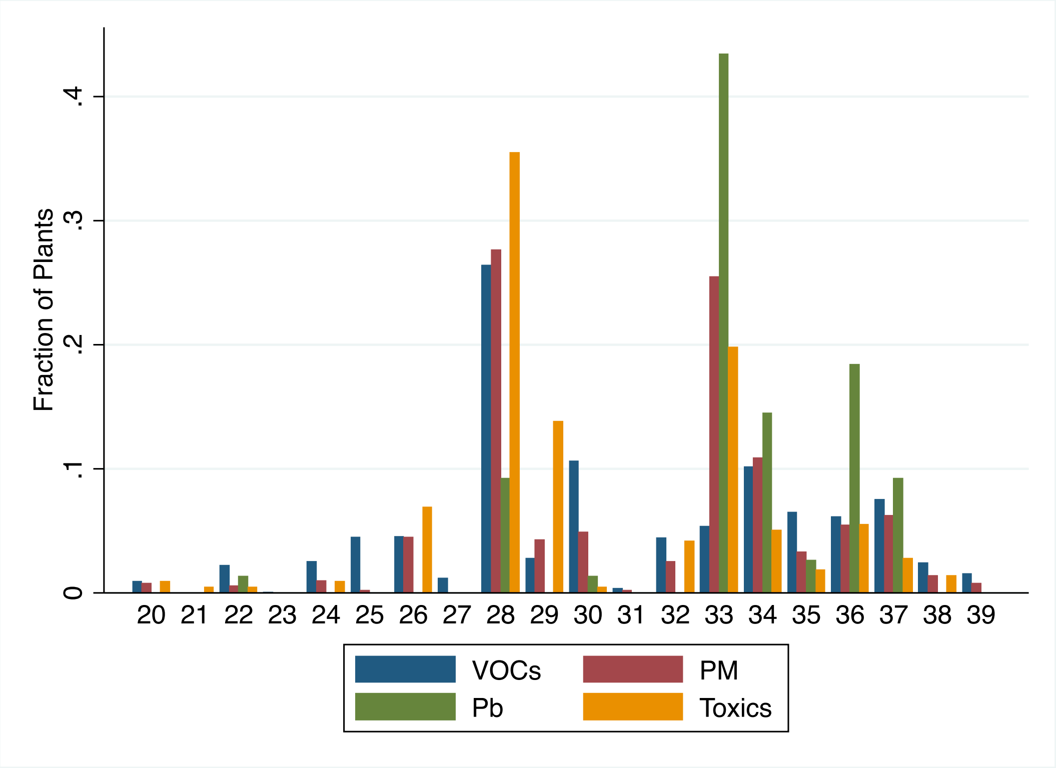
Pollutant	Mean	Std. Dev.	Median
VOCs ($N = 13,632$, $J = 219$, $S = 46$)			
Emissions (lbs)	217,940	(1,069,871)	45,189
Sales ($1,000,000s)	80	(163)	28
Employees	490	(994)	200
Emissions/Sales	5,771	(19,210)	1,678
Emissions/Employee	831	(3,373)	238
PM ($N = 4112$, $J = 120$, $S = 44$)			
Emissions (lbs)	84,288	(784,506)	1,760
Sales ($1,000,000s)	124	(219)	52
Employees	670	(1,381)	300
Emissions/Sales	1,044	(9,107)	36
Emissions/Employee	201	(1,792)	6
Pb ($N = 608$, $J = 29$, $S = 29$)			
Emissions (lbs)	3,467	(7,564)	704
Sales ($1,000,000s)	76	(107)	38
Employees	479	(692)	266
Emissions/Sales	82	(185)	20
Emissions/Employee	14	(41)	3
Toxics ($N = 1,736$, $J = 60$, $S = 40$)			
Emissions (lbs)	76,409	(181,002)	12,000
Sales ($1,000,000s)	180	(256)	104
Employees	891	(1,743)	475
Emissions/Sales	1,050	(3,465)	134
Emissions/Employee	184	(469)	31

Notes: Standard deviations are reported in parentheses. The unit of observation is a plant. N refers to the number of observations in each dataset. J and S refer to the number of industries and states covered in each data set.

example, VOCs are produced by plants in 219 industries, while Pb is only produced by plants in 29 industries. This reflects the fact that some pollutants are primarily tied to specific sectors.

This feature is displayed in Figure 1.2, which depicts the fraction of plants that emit each pollutant by broad industry grouping (2-digit SIC category). As is indicated in the Figure, VOCs are most often emitted by plants that produce chemicals and allied products (SIC 28), rubber and miscellaneous plastic products (SIC 30), and fabricated metal products (SIC 34). Plants that emit PM are most prevalent in

Figure 1.2: Share of Plants by SIC2 Industry Group

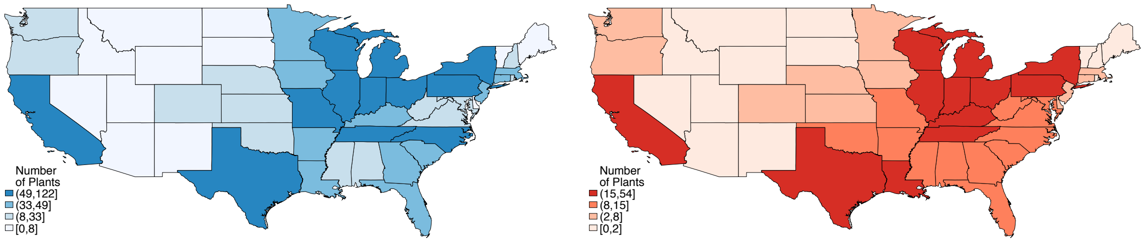


chemicals and allied products, primary metals (SIC 33) and fabricated metal products. Toxics are most often emitted by plants that produce chemicals and allied products, petroleum refining and related industries (SIC 29), and primary metals. Pb is primarily emitted by plants in chemicals and allied products, primary metals, fabricated metal products and electronic and other electrical equipment and components (SIC 36).

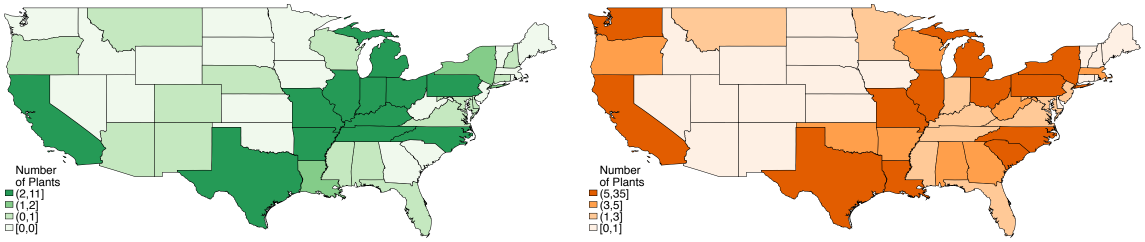
Finally, there is substantial variation in the location of plants across the continental United States. This variation is depicted in Figure 1.3, which illustrates the number of plants in each state that produce each pollutant. As the figure shows, plants are primarily located in the southwest (in Texas and California) and the northeast (in states that border the great lakes). Given that distance to market is an important determinant of trade costs (Anderson and van Wincoop, 2004), the variation in location depicted in the figure provides suggestive evidence that there is considerable

Figure 1.3: Plant Locations

(a) VOCs (b) PM



(c) Pb (d) Toxics



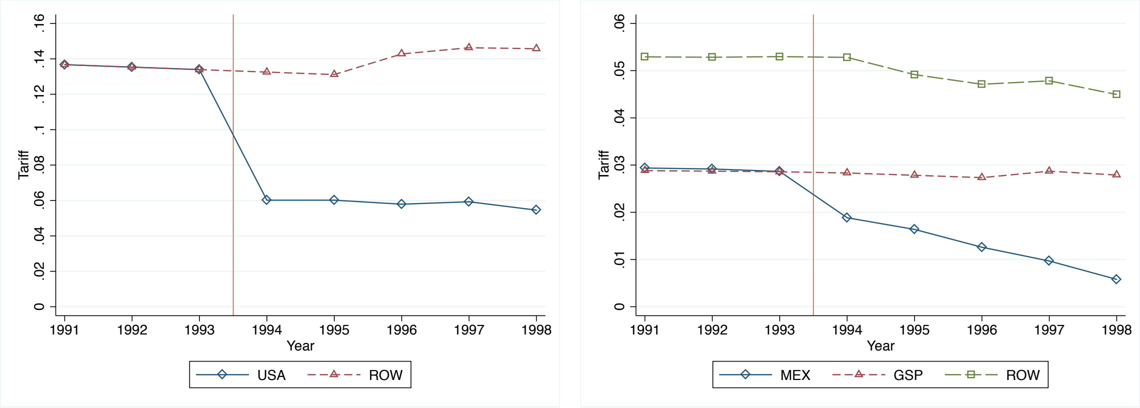
variation in the trade frictions faced by plants for each of the pollutants under study.

1.3.3 Measuring Protection

My research design relies on variation in trade policy and trade costs to identify the effects of trade liberalization on the pollution emitted by manufacturing plants. The following describes how I measure each form of protection.

Measuring Trade Liberalization

A key feature of NAFTA is that is was a preferential trade agreement, meaning that it reduced barriers to trade between member countries without changing the barriers that they extended to other nations around the world. This feature is illustrated in Figure 1.4, which displays the average tariff rates on all imports for the U.S. and Mexico during my period of study, 1991-1998. Panel (A) plots Mexico's average tariff on imports from the United States, labeled USA, and the rest of the world, labeled ROW. Similarly, panel (B) plots the average U.S. tariff on imports from Mexico, labeled MEX, as well as the average tariff rates the U.S. extended to the rest of the



(a) Mexico's Tariffs on Final Goods (b) U.S. Tariffs on Final Goods

Figure 1.4: Bilateral Tariff Reductions

world, labeled MFN and GSP respectively.

The preferential nature of NAFTA is evident from the Figure. For example, consider Mexico's tariffs on imports shown in panel (A). Prior to NAFTA, the average tariff on imports was close to 0.13, regardless of source. After NAFTA was implemented in 1994 (denoted by the vertical line), the average tariff on U.S. imports fell by half to close to 0.06, while the average tariff on imports from other countries remained near its pre-NAFTA level. Hence, following the agreement, Mexico's trade policy favoured imports from the U.S. relative to imports from the rest of the world.

I exploit this feature of NAFTA to measure the magnitude of trade liberalization between the U.S. and Mexico. In particular, I measure bilateral trade liberalization between the United States and Mexico using the change in tariff preferences (the difference in tariff rates faced by NAFTA members and non-members) for each industry.[29]

This approach exploits the fact that the preferential nature of the agreement creates an implicit counterfactual for the level of protection that would have occurred in the absence of trade liberalization. Employing such a counterfactual is impor-

---

[29] A similar approach was taken by Trefler (2004) to analyze the effects of the Canada-U.S. Free Trade Agreement.

tant because there was increased globalization resulting from the Uruguay Round of the General Agreement on Tariffs and Trade as well as changes to the Generalized System of Preferences (GSP) that gave developing countries preferential tariff rates for the U.S. market during my period of study. This means that there would have been changes to the tariff rates faced by NAFTA members even in the absence of the agreement. These changes will not be captured by the changes in bilateral tariffs between the U.S. and Mexico. Hence, simply comparing changes in tariff levels extended between member states could overstate the magnitude of trade liberalization. Measuring trade liberalization using tariff preferences addresses this issue directly by incorporating the tariffs extended to non-members.

Figure 1.4 also provides suggestive evidence of the appropriate levels of protection to employ when measuring tariff preferences. This is particularly important in the case of the United States because American trade policy discriminated between developed and developing countries prior to NAFTA. As panel (B) indicates, for most imports the United States extended preferential tariffs to Mexico at the GSP rate prior to NAFTA. This suggests that the GSP rate is the relevant counterfactual for the level of protection that would have occurred in the absence of trade liberalization. Hence, letting t_{jt}^{U-d} denote U.S. ad-valorem tariff rates on imports from industry j in region d, U.S. tariff preferences for Mexican imports are given by:

$$\tau_{jt}^{US-Mex} = t_{jt}^{US-GSP} - t_{jt}^{US-Mex} \tag{1.1}$$

This value corresponds to the vertical distance between the lines labeled MEX and GSP in panel (B) of Figure 1.4. Panel (A) shows that prior to NAFTA, Mexican trade policy treated the United States like any other country. This suggests that the appropriate counterfactual are the tariffs that Mexico extended to countries that were not NAFTA members. Letting t_{jt}^{M-d} denote Mexican ad-valorem tariff rates on imports from industry j in region d, Mexican tariff preferences for U.S. imports are

(a) Mexico's Tariff Preference for U.S. Imports (b) U.S. Tariff Preferences for all Mexican Imports

Figure 1.5: Bilateral Tariff Preferences

given by:

$$\tau_{jt}^{Mex-US} = t_{jt}^{Mex-ROW} - t_{jt}^{Mex-US} \tag{1.2}$$

This value corresponds to the vertical distance between the lines labeled USA and ROW in panel (A) of Figure 1.4.

The changes in tariff preferences for the U.S. and Mexico following NAFTA are shown in Figure 1.5. This figure displays Mexico's tariff preferences for U.S. imports (panel (A)) and U.S. preferences for all Mexican imports (panel (B)) during my period of study. As the Figure shows, NAFTA increased tariff preferences in both countries. It is important to note that the magnitude of this increase was substantially larger for Mexico than the United States. This is a product of the GSP program in the United States; under this program some Mexican products received preferential treatment prior to NAFTA.

Measuring Exposure to Trade

Implementing my research design also requires a method of quantifying differences in the ease of trading with Mexico across locations. Ideally I would be able to employ data on trade costs for this purpose, but unfortunately, such data is currently unavailable. As such, I construct a measure of trade exposure for each state based on trade flows using data on exports by state.[30]

The starting point for my approach is the standard gravity equation, which states that total exports from state s to Mexico can be expressed as:[31]

$$X_s^{Mex} = \kappa Y^s Y^{Mex} \phi_s^{Mex} \tag{1.3}$$

Hence, trade between state s and Mexico depends not only on trade frictions ($\phi_s^{Mex} \in [0,1]$) and a constant (κ), but also on vectors of exporter and destination characteristics (Y^s and Y^{Mex} respectively). Rewriting equation (1.3) yields an expression for trade frictions:

$$\phi_s^{Mex} = \frac{X_s^{Mex}}{\kappa Y^s Y^{Mex}} \tag{1.4}$$

I employ an approach that is common in the gravity literature and proxy for Y^s and Y^{Mex} using state and country GDP. I then normalize this expression by the average ratio of exports to GDP for all U.S. states to eliminate κ and obtain:

$$\Phi_s \equiv \frac{\phi_s^{Mex}}{\bar{\phi}_s^{Mex}} = \left[\frac{X_s^{Mex}}{Y^s Y^{Mex}}\right] \Big/ \overline{\left[\frac{X_s^{Mex}}{Y^s Y^{Mex}}\right]} \tag{1.5}$$

where $\overline{[X_s^{Mex}/Y^s Y^{Mex}]} = 1/N \sum_{s \in S} [X_s^{Mex}/Y^s Y^{Mex}]$ and $\bar{\phi}_s^{Mex} = 1/N \sum_{s \in S} \phi_s^{Mex}$. The resulting indicator, $\Phi_s \in [0, \infty)$ measures bilateral trade frictions between state s and Mexico relative to the average bilateral frictions for all U.S. states and varies inversely with the relative frictions of trading with Mexico. This means Φ_s increases as bilateral trade frictions with Mexico fall. Moreover, this variation only captures the frictions that are specific to each state; any frictions that are common across states (such as trade policy) are eliminated by the normalization.[32] Thus, based on this measure, states with high values of Φ_s are relatively more exposed to trade with Mexico.

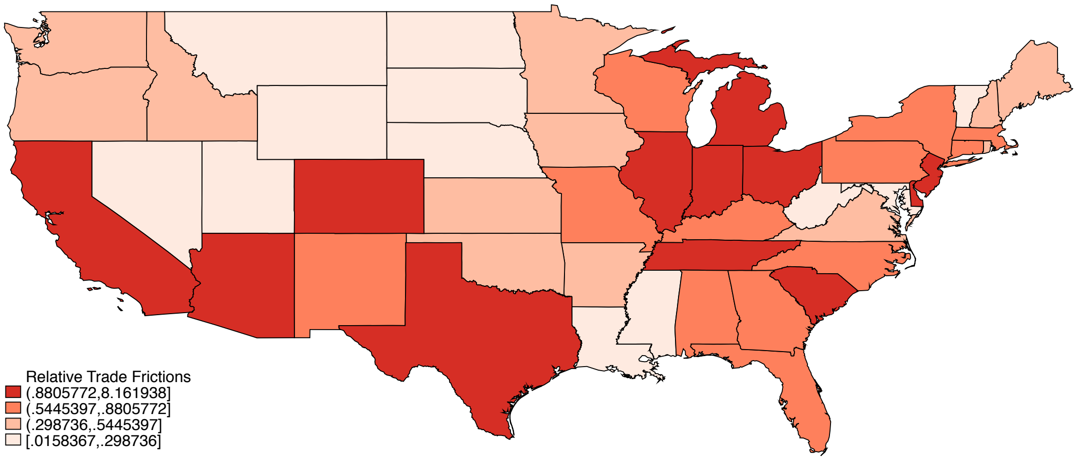
---

[30] Unfortunately state-level import data is unavailable for my period of study, making many common measures of trade frictions, such as the Head and Ries Index (Head and Ries, 2001), impossible to calculate.

[31] For evidence that trade by U.S. states conforms to the gravity model, see Wolf (2000), Anderson and van Wincoop (2003), Hillberry and Hummels (2003), Hillberry and Hummels (2008), and Yilmazkuday (2012).

[32] The normalization is also convenient for the interpretation of the estimates presented below.

Figure 1.6: Trade Frictions by State



Source: Author's calculations using data from Feenstra (1997).

I construct Φ_s for each state in the continental U.S. using state export data and GDP data from 1993.[33] The variation in Φ_s across states is displayed in Figure 1.6. In the Figure, darker values correspond to higher values of Φ_s, meaning that darker states have lower trade frictions than lighter states. Two elements of this figure are worth mentioning. First, there is substantial geographic variation in trade frictions across states. Second, trade exposure is not concentrated in the south and southwest regions of the U.S.; states in the midwest and northeast are also highly exposed. This feature reflects differences in trade frictions that would not be captured by a naive measure (such as distance from the Mexican border).

1.4 Empirical Specification

My main empirical specification is given by:

$$\ln z_{ijst} = \beta_1[\tau_{jt}^{Mex-US} \times \Phi_s] + \beta_2[\tau_{jt}^{US-Mex} \times \Phi_s] + \rho_i + \mu_{jt} + \delta_{st} + \lambda_t + \varepsilon_{ijst} \qquad (1.6)$$

---

[33] Employing data from prior to NAFTA is important as it ensures that the measured difference in exposure is not the result of an endogenous response to the agreement.

where $\ln z_{ijst}$ is the natural log of pollution emissions from plant i in industry j and state s at time t.[34] τ_{jt}^{US-Mex} and τ_{jt}^{Mex-US} are the tariff preferences defined in equations (1.1) and (1.2), and Φ_s is the measure of trade exposure defined in equation (1.5). ρ_i is a plant fixed effect that captures time-invariant plant heterogeneity, as well as constant industry and geographic characteristics such as industry factor intensity or state factor endowments that affect pollution emissions. μ_{jt} are industry×year fixed effects that capture temporal variation in industry outcomes, such as industry-specific demand shocks. δ_{st} are state×year fixed effects that capture state specific shocks such as changes in environmental policy. λ_t are year fixed effects that capture aggregate shocks that may affect pollution. ε_{ijst} is an error term that captures idiosyncratic changes in emissions.

The coefficients of interest in equation (1.6) are β_1 and β_2. The estimated coefficient $\hat{\beta}_1$ measures the average percentage change in pollution emissions specific to plants that experience an increase in access to the Mexican market following trade liberalization relative to the change in pollution for plants in the same industry and plants in the same location that do not. Similarly, $\hat{\beta}_2$ measures the average percentage change in pollution from plants that experience an increase in Mexican competition following trade liberalization relative to the change in pollution for plants in the same industry and plants in the same location that do not. These coefficients are identified from within industry×state comparisons over time.

Equation (1.6) is a triple difference estimator with continuous measures of treatment. As such, identification requires that there be no unobserved industry×state shocks that are correlated with trade policy. Put differently, the underlying identification assumption requires that there be no other factors aside from changes in trade policy generating a difference in outcomes for plants that were affected and un-

---

[34] I employ the natural log of pollution emissions as the dependent variable to remove the skewness in the distribution of emissions for each pollutant.

affected by NAFTA. This assumption would fail if state legislators respond to trade liberalization by relaxing regulations faced by plants in liberalized industries, without making similar policy concessions for unliberalized industries.

1.5 Results

1.5.1 NAFTA and Pollution Levels

The results of estimating three specifications based on equation (1.6) for each pollutant are reported in Table 1.2. The first specification, reported in column (1) of each panel, includes plant and year fixed effects only. The second specification, reported in column (2), adds industry×year fixed effects to control for omitted time-varying industry factors. The final specification, reported in column (3) also includes state×year fixed effects to control for omitted time-varying state factors. In all cases, the standard errors are clustered by industry×state.

Together, the estimates reported in column (1) of each panel suggest that NAFTA had limited effects on the level of pollution emitted by US manufacturing plants. In particular, it appears that increased access to the Mexican market is associated with reduced PM emissions, but is not associated with a statistically significant effect for VOCs and Pb. The results also suggest that changes in Mexican market access may be associated with increased Toxic emissions, but this effect is imprecisely estimated. On the other hand, the estimates indicate that decreased protection from Mexican competition only affected Toxic emissions; the change in protection is associated with a reduction in Toxic emissions, but is not associated with a statistically significant effect for any other pollutant.

However, the omission of industry×year fixed effects means that the estimates presented in column (1) of each panel may be capturing both the effects of trade liberalization and the effects of other omitted time-varying industry factors that are

Table 1.2: NAFTA and Pollution Emissions

	Panel A: VOC			Panel B: PM		
	(1)	(2)	(3)	(1)	(2)	(3)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-0.066	-0.162^{c}	0.058	-0.958^{a}	-1.284^{a}	-2.098^{c}
	(0.107)	(0.098)	(0.207)	(0.344)	(0.403)	(1.125)
$\tau_{jt}^{US-Mex} \times \Phi_s$	0.148	-0.084	-0.023	0.137	7.284^{b}	5.810
	(0.414)	(0.613)	(0.593)	(2.039)	(3.625)	(4.446)
Plant FE	Y	Y	Y	Y	Y	Y
Industry×Year FE		Y	Y		Y	Y
State×Year FE			Y			Y
Year FE	Y	Y	Y	Y	Y	Y
N	13632	13632	13632	4112	4112	4112
R^2	0.08	0.25	0.27	0.01	0.29	0.37
	Panel C: Pb			Panel D: Toxics		
	(1)	(2)	(3)	(1)	(2)	(3)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-0.698	-1.447	-5.371^{a}	0.555	0.638	-0.913
	(0.662)	(0.912)	(1.640)	(0.368)	(0.419)	(1.054)
$\tau_{jt}^{US-Mex} \times \Phi_s$	8.710	16.442	17.151	-3.843^{c}	-4.222	-5.124
	(8.955)	(16.362)	(13.701)	(2.195)	(3.303)	(3.614)
Plant FE	Y	Y	Y	Y	Y	Y
Industry×Year FE		Y	Y		Y	Y
State×Year FE			Y			Y
Year FE	Y	Y	Y	Y	Y	Y
N	608	608	608	1736	1736	1736
R^2	0.07	0.38	0.73	0.04	0.31	0.48

Notes: Table reports regressions of log pollution emissions on measures of the level of protection from and the level of access to the Mexican market. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

correlated with protection, leading to biased results. As the estimates reported in column (2) show, controlling for this form of heterogeneity alters the estimated effects of increased market access and decreased protection considerably. These estimates suggest increased access to the Mexican market is associated with decreases in the emissions of VOCs, PM. The change in market access may have also decreased Pb emissions and increased Toxic emissions, but these effects are imprecisely estimated. The results also indicate that decreased protection is associated with an increase in

Table 1.3: Changes in Pollution Emissions due to NAFTA

	VOCs (1)	PM (2)	Pb (3)	Toxics (4)
Δ Mexico Tariff Preferences				
× Mean Φ_s	0.51	**-18.38**	**-47.05**	-8.00
Δ US Tariff Preferences				
× Mean Φ_s	0.04	9.17	27.10	-8.10

Notes: Table reports the changes in emissions due to NAFTA for a plant with average exposure to the Mexican market. See text for details. Numbers in bold are statistically significant at the 10% level.

PM emissions

While the specification presented in column (2) controls for time-varying industry heterogeneity, the estimates may still be capturing the effects of omitted time-varying state factors that are correlated with protection, such as changes in environmental policy. As column (3) of each panel shows, adding state×year fixed effects to control for this form of heterogeneity leads to additional changes in the estimates for all pollutants.

To quantify the magnitude of these effects, I calculate the percentage change in pollution emissions implied by the estimates. Specifically, for each pollutant I calculate the percentage change in pollution emissions for a hypothetical plant with average exposure to the Mexican market that faces the average change in U.S. and Mexican tariff preferences following NAFTA using the coefficients reported in column (3) of Table 1.2. The results of these calculations are presented in Table 1.3.

For example, the estimated effect of increased access to the Mexican market for PM ($\beta_1 = -2.098$) implies that for a plant facing the average level of trade frictions ($\Phi_s = 1$), the average increase in Mexican tariff preferences (8.76 percentage points) reduced the level of pollution emitted by 18.38%, which is the value reported in the table. Similarly, the estimated effect of reducing protection from Mexican competition ($\beta_2 = 5.810$) implies that the average increase in U.S. tariff preferences (1.58 percentage points) increased PM emissions by 9.17% for plants facing the average level of trade frictions.

Together, the results presented in Tables 1.2 and 1.3 suggest that the effect of NAFTA on pollution emissions was mixed. The results indicate that increased access to the Mexican market led to statistically significant reductions in the emissions of PM and Pb from affected plants, but had little to no effect on the emissions of Toxics and VOCs. In contrast, decreased protection from Mexican imports appears to have little effect on the emissions of any pollutant; the results suggest that decreased protection may have led to modest changes in the emissions of PM, Pb and Toxics, but these changes are not significant at conventional levels.

In the context of the debate over NAFTA's effect on the environment prior to the agreement, these findings are surprising. Prior to NAFTA, many commentators suggested that the pollution emitted by U.S. manufacturing plants would fall as a result of increased competitive pressure from Mexico. The results presented in Tables 1.2 and 1.3 provide little evidence of this phenomenon. Instead, the results indicate that any reductions in emissions were instead driven by increased access to the Mexican market, which suggests the reductions may be tied to the export decisions of plants that produce these pollutants.

Flexible Estimates

I now turn to address the concern that my results may be capturing pre-existing differences in trends across industry×states rather than the effects of trade liberalization due to NAFTA. To do so, I estimate a fully flexible version of equation (1.6) that takes the form:

$$\begin{aligned}\ln z_{ijst} = &\sum_{t=1992}^{1998} \beta_1^t [\tilde{\tau}_j^{Mex-US} \times \Phi_s \times \lambda_t] \\ &+ \sum_{t=1992}^{1998} \beta_2^t [\tilde{\tau}_j^{US-Mex} \times \Phi_s \times \lambda_t] + \rho_i + \mu_{jt} + \delta_{st} + \lambda_t + \varepsilon_{ijst} \end{aligned} \qquad (1.7)$$

where $\tilde{\tau}_j^{Mex-US}$ and $\tilde{\tau}_j^{US-Mex}$ are measures of the tariff preferences in industry j over the entire post-NAFTA period, and all other variables are defined as in equation (1.6). The interactions $\tilde{\tau}_j^{Mex-US} \times \Phi_s$ and $\tilde{\tau}_j^{US-Mex} \times \Phi_s$ reflect differences in the extent of trade liberalization across plants following NAFTA, so the estimated vectors of β_1 and β_2 describe the correlation between post-NAFTA treatment status and pollution emissions in each year, relative to a baseline year, which I choose to be 1991.[35] Hence, the estimated coefficients reveal differences in the correlation between treatment status and pollution emissions over time. As such, I am interested in the pattern the coefficients display over time; if there are no pre-existing differences in trends in pollution emissions across plants, the estimated coefficients should be zero prior to NAFTA.

Estimates of equation (1.7) for each pollutant are reported in Table 1.4. For each pollutant, I estimate two specifications. In the first, reported in the odd-numbered columns, I measure $\tilde{\tau}_j^{Mex-US}$ and $\tilde{\tau}_j^{US-Mex}$ as the average tariff preference in industry j post-NAFTA. In the even-numbered columns, I measure $\tilde{\tau}_j^{Mex-US}$ and $\tilde{\tau}_j^{US-Mex}$ as the maximum tariff preference in industry j post-NAFTA. In all cases, the standard errors are clustered by industry×state.

These results provide two key insights. First and foremost, there are no clear trends in the estimates for the years prior to NAFTA. This is an important validation of my research design; it indicates that the results documented above are not simply capturing pre-existing differences in trends across industry×states. This can be seen clearly in Figure 1.7, which plots the point estimates from the even-numbered columns and their associated 95 percent confidence intervals. In each graph, the vertical red line represents the implementation of NAFTA. For each pollutant, the values β_1^{1991} and β_2^{1991} have been normalized to zero through choice of the baseline year.

---

[35] It should be noted that the choice of baseline year is arbitrary; choosing a different year changes all of the estimated coefficients and the associated standard errors.

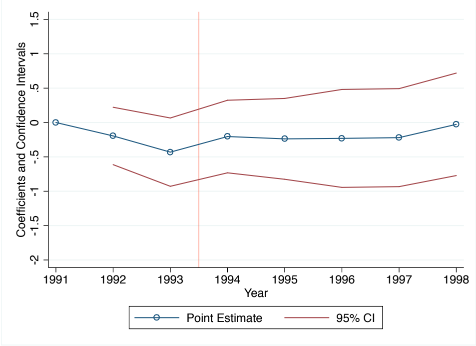
Table 1.4: Flexible Estimates: Pollution Emissions

	VOC		PM		Pb		Toxics	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$\tilde{\tau}_j^{Mex-US} \times \Phi_s$								
×1992	-0.221	-0.195	-1.041	-1.343	3.195	0.155	0.459	0.963
	(0.253)	(0.213)	(1.351)	(1.023)	(7.315)	(7.037)	(1.364)	(1.269)
×1993	-0.322	-0.431^{c}	0.584	-0.208	0.325	-6.056	0.279	-0.344
	(0.291)	(0.253)	(1.809)	(1.382)	(9.070)	(9.516)	(2.219)	(2.001)
×1994	-0.207	-0.204	-2.202	-2.264	-14.995^{b}	-14.629^{c}	0.247	0.655
	(0.329)	(0.269)	(1.764)	(1.541)	(7.335)	(7.676)	(1.794)	(1.754)
×1995	-0.333	-0.238	-3.336^{c}	-4.589^{b}	-21.895^{a}	-17.973^{a}	-0.705	-0.982
	(0.341)	(0.300)	(2.013)	(1.789)	(4.653)	(5.502)	(1.812)	(1.845)
×1996	-0.265	-0.231	-4.539^{b}	-5.538^{a}	-34.060^{a}	-24.753^{b}	-0.463	-1.182
	(0.425)	(0.363)	(2.033)	(1.875)	(9.575)	(11.346)	(2.008)	(2.200)
×1997	-0.309	-0.220	-5.073^{b}	-5.923^{a}	-21.880^{b}	-16.031	-1.555	-2.488
	(0.424)	(0.363)	(2.207)	(1.952)	(10.330)	(10.227)	(1.962)	(2.146)
×1998	-0.152	-0.027	-4.924^{b}	-4.795^{b}	-30.826^{a}	-25.507^{a}	-2.318	-3.293
	(0.435)	(0.380)	(2.292)	(2.193)	(4.840)	(6.658)	(2.688)	(2.945)
$\tilde{\tau}_j^{US-Mex} \times \Phi_s$								
×1992	-0.123	-0.017	-3.834	-2.611	14.213	2.109	1.957	0.905
	(0.448)	(0.263)	(4.234)	(3.531)	(24.008)	(23.665)	(5.608)	(4.461)
×1993	0.025	0.048	2.608	1.305	6.398	-17.097	-6.528	-4.711
	(0.498)	(0.297)	(6.337)	(5.575)	(35.093)	(35.829)	(6.558)	(5.387)
×1994	-0.149	-0.050	5.983	5.869	-32.917	-30.094	-0.841	-1.119
	(0.556)	(0.321)	(5.542)	(4.669)	(28.542)	(27.814)	(5.433)	(4.662)
×1995	-0.103	0.006	1.843	0.964	-45.931^{a}	-30.027	-2.567	-2.916
	(0.616)	(0.368)	(6.601)	(5.557)	(17.290)	(18.791)	(6.168)	(5.010)
×1996	-0.340	-0.064	-1.003	-1.267	-74.967^{b}	-38.838	-5.913	-4.356
	(0.717)	(0.401)	(6.579)	(5.591)	(32.695)	(35.665)	(5.476)	(4.624)
×1997	-1.022	-0.359	3.450	4.495	-34.888	-13.104	-13.140^{b}	-10.478^{b}
	(0.816)	(0.457)	(6.913)	(5.944)	(34.626)	(32.360)	(5.241)	(4.357)
×1998	-0.341	0.163	10.432	9.063	-69.791^{a}	-47.704^{b}	-15.815^{c}	-12.480
	(1.332)	(0.816)	(8.121)	(7.280)	(17.574)	(22.221)	(8.769)	(7.749)
N	13632	13632	4112	4112	608	608	1736	1736
R^2	0.28	0.27	0.38	0.38	0.76	0.75	0.49	0.49

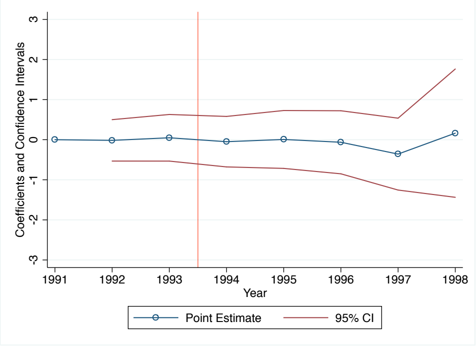
Notes: Table reports regressions of log pollution emissions on the average (odd-numbered columns) and maximum (even-numbered columns) post-NAFTA tariff preferences interacted with state trade frictions and year fixed effects. All regressions include plant, industry×year, state×year and year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

Figure 1.7: Flexible Estimates

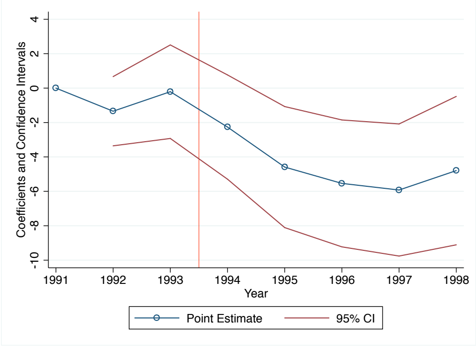
(a) VOCs: Mexican Liberalization



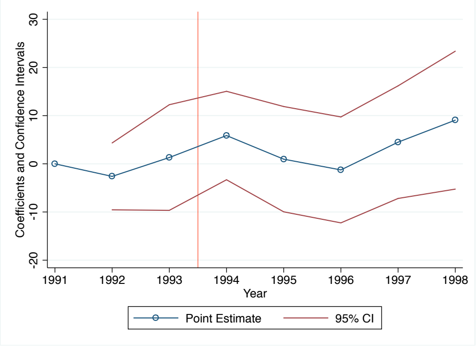
(b) VOCs: U.S. Liberalization



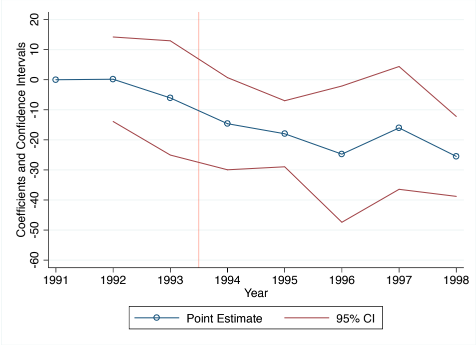
(c) PM: Mexican Liberalization



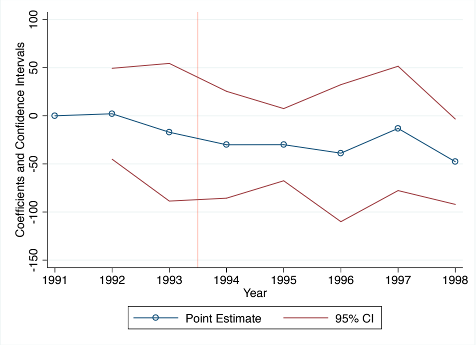
(d) PM: U.S. Liberalization



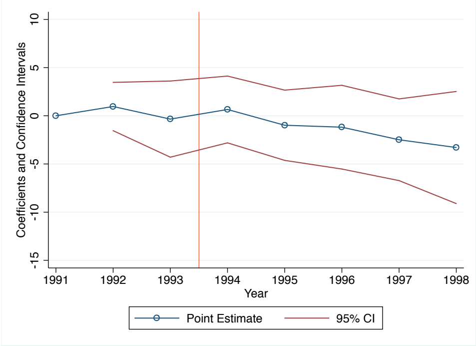
(e) Pb: Mexican Liberalization



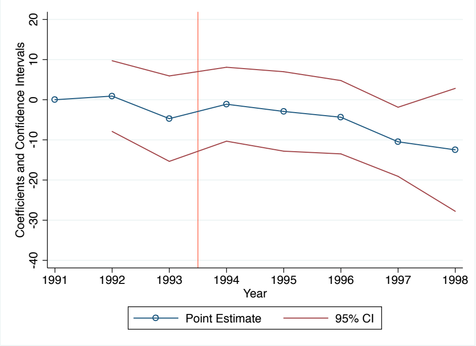
(f) Pb: U.S. Liberalization



(g) Toxics: Mexican Liberalization



(h) Toxics: U.S. Liberalization



Second, the results indicate that the emissions of PM and Pb did not adjust immediately after NAFTA was implemented. For both pollutants, emissions declined gradually over the 1994-1996 period in response to increased market access. These gradual responses are unsurprising given the nature of the liberalization; most tariffs were phased out gradually after the agreement was implemented.

The Mexican Peso Crisis, the Canada-U.S. Free Trade Agreement and the Clean Air Act Amendments

My results thus far show that increased market access following NAFTA decreased the level of PM and Pb emitted by affected plants, and had little effect on the emissions of VOCs and Toxics. However, my period of study overlaps with three additional events that might have also affected pollution emissions from U.S. manufacturing plants: the Mexican Peso Crisis, the implementation of the Canada-U.S. Free Trade Agreement (CUSTFA), and the implementation of the 1990 Clean Air Act Amendments. I now consider these events in my analysis.

The first event that I consider is the Mexican Peso Crisis.[36] The crisis began in December of 1994, when foreign investors lost confidence in the Mexican economy, resulting in a large reduction in the value of the peso. This shock lead to a significant contraction of the Mexican economy in 1995, potentially offsetting the effects of increased market access due to NAFTA.[37] To account for this, I amend my baseline estimating equation to include an interaction of the Mexican liberalization measure with a peso crisis dummy equal to one for the year 1995.

I also examine the effects of trade liberalization between Canada and the United States as result of the Canada-U.S. Free Trade Agreement (CUSTFA). While CUSTFA predates NAFTA, the agreement set a 10 year timeline for the reduction of bilateral

---

[36] For overviews of the events surrounding the Mexican Peso Crisis, see Sachs et al. (1996) or Edwards (1998).

[37] The peso crisis decreased exports from the U.S., but did not affect U.S. imports from Mexico (Burfisher et al., 2001).

trade barriers, meaning that the trade liberalization was ongoing during my period of study. To control for this, I incorporate measures of trade liberalization between Canada and the U.S. that are analogous to $[\tau_{jt}^{Mex-US} \times \Phi_s]$ and $[\tau_{jt}^{US-Mex} \times \Phi_s]$. Specifically, I add measures of the bilateral tariff preferences for Canada and the U.S. (τ_{jt}^{Can-US} and τ_{jt}^{US-Can} respectively) interacted with Φ_s^{Can}, a measure of bilateral trade frictions between each state s and Canada, to my baseline estimating equation.[38]

Lastly, I consider the role played by the 1990 Clean Air Act Amendments (CAAA). Under the CAAA, the Environmental Protection Agency is responsible for setting minimum air quality standards for six criteria pollutants, including ozone, PM and Pb, that determine the stringency of environmental regulation faced by plants.[39] Plants located in "non-attainment" counties that have ambient air concentrations which exceed the minimum standards face tougher regulations than those located in "attainment" counties where ambient air concentrations fall below the minimum standards. The 1990 CAAA tightened these standards, leading to new regulations for many counties across the United States at the beginning of 1991. Hence, I also amend my baseline specification to include an indicator of the county attainment status facing plant i at time t.[40]

The estimates are reported in Table 1.5. Each panel displays results for a dif-

---

[38] Bilateral tariff preferences between Canada and the U.S. are given by:

$$\begin{aligned}\tau_{jt}^{Can-US} &= t_{jt}^{Can-ROW} - t_{jt}^{Can-US}\\ \tau_{jt}^{US-Can} &= t_{jt}^{US-ROW} - t_{jt}^{US-Can}\end{aligned}$$

where the t_{jt}^{c-d} are country c's ad-valorem tariff rates on imports in industry j from region d at time t. Φ_s^{Can} is analogous to equation (1.5), and is given by:

$$\Phi_s^{Can} = \left[\frac{X_s^{Can}}{Y^s Y^{Can}}\right] \Big/ \left[\overline{\frac{X_s^{Can}}{Y^s Y^{Can}}}\right]$$

where X_s^{Can} are exports from state s to Canada, and Y^{Can} is Canadian GDP. Like Φ_s, I construct Φ_s^{Can} using data from 1993.

[39] VOCs are a key precursor to ozone, meaning ozone regulations are a key determinant of VOC emissions (Greenstone, 2003).

[40] I obtain data on county non-attainment status from the EPA Green Book.

ferent pollutant. The first column in each panel (column (1)) reports my baseline estimates as a benchmark for comparison. Columns (2)-(4) report estimates that separately control for each of the shocks. The last column in each panel (column (5)) controls for all shocks simultaneously. As before, the standard errors are clustered by industry×state in all specifications.

As the table shows, the estimates for VOCs and PM are stable across specifications, suggesting the effects of NAFTA on the emissions of these pollutants are robust to controlling for other major economic shocks that occurred in the same time period. The estimates for Pb and Toxics are also robust to controlling for the Peso Crisis and CAAA, but are affected by controlling for the effects of CUSTFA. In particular, controlling for CUSTFA reduces the effect of increased access to the Mexican market for plants that produce Pb; the estimated coefficient reported in column (3) of Panel C implies a 35.04% decrease in Pb emissions for an average plant facing the average level of trade frictions. While this estimate is slightly smaller than those reported in Table 1.3, it still suggest that the reduction in Mexican trade barriers had a significant effect on the emissions of Pb. For plants that produce Toxics, controlling for CUSTFA alters both the magnitude and significance of the effect of decreased protection. The estimated coefficient reported in column (3) of Panel D indicates that the average increase in U.S. tariff preferences decreased the level of Toxic emissions from an average plant facing the average level of trade frictions by 11.61%.

1.5.2 Emission Intensity

Altogether, the results presented in section 1.5.1 suggest that NAFTA led to significant reductions in the levels of PM, Pb and Toxics emitted by affected manufacturing plants, but had little effect on the emissions of VOCs. In this section I examine the mechanisms driving these findings.

By definition, trade liberalization can affect the level of pollution emitted by a

Table 1.5: Pollution Emissions and Other Shocks

	Panel A: VOC				
	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	0.058	0.070	0.073	0.058	0.085
	(0.207)	(0.224)	(0.207)	(0.207)	(0.224)
$\tau_{jt}^{US-Mex} \times \Phi_s$	-0.023	-0.022	-0.067	-0.018	-0.060
	(0.593)	(0.592)	(0.633)	(0.593)	(0.633)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		-0.078			-0.070
		(0.216)			(0.217)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			0.400		0.411
			(1.044)		(1.042)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			0.553		0.554
			(1.325)		(1.326)
$\text{Nonattainment}_{it}$				0.015	0.025
				(0.054)	(0.054)
N	13632	13632	13480	13632	13480
R^2	0.27	0.27	0.27	0.27	0.27

	Panel B: PM				
	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-2.098^{c}	-2.141^{c}	-2.002^{c}	-2.111^{c}	-2.032^{c}
	(1.125)	(1.151)	(1.071)	(1.121)	(1.099)
$\tau_{jt}^{US-Mex} \times \Phi_s$	5.810	5.798	5.043	5.608	4.874
	(4.446)	(4.448)	(4.225)	(4.430)	(4.213)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		0.232			0.079
		(0.851)			(0.818)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			-2.449		-2.474
			(4.662)		(4.663)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			10.235		9.832
			(7.699)		(7.688)
$\text{Nonattainment}_{it}$				-0.222	-0.217
				(0.177)	(0.177)
N	4112	4112	4096	4112	4096
R^2	0.37	0.37	0.38	0.38	0.38

Notes: Table reports regressions of log pollution emissions on measures of protection from and access to the Mexican market and controls for other shocks. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

Pollution Emissions and Other Shocks (Continued)

	Panel C: Pb				
	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-5.271[a]	-5.415[a]	-4.000[b]	-5.373[a]	-4.041[a]
	(1.640)	(1.568)	(1.698)	(1.633)	(1.432)
$\tau_{jt}^{US-Mex} \times \Phi_s$	17.151	16.713	18.388	17.194	17.533
	(13.701)	(14.663)	(13.324)	(13.749)	(13.347)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		-0.473			-1.307
		(1.742)			(1.832)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			11.880		13.238
			(9.664)		(8.545)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			22.032		22.829
			(18.945)		(17.864)
$\text{Nonattainment}_{it}$				-0.043	-0.126
				(0.470)	(0.467)
N	608	608	608	608	608
R^2	0.73	0.73	0.73	0.73	0.73

	Panel D: Toxics				
	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-0.913	-1.080	-0.309	-0.903	-0.416
	(1.054)	(1.153)	(1.124)	(1.052)	(1.227)
$\tau_{jt}^{US-Mex} \times \Phi_s$	-5.124	-5.092	-7.351[c]	-4.960	-7.155[c]
	(3.614)	(3.600)	(3.866)	(3.527)	(3.761)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		0.671			0.512
		(0.797)			(0.790)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			3.698		3.927
			(11.045)		(6.075)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			20.828[c]		20.783[c]
			(11.504)		(11.591)
$\text{Nonattainment}_{it}$				0.125	0.148
				(0.272)	(0.267)
N	1736	1736	1736	1736	1736
R^2	0.48	0.48	0.48	0.48	0.48

Notes: Table reports regressions of log pollution emissions on measures of protection from and access to the Mexican market and controls for other shocks. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: [a] 1 percent; [b] 5 percent; [c] 10 percent.

plant through two channels: by altering the physical quantity of output produced, or by altering the emission intensity of production (the level of pollution produced per unit of output). The relative importance of these channels in determining the effects of trade liberalization cannot be separately identified through the examination of changes in pollution levels. To address this, I exploit the fact that each of the estimated βs reported in Tables 1.2 and 1.5 can be decomposed into two components: the change in emissions due changes in emission intensity and the change in emissions due to changes in the scale of output.[41] Both of these components can be estimated directly using my empirical approach. Hence, to distinguish between the two effects, I estimate the effect of NAFTA on emission intensity using an specification similar to equation (1.6):

$$\ln e_{ijst} = \gamma_1[\tau_{jt}^{Mex-US} \times \Phi_s] + \gamma_2[\tau_{jt}^{US-Mex} \times \Phi_s] + \rho_i + \mu_{jt} + \delta_{st} + \lambda_t + \varepsilon_{ijst} \qquad (1.8)$$

where $e_{ijst} = z_{ijst}/x_{ijst}$ is a measure plant i's emission intensity and γ_1 and γ_2 are the coefficients of interest. As before, identification requires that there be no unobserved industry×state specific shocks that are correlated with protection. The relative importance of changes in output and changes in emission intensity can be recovered by comparing the magnitudes of the estimated coefficients from equation (1.8) with the magnitudes of the corresponding estimates from equation (1.6).

Estimates of five different specifications based on equation (1.8) are reported in Table 1.6. Given that I do not observe physical output, in all cases I use the log emissions-sales ratio as the dependent variable. Each specification includes plant, year, industry×year and state×year fixed effects and reports standard errors that are clustered by industry×state.

---

[41] To see this, let x_{ijst} denote output from plant i at time t. Then, by definition emissions can be written as $z_{ijst} = e_{ijst} \times x_{ijst}$, where $e_{ijst} = z_{ijst}/x_{ijst}$ is the emission intensity of production. Partially differentiating log emissions with respect to any variable y yields:

$$\frac{\partial z_{ijst}/\partial y}{z_{ijst}} = \frac{\partial e_{ijst}/\partial y}{e_{ijst}} + \frac{\partial x_{ijst}/\partial y}{x_{ijst}}$$

where $(\partial z_{ijst}/\partial y)/z_{ijst}$, $(\partial e_{ijst}/\partial y)/e_{ijst}$, and $(\partial x_{ijst}/\partial y)/x_{ijst}$ are the percentage changes in emissions, pollution intensity and output due to a change in y.

The results presented in column (1) of each panel indicate that NAFTA is associated with significant reductions in the level of emissions per dollar of sales for PM, Pb and Toxics. For both PM and Pb, these changes are driven by increased access to the Mexican market. On the other hand, the reduction for Toxics is primarily due to decreased protection from Mexican competitors. Given the magnitude of the baseline estimates of equation (1.6) presented in Table 1.2, these results suggest that the decreases in emission levels documented above are primarily due to changes in emission intensity.

In each columns (2)-(5) of each panel, I examine the robustness of this finding to effects of the Mexican Peso Crisis, CUSFTA and the CAAA. As the table shows, the estimates for VOCs and PM are robust to each of these shocks. The estimates for Pb and Toxics are also stable across most specifications, but the inclusion of controls for changes in protection and market access due to CUSTFA leads to modest changes in the magnitudes of the estimated coefficients. Controlling for CUSTFA's effect reduces the magnitude of the effect of increased Mexican market access for plants that produce Pb. For Toxics, controlling for CUSTFA increases the magnitude of the effect of decreased protection from Mexican competitors. Despite these changes, the estimated effects remain statistically significant and negative for both pollutants.

A potential concern with using sales instead of value added to calculate emission intensity is that any changes in intensity that I observe may not be due to changes in production. To address this, I also employ log emissions per worker as the dependent variable because employment may be more closely tied to productive activity. These estimates are reported in Table 1.7. As in Table 1.6, column (1) of each panel reports baseline estimates of equation (1.8), while columns (2)-(5) control for the effects of the Mexican Peso Crisis, CUSFTA and the CAAA. As these results show, employing emissions per worker instead of the emissions-sales ratio does not affect the qualitative

Table 1.6: NAFTA and Emission Intensity

	Panel A: VOC				
	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-0.208	-0.197	-0.196	-0.208	-0.186
	(0.259)	(0.267)	(0.259)	(0.259)	(0.268)
$\tau_{jt}^{US-Mex} \times \Phi_s$	0.119	0.120	0.056	0.125	0.064
	(0.665)	(0.664)	(0.715)	(0.664)	(0.715)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		-0.068			-0.059
		(0.234)			(0.235)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			0.831		0.843
			(1.061)		(1.060)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			0.154		0.156
			(1.426)		(1.427)
$\text{Nonattainment}_{it}$				0.021	0.028
				(0.053)	(0.053)
N	13632	13632	13480	13632	13480
R^2	0.38	0.38	0.38	0.38	0.38

	Panel B: PM				
	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-2.156^c	-2.176^c	-2.031^c	-2.174^c	-2.035^c
	(1.135)	(1.168)	(1.060)	(1.127)	(1.090)
$\tau_{jt}^{US-Mex} \times \Phi_s$	6.457	6.451	5.466	6.157	5.221
	(4.561)	(4.562)	(4.299)	(4.531)	(4.275)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		0.108			-0.110
		(0.876)			(0.841)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			-2.791		-2.818
			(4.537)		(4.545)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			13.180^c		12.619
			(7.796)		(7.798)
$\text{Nonattainment}_{it}$				-0.329^c	-0.323^c
				(0.179)	(0.178)
N	4112	4112	4096	4112	4096
R^2	0.41	0.41	0.41	0.41	0.41

Notes: Table reports regressions of the log emissions-sales ratio on measures of the level of protection from and level of access to the Mexican market and controls for other shocks. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

NAFTA and Emission Intensity (Continued)

	Panel C: Pb				
	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-6.156^a	-6.122^a	-4.514^b	-6.154^a	-4.544^b
	(2.086)	(1.953)	(2.235)	(2.111)	(1.983)
$\tau_{jt}^{US-Mex} \times \Phi_s$	11.255	11.605	13.291	11.215	12.779
	(14.068)	(15.327)	(13.677)	(14.098)	(13.718)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		0.378			-0.746
		(2.257)			(2.501)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			16.492^c		17.192
			(9.879)		(10.776)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			24.302		24.660
			(24.102)		23.251
Nonattainment$_{it}$				0.040	-0.058
				(0.431)	(0.420)
N	608	608	608	608	608
R^2	0.75	0.75	0.76	0.75	0.76

	Panel D: Toxics				
	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-1.919	-1.977	-1.424	-1.917	-1.460
	(1.292)	(1.371)	(1.301)	(1.294)	(1.395)
$\tau_{jt}^{US-Mex} \times \Phi_s$	-7.020^c	-7.009^c	-8.895^b	-6.994^c	-8.850^b
	(3.780)	(3.783)	(4.141)	(3.752)	(4.137)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		0.236			0.162
		(0.814)			(0.808)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			1.124		1.158
			(5.843)		(5.828)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			20.502^c		20.502
			(12.383)		(12.399)
Nonattainment$_{it}$				0.020	0.032
				(0.292)	(0.288)
N	1736	1736	1736	1736	1736
R^2	0.52	0.52	0.52	0.52	0.52

Notes: Table reports regressions of the log emissions-sales ratio on measures of the level of protection from and level of access to the Mexican market and controls for other shocks. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

results significantly.

To quantify the magnitudes of the estimates reported in Tables 1.6 and 1.7, I calculate the percentage change in emission intensity for a hypothetical plant with average exposure to the Mexican market, that faces the average change in tariff preferences following NAFTA. These results are presented in Panels (A) through (D) of Table 1.8. In each case, I use the coefficients reported in column (5) in my calculations. For ease of comparison, Table 1.8 also includes the percentage change in emissions implied by the coefficients reported in column (5) of Table 1.5. In each panel, column (1) reports the percentage change in emissions, column (2) reports the percentage change in the emissions-sales ratio and column (3) reports the percentage change in emissions per worker.

These results indicate that emission intensity is the primary channel through which NAFTA affected plant pollution emissions. For PM, the percentage changes in the emissions-sales ratio and the level of emissions per worker due to increased Mexican market access are approximately the same magnitude as the percentage change in emissions. This suggests the entire decrease is due to changes in emission intensity. For Pb, increased Mexican market access decreased emission intensity by more than the observed change in emissions, suggesting that the reduction in emissions due to decreased intensity was partially offset by a 2.40-4.40% increase in the scale of production. A similar phenomenon occurred for Toxics; decreased protection reduced emission intensity by 13.98-15.50%, but only reduced emissions by 11.30%, suggesting the reduction in intensity was partially offset by a 2.68-4.20% increase in the scale of production.

In the context of the literature, these results are striking. While previous research has suggested that changes in emission intensity are an important determinant of how international trade affects the environment, these changes are usually motivated as

Table 1.7: NAFTA and Emissions Per Worker

	Panel A: VOC				
	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-0.086	-0.074	-0.073	-0.086	-0.062
	(0.261)	(0.269)	(0.261)	(0.261)	(0.270)
$\tau_{jt}^{US-Mex} \times \Phi_s$	-0.043	-0.042	0.110	-0.042	-0.107
	(0.665)	(0.664)	(0.720)	(0.665)	(0.720)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		-0.079			-0.071
		(0.233)			(0.234)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			0.922		0.927
			(1.097)		(1.096)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			0.287		0.287
			(1.456)		(1.456)
$\text{Nonattainment}_{it}$				0.002	0.011
				(0.054)	(0.054)
N	13632	13632	13480	13632	13480
R^2	0.29	0.29	0.29	0.29	0.29
	Panel B: PM				
	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-2.163^c	-2.212^c	-2.048^c	-2.181^c	-2.084^c
	(1.119)	(1.145)	(1.054)	(1.113)	(1.079)
$\tau_{jt}^{US-Mex} \times \Phi_s$	5.812	5.798	4.906	5.522	4.663
	(4.526)	(4.527)	(4.280)	(4.499)	(4.258)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		0.269			0.068
		(0.882)			(0.846)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			-3.011		-3.045
			(4.549)		(4.553)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			12.118		11.546
			(7.791)		(7.797)
$\text{Nonattainment}_{it}$				-0.317^c	-0.312^c
				(0.180)	(0.179)
N	4112	4112	4096	4112	4096
R^2	0.38	0.38	0.38	0.38	0.38

Notes: Table reports regressions of the log emissions per worker on measures of the level of protection from and level of access to the Mexican market and controls for other shocks. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

NAFTA and Emissions Per Worker (Continued)

Panel C: Pb	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-5.881^a	-5.845^a	-4.294^b	-5.880^a	-4.315^b
	(1.987)	(1.861)	(2.137)	(2.007)	(1.883)
$\tau_{jt}^{US-Mex} \times \Phi_s$	12.029	12.388	13.921	12.000	13.481
	(14.078)	(15.262)	(13.649)	(14.099)	(13.648)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		0.387			-0.675
		(2.265)			(2.554)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			15.630		16.335
			(10.101)		(11.053)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			23.758		24.174
			(24.317)		23.519
$\text{Nonattainment}_{it}$				0.029	-0.066
				(0.412)	(0.405)
N	608	608	608	608	608
R^2	0.71	0.71	0.72	0.71	0.72

Panel D: Toxics	(1)	(2)	(3)	(4)	(5)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-1.754	-1.812	-1.228	-1.750	-1.260
	(1.252)	(1.319)	(1.275)	(1.254)	(1.356)
$\tau_{jt}^{US-Mex} \times \Phi_s$	-7.885^b	-7.874^c	-9.892^b	-7.817^b	-9.813^b
	(3.825)	(3.829)	(4.134)	(3.785)	(4.115)
$\tau_{jt}^{Mex-US} \times \Phi_s \times \text{Crisis}_t$		0.233			0.167
		(0.810)			(0.799)
$\tau_{jt}^{Can-US} \times \Phi_s^{Can}$			0.681		0.793
			(5.780)		(5.750)
$\tau_{jt}^{US-Can} \times \Phi_s^{Can}$			22.724^c		22.696^c
			(12.648)		(12.701)
$\text{Nonattainment}_{it}$				0.052	0.063
				(0.294)	(0.289)
N	1736	1736	1736	1736	1736
R^2	0.48	0.48	0.49	0.48	0.49

Notes: Table reports regressions of the log emissions per worker on measures of the level of protection from and level of access to the Mexican market and controls for other shocks. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

Table 1.8: Changes in Emission Intensity due to NAFTA

	Panel A: VOC			Panel B: PM		
	(1)	(2)	(3)	(1)	(2)	(3)
Δ Mexico Tariff Preferences						
× Mean Φ_s	0.74	1.63	0.54	**-17.80**	**-17.83**	**-18.26**
Δ US Tariff Preferences						
× Mean Φ_s	0.09	0.10	-0.17	7.70	8.25	7.37
	Panel C: Pb			Panel D: Toxics		
	(1)	(2)	(3)	(1)	(2)	(3)
Δ Mexico Tariff Preferences						
× Mean Φ_s	**-35.40**	**-39.80**	**-37.80**	-3.64	12.79	11.04
Δ US Tariff Preferences						
× Mean Φ_s	27.70	20.19	21.30	**-11.30**	**-13.98**	**-15.50**

Notes: Table reports the changes in emissions (column (1)), the emissions-sales ratio (column (2)) and emissions per worker (column (3)) for with various levels of exposure to the Mexican market. See text for discussion of construction. Numbers in bold are statistically significant at the 10% level.

a response to income induced changes in environmental policy (e.g. Grossman and Krueger (1991) or Copeland and Taylor (1994)). My empirical approach controls for such changes through the inclusion of aggregate, industry-specific and state-specific trends. Hence, my results suggest that changes in environmental regulations are not necessary for plants to alter their emission intensities following trade liberalization.

1.5.3 NAFTA, Emission Intensity, and the Pollution Haven Hypothesis

My results demonstrate that the North American Free Trade Agreement reduced pollution emissions by causing plants to decrease the emission intensity of their production. While this finding is new, from the perspective of many commentators, it is perhaps unsurprising. Prior to the agreement it was often predicted that U.S. producers would respond to NAFTA by revamping their supply chains to take advantage of lax environmental regulation in Mexico, leading to a reallocation of dirty production abroad.[42]

---

[42] For example, in the 1992 presidential debates Ross Perot claimed that NAFTA would lead to a “giant sucking sound going south” as production relocated to Mexico to take advantage of low

This claim is simply an assertion of the pollution haven hypothesis, which predicts that trade liberalization will lead to the relocation of pollution intensive production from high income and stringent environmental regulation countries to low income and lax environmental regulation countries.[43] Like most of the debate over trade and the environment, the pollution haven hypothesis is typically framed in terms of industry responses to trade liberalization. However, these forces also apply at the plant level, as plants may relocate the dirty aspects of their production in response to trade liberalization. Moreover, the available evidence suggests that differences in environmental regulations are an important determinant of trade flows between the U.S. and Mexico (Levinson and Taylor, 2008). This suggests that my findings may be due to the reallocations predicted before the agreement. I now turn to examine this possibility to the extent permitted by the data.

Intermediate Inputs

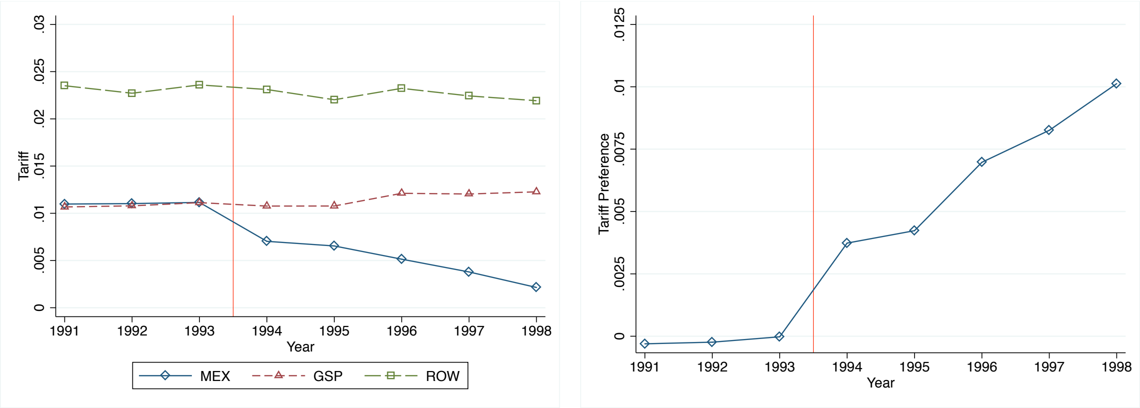
I begin by examining the role played by intermediate inputs. In addition to reducing the level of protection afforded to final goods, trade liberalization reduced the cost of intermediate inputs for U.S. producers. This would allow U.S. manufacturers to change their emission intensity by sourcing dirty intermediate goods from Mexico instead of producing them domestically. To investigate this channel, I supplement equation (1.8) to include a measure of the level of protection on intermediate inputs.

I measure protection on inputs for a plant in industry j located in state s as the product of U.S. tariff preferences on inputs (τ_j^{Int}) and the importance of trade with the Mexican market (Φ_s). Given that tariffs on intermediate inputs are not available in the data from Feenstra et al. (2002), I follow the approach of Amiti and Konings (2007) and construct input tariffs for each industry using data on output tariffs and

---

wages and weak environmental standards.

[43] In fact, the pollution haven hypothesis has its origins in the NAFTA debate. For an overview, see Taylor (2004).



(a) Tariffs on Intermediate Inputs

(b) Tariff Preferences for Intermediate Inputs from Mexico

Figure 1.8: Protection on Intermediate Inputs

cost shares. Doing so, the input tariff for industry j at any time t is given by:

$$t_{jt}^{Int} = \sum_{h} \theta_{hj} \times t_{jt}^{US} \tag{1.9}$$

where t_{jt}^{Int} and t_{jt}^{US} denote the U.S. ad-valorem tariffs on inputs and final goods in industry j at time t, and θ_{hj} is the cost share of input h in the total cost of output j from the Bureau of Economic Analysis's (BEA) benchmark input-output table for 1992. Hence, at any time t, U.S. tariff preferences on inputs sourced from Mexico are:

$$\tau_{jt}^{Int} = t_{jt}^{Int-GSP} - t_{jt}^{Int-Mex} \tag{1.10}$$

where, as before, the GSP rate is used as the relevant counterfactual for the level of protection that would have occurred in the absence of trade liberalization. These tariffs and the corresponding tariff preferences are illustrated in Figure 1.8.

The estimation results are presented in Table 1.9. In each panel, the dependent variable in columns (1) and (2) is the log of the emissions-sales ratio, while in columns (3) and (4) the dependent variable is the log of emissions per worker. Each specification also includes controls for the Mexican Peso Crisis, CUSFTA and the CAAA. In all cases the standard errors are clustered by industry×state.

Table 1.9: Emission Intensity and Intermediate Inputs

	Panel A: VOC			
	(1)	(2)	(3)	(4)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-0.186	-0.211	-0.062	-0.086
	(0.268)	(0.264)	(0.270)	(0.266)
$\tau_{jt}^{US-Mex} \times \Phi_s$	0.064	-0.378	-0.107	-0.533
	(0.715)	(0.579)	(0.720)	(0.585)
$\tau_{jt}^{US-Int} \times \Phi_s$		2.671		2.575
		(1.968)		(1.992)
N	13480	13480	13480	13480
R^2	0.38	0.38	0.29	0.29
	Panel B: PM			
	(1)	(2)	(3)	(4)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-2.035^c	-2.021^c	-2.084^c	-2.074^c
	(1.090)	(1.084)	(1.079)	(1.072)
$\tau_{jt}^{US-Mex} \times \Phi_s$	5.221	5.312	4.663	4.733
	(4.275)	(4.150)	(4.258)	(4.141)
$\tau_{jt}^{US-Int} \times \Phi_s$		-2.941		-2.248
		(8.434)		(8.339)
N	4096	4096	4096	4096
R^2	0.41	0.41	0.38	0.38

Notes: Table reports regressions of log pollution emissions on measures of the level of protection from and level of access to the Mexican market. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

Emission Intensity and Intermediate Inputs (Continued)

	Panel C: Pb			
	(1)	(2)	(3)	(4)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-4.544^b	-4.178^b	-4.315^b	-3.970^b
	(1.983)	(1.737)	(1.883)	(1.671)
$\tau_{jt}^{US-Mex} \times \Phi_s$	12.779	13.493	13.481	14.155
	(13.718)	(12.913)	(13.648)	(12.927)
$\tau_{jt}^{US-Int} \times \Phi_s$		17.848		16.849
		(19.184)		(19.131)
N	608	608	608	608
R^2	0.76	0.76	0.72	0.72
	Panel D: Toxics			
	(1)	(2)	(3)	(4)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-1.460	-1.627	-1.260	-1.378
	(1.395)	(1.345)	(1.356)	(1.314)
$\tau_{jt}^{US-Mex} \times \Phi_s$	-8.850^b	-8.663^b	-9.813^b	-9.682^b
	(4.137)	(3.939)	(4.115)	(3.980)
$\tau_{jt}^{US-Int} \times \Phi_s$		5.444		3.816
		(9.583)		(10.020)
N	1736	1736	1736	1736
R^2	0.52	0.52	0.49	0.49

Notes: Table reports regressions of log pollution emissions on measures of the level of protection from and level of access to the Mexican market. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

As Table 1.9 shows, the inclusion of protection on intermediate inputs ($\tau_{jt}^{US-Int} \times \Phi_s$) has little effect on the estimates. Furthermore, the estimated effect of a change in the level of protection on intermediate inputs is statistically insignificant in all cases. This suggests that plants are not systematically altering their emission intensity by splitting up the production process to source dirtier (or cleaner) inputs from Mexico in response to trade liberalization.

Product Switching

I also examine the role played by product switching. Recent research, such as Bernard et al. (2011), has suggested that trade liberalization may induce compositional changes within plants as producers alter their product mix. In the present context, this means U.S. manufacturers may be altering their emission intensity by switching to cleaner products as the production of dirty products is relocated to Mexico.

To investigate this possibility, I exploit the fact that the NETS data includes 8-digit SIC codes from Dunn and Bradstreet in addition to the standard 4-digit SIC codes. The 8-digit codes document the main activity at the plant at a much finer level of detail than the 4-digit codes in any given year.[44] I take a similar approach to Bernard et al. (2010) and treat each 8-digit SIC code within an industry as unique product category. This allows me to identify whether a plant is changing its main product category over time. To analyze these product switching decisions, I estimate the following linear probability model which is analogous to equations (1.6) and (1.8):

$$Switch_{ijst} = \alpha_1[\tau_{jt}^{Mex-US} \times \Phi_s] + \alpha_2[\tau_{jt}^{US-Mex} \times \Phi_s] + \rho_i + \mu_{jt} + \delta_{st} + \lambda_t + \varepsilon_{ijst} \quad (1.11)$$

where $Switch_{ijst}$ is an dummy variable indicating if plant i switches its main product

---

[44] For example, the 4 digit industry *"Industrial inorganic chemicals, Not Elsewhere Classified"* (SIC 2819) contains 101 unique 8 digit SIC categories.

Table 1.10: NAFTA and Product Switching

	VOCs		PM	
	(1)	(2)	(3)	(4)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-0.028	-0.034	0.102	0.138^c
	(0.029)	(0.030)	(0.082)	(0.079)
$\tau_{jt}^{US-Mex} \times \Phi_s$	-0.128^a	-0.160^b	-0.679^b	-0.702^b
	(0.048)	(0.065)	(0.343)	(0.352)
N	13632	13480	4112	4096
R^2	0.15	0.15	0.32	0.32
	Pb		Toxics	
	(5)	(6)	(7)	(8)
$\tau_{jt}^{Mex-US} \times \Phi_s$	0.378^c	0.515^c	0.024	0.051
	(0.201)	(0.277)	(0.068)	(0.094)
$\tau_{jt}^{US-Mex} \times \Phi_s$	-1.741^b	-0.731	-0.076	-0.139
	(0.724)	(1.173)	(0.277)	(0.254)
N	608	608	1736	1736
R^2	0.80	0.81	0.40	0.41

Notes: The odd-numbered columns report results from regressions of product switching on measures of the level of protection from and level of access to the Mexican market. The even-numbered columns also include controls for the Peso Crisis, CUSTFA and the CAAA. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{c} 10 percent; ^{b} 5 percent; ^{a} 1 percent.

category in year t, α_1 and α_2 are the parameters of interest and other variables are defined as before.[45]

The odd-numbered columns of Table 1.10 report baseline estimates of equation (1.11). These results indicate that decreased protection from import competition following NAFTA is associated with decreased product switching for affected plants that produce VOCs, PM and Pb. Given that this suggests plants are less likely to change their main product lines in response to NAFTA, these results are consistent with the findings of Liu (2010), who examines the relationship between trade and product switching by U.S. firms and shows that increased import competition causes

---

[45] I estimate equation (1.11) as a linear probability model instead of using a probit to avoid the incidental parameters problem arising from plant fixed effects.

Table 1.11: Emission Intensity and Product Switching

	Panel A: VOC			
	(1)	(2)	(3)	(4)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-0.186	-0.187	-0.062	-0.063
	(0.268)	(0.268)	(0.270)	(0.270)
$\tau_{jt}^{US-Mex} \times \Phi_s$	0.064	0.060	-0.107	-0.111
	(0.715)	(0.716)	(0.720)	(0.721)
Switch$_{it}$		-0.022		-0.029
		(0.040)		(0.040)
N	13480	13480	13480	13480
R^2	0.38	0.38	0.29	0.29
	Panel B: PM			
	(1)	(2)	(3)	(4)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-2.035^c	-2.014^c	-2.084^c	-2.058^c
	(1.090)	(1.086)	(1.079)	(1.075)
$\tau_{jt}^{US-Mex} \times \Phi_s$	5.221	5.114	4.663	4.532
	(4.275)	(4.266)	(4.258)	(4.248)
Switch$_{it}$		-0.152		-0.186
		(0.123)		(0.123)
N	4096	4096	4096	4096
R^2	0.41	0.42	0.38	0.38

Notes: Table reports regressions of log pollution emissions on measures of the level of protection from and level of access to the Mexican market. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

firms to focus on their core products. My results also indicate that increased access to the Mexican market is associated with increased product switching for plants that produce PM emissions.

In the even-numbered columns of Table 1.10 I examine the robustness of these findings to the effects of Peso Crisis, CUSTFA and the CAAA. Including controls for these shocks leads to moderate changes in the estimates for plants that produce PM and Pb. These estimates indicate that for plants that produce VOCs or PM, decreased protection reduced product switching by affected plants. The estimates also show that increased access to the Mexican market is associated with increased product switching for plants that produce PM and Pb. Together, these results suggest

Emission Intensity and Product Switching (Continued)

	Panel C: Pb			
	(1)	(2)	(3)	(4)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-4.544^b	-4.589^b	-4.315^b	-4.351^b
	(1.983)	(2.020)	(1.883)	(1.916)
$\tau_{jt}^{US-Mex} \times \Phi_s$	12.779	12.844	13.481	13.532
	(13.718)	(13.761)	(13.648)	(13.679)
Switch$_{it}$		0.089		0.069
		(0.253)		(0.254)
N	608	608	608	608
R^2	0.76	0.76	0.72	0.72

	Panel D: Toxics			
	(1)	(2)	(3)	(4)
$\tau_{jt}^{Mex-US} \times \Phi_s$	-1.460	-1.444	-1.260	-1.241
	(1.395)	(1.401)	(1.356)	(1.363)
$\tau_{jt}^{US-Mex} \times \Phi_s$	-8.850^b	-8.894^b	-9.813^b	-9.867^b
	(4.137)	(4.160)	(4.115)	(4.137)
Switch$_{it}$		-0.322		-0.386
		(0.303)		(0.296)
N	1736	1736	1736	1736
R^2	0.52	0.53	0.49	0.49

Notes: Table reports regressions of log pollution emissions on measures of the level of protection from and level of access to the Mexican market. All specifications include plant, year, industry×year and state×year fixed effects. Standard errors clustered by industry and state are reported in parentheses. Significance: ^{a} 1 percent; ^{b} 5 percent; ^{c} 10 percent.

that trade liberalization led to compositional changes at plants that produce VOCs, PM and Pb, which suggests the observed changes in emission intensity may be due to plants altering their product mix in response to NAFTA.

To check for this, I also estimate a version of equation (1.8) that includes an indicator for product switching in plant i at time t. If product switching is an important channel through which trade liberalization affects emission intensity, then controlling for it in equation (1.8) should significantly affect my results. The estimates presented in the even-numbered columns of Table 1.11 indicate this is not the case.

In each panel of Table 1.11, the dependent variable in columns (1) and (2) is the log emissions-sales ratio and the dependent variable in columns (3) and (4) is the log of emissions per worker. All specifications include controls for the Mexican Peso Crisis, CUSTFA and the CAAA and the standard errors are clustered by industry×state.

As the table shows, controlling for product switching has little effect on the results for any pollutant. Moreover, the estimated effect of product switching is insignificant in all cases. Given that NAFTA led to product switching by some plants, this suggests the switches did not have a significant effect on emission intensity. This provides further evidence that the observed changes in emission intensity are not driven by the reallocation of pollution intensive production to Mexico.

1.5.4 Summary and Discussion

The findings in this paper suggest that plant-level responses are an important determinant of how international trade affects the environment. My results show that NAFTA reduced the emissions of PM, Pb, and Toxics from affected plants. However, these results are not simply due to reductions in the scale of production; instead they are a result of plants reducing their emission intensity in response to trade liberalization. My research design ensures that these reductions are not due to concurrent changes in environmental regulations. Furthermore, there is little evidence that the reductions in the emission intensity of PM, Pb, and Toxics following NAFTA are due to the reallocation of dirty production to Mexico. These results suggest that the usual explanations are not responsible for the cleanup that I observe.

Instead, the reductions in emission intensity can be rationalized as a consequence of productivity improvements following trade liberalization. In models where pollution depends on plant productivity, such as that of Li and Shi (2012), equilibrium emission intensity is typically decreasing in productivity. Hence, an increase in plant productivity will lead to a reduction in the emission intensity of production in these settings. Moreover, there is a large body of work that finds trade liberalization increases productivity, both through the effects of increased import competition (e.g. Pavcnik (2002), Trefler (2004), Amiti and Konings (2007), Fernandes (2007), or Bloom et al. (2011)), and increased access to foreign markets (e.g. Verhoogen (2008), Lileeva and Trefler (2010), or Bustos (2011)). This suggests that the reductions in emission intensity that I observe for PM, Pb, and Toxics may be due to productivity improvements, but data limitations prevent me from examining this channel directly.[46]

Two additional points bear mention. First and foremost, it is worth emphasizing that this study examines the effects of an episode of North-South trade liberalization on the the pollution emitted by manufacturing plants in the North. The results presented here may not hold in the South due to differences in many factors, such as the enforcement of environmental policy. Similarly, episodes of North-North trade or South-South trade may have different effects on pollution emissions that are not captured in the present context.

Second, it is important to note that NAFTA may have had additional effects on U.S. pollution emissions that are not captured by my analysis. Given that I lack reliable information on plant entry and exit, my analysis focuses on a constant set of

---

[46] The NETS data does not include information on investment or capital, making it impossible to calculate productivity using standard methods.

plants from U.S. manufacturing. This means my results provide evidence about the effects of trade liberalization on the environment via the intensive margin. However, NAFTA may have also affected the environment via the extensive margin, as the agreement may have led to plant entry and exit. These extensive margin effects could potentially offset the intensive margin depending on whether clean or dirty firms are entering or exiting. Hence, while my results provide evidence that trade liberalization reduced emissions from some plants in the U.S., the question of whether or not NAFTA was good or bad for the environment remains open.

1.6 Conclusion

This paper contributes to a long standing debate over the environmental consequences of trade liberalization. To date, research has primarily focused on the relationship between trade and aggregate pollution levels. While these studies find that trade is not necessarily bad for the environment, they often appeal to the unmeasured responses of individual polluters, such as the adoption of new technologies or the exit of dirty plants, to explain the mechanisms underlying their findings. Yet, there has been little evidence of how trade liberalization affects the pollution from plants to date.

In this paper, I provide the first empirical evidence of how trade liberalization affects the pollution emitted by plants. My analysis examines how one of the most significant episodes of trade liberalization in history, the North American Free Trade Agreement (NAFTA), affected pollution emissions from U.S. manufacturing plants. I rely a unique longitudinal dataset containing detailed information on the emissions of volatile organic compounds, particulate matter, lead and toxic chemicals, as well as other plant characteristics. To identify NAFTA's effect, I employ a novel empirical approach that exploits variation in protection across time, industries and states.

I find that NAFTA had significant effects on the emissions of particulate matter, lead and toxic compounds. My results show that, for the average plant, trade liberalization reduced particulate matter emissions by close to 18%, lead emissions by close to 35% and Toxic emissions by 11%. I find that the decreases in emissions of lead and volatile organic compounds are primarily due to shifts towards lower emission intensities, as opposed to changes in the scale of plant output. Moreover, my empirical approach includes aggregate, industry-specific, state-specific trends that capture any significant changes in environmental regulations, meaning these findings are not due to contemporaneous changes in environmental policy. I also do not find any evidence that suggests that the changes in emission intensity are due to plant reallocating dirty production to Mexico.

Instead, my results can be explained as a result of productivity improvements following trade liberalization. In models where pollution depends on plant productivity, equilibrium emission intensity is typically decreasing in productivity, meaning an increase in plant productivity will lead to a reduction in the emission intensity of production. Recent research in trade has demonstrated that increased import competition and increased access to foreign markets following trade liberalization both lead to increased plant productivity. This suggests that the reductions in emission intensity that I observe for PM, Pb, and Toxics may be due to productivity improvements, but data limitations prevent me from examining this channel directly.

Chapter 2

Economic Growth, Industrialization, and The Environment

Published in Resource and Energy Economics,
Volume 24, Issue 4, November 2012, Pages 442-467

2.1 Introduction

Over the past thirty years, emissions levels of key industrial pollutants have decreased in the developed world, but have increased in developing countries. This observation, known as the Environmental Kuznets Curve (or EKC), has dominated how researchers and policy makers think about the relationship between economic growth and the environment.[1] While there have been many attempts to explain the EKC, existing theories have not come to grips with three other puzzling features of the data: (i) there has been a great deal of cross-country convergence in pollution emissions over time, (ii) there is substantial variation in the emission intensities (the level of emissions produced per unit of output) of industrial pollutants both over time and across countries and (iii) as a fraction of GDP, pollution abatement costs have been small and constant over time in the industrialized world.

This paper provides a theory of economic growth and the environment that explains these features of the data, and offers new testable implications. Specifically, the theory predicts cross-country convergence in pollution emissions as economies in-

---

[1] For recent overviews of the literature on economic growth and the environment, see Brock and Taylor (2005) and Xepapadeas (2005). For surveys specific to the empirical literature on the EKC, see Barbier (1997) and Stern (2004). Kijima et al. (2010) survey the theoretical literature on the EKC.

dustrialize. The empirical results in turn demonstrate the process of industrialization is a significant determinant of observed changes in sulfur emissions: a 1% increase in industry's share of total output is associated with an 11.8% increase in the level of emissions per capita.[2]

I develop a simple two-sector neoclassical model of economic growth and the environment in a small open economy in which growth is driven by a combination of capital accumulation and technological progress. The model features two goods, each of which is produced using a combination of capital and labor: a clean agricultural good, and a dirty industrial good that produces pollution as a joint output. I assume the agricultural good is consumed while the capital intensive industrial good is used in investment. I adopt a simple Solow-type framework with a fixed savings rate and abatement intensity. Technological progress in the production of goods and abatement is exogenous.

In this context, the compositional shift from agricultural to industrial production as an economy grows - industrialization - drives changes in pollution levels during the transition to the balanced growth path. Development begins with rapid economic growth as capital is accumulated and this growth increases emissions in two ways. With growth, more output is produced and this increase in the scale of production causes emissions to rise. As capital becomes relatively more abundant, the composition of output shifts towards pollution intensive industrial production, leading to a further increase in pollution emissions. At the same time, improvements in the techniques of production arising from ongoing technological progress in abatement work to lower emissions.

If growth is initially rapid, then compositional shifts towards industrial produc-

---

[2] In the context of the literature, this finding is striking: existing empirical work has shown compositional changes are typically responsible for decreases in emissions levels. See for example, Selden et al. (1999) or Bruvoll and Medin (2003). It is however, consistent with Antweiler et al. (2001), who find strong compositional effects for sulfur.

tion overwhelm technological progress in abatement, so emissions levels rise. As development proceeds, diminishing returns to capital cause growth and compositional changes to slow. Technological progress in abatement then occurs faster than emissions growth, so emissions levels fall.

Together, changes in the scale, composition and techniques of production during industrialization give rise to the EKC.[3] While this interaction explains why an EKC could arise, it is important to note that the EKC is not a necessary result. Whether an EKC is observed depends on the initial capital stock and rate of technological progress in abatement; moreover, even when EKC patterns are produced, they differ across countries. This finding is consistent with the evidence; the EKC is not a robust feature of the data.[4]

The process of industrialization does, however, generate convergence in cross-country emissions levels during the transition to the balanced growth path. Economy-wide diminishing returns to capital cause the scale and composition effects to decrease as capital accumulates. As a result, countries that differ only in their initial capital stock will exhibit convergence in pollution emission levels; the growth rate of pollution changes faster in poor countries than in rich countries. This takes place regardless of whether pollution levels are increasing or decreasing along the balanced growth path; and arises regardless of the trade pattern. Moreover, the model tells us that convergence occurs through industrialization. There is, in fact, considerable evidence of convergence in pollution emissions over time, both within and across countries.[5]

As development proceeds, and more of the industrial good is produced domestically, expenditures on pollution abatement increase. However, because of diminishing returns to capital the growth rate of pollution abatement costs falls as industrializa-

---

[3] Copeland and Taylor (1994) term these the *scale*, *composition* and *technique* effects.

[4] See, for example, Stern and Common (2001) and Harbaugh et al. (2002).

[5] See, for example, Strazicich and List (2003), Lee and List (2004), Aldy (2006), Bulte et al. (2007) and Brock and Taylor (2010).

tion occurs, meaning that growth rate of pollution abatement costs and income are roughly the same once an economy is industrialized. This fits with the data: the available evidence indicates that for members of the OECD, pollution abatement costs have been a small and constant fraction of GDP over time.[6]

To evaluate the theory, I log-linearize the model around the balanced growth path to derive an estimating equation linking emissions per capita in any period to emissions per capita in the previous period and additional controls.[7] These controls include typical determinants of the balanced growth path, such as the savings rate and population growth, but also include a measure of industrialization. I formulate the estimating equation as a dynamic panel data model and estimate it using the Least Squares with Dummy Variables (LSDV) estimator suggested by Islam (1995). This approach allows me to directly estimate the effect of industrialization on pollution levels and evaluate the testable restrictions implied by the theory.

I estimate the model using a unique panel data set obtained by combing data on sulfur emissions (Stern, 2006), with data on population, savings and income from the Penn World Tables (Heston et al., 2009), and data on sectoral composition from the World Bank's World Development Indicators. There are two reasons for using data on sulfur emissions. First, while sulfur emissions have been studied extensively in the context of the EKC, there is little support for an EKC type relationship in the data (Stern and Common, 2001; Harbaugh et al., 2002). Hence, little is known about what forces are driving changes in sulfur dioxide pollution across countries. The second reason for doing so is data availability. Sulfur is one of two pollutants (carbon dioxide being the other) for which there is data on emissions for a large number of countries over a substantial period of time. The data set is an unbalanced panel and

---

[6] See Table 2A of the 2006 OECD publication, "Pollution abatement and control expenditures in OECD countries", Paris: OECD Secretariat.

[7] This approach is commonly employed in the macroeconomics literature on income convergence. See, for example, Mankiw et al. (1992) and Islam (1995).

includes observations for 157 countries over the period 1970-2000.[8]

My main empirical results indicate that the process of industrialization is a significant determinant of observed changes in sulfur emissions. A 1% increase in industry's share of total output is associated with an 11.8% increase in the level of emissions per capita. This finding is robust to including unmodeled determinants of the balanced growth path, endogeneity caused by using a lagged dependent variable as a regressor, endogeneity caused by simultaneity, and restricting the sample to exclude outliers.[9]

This paper contributes to the literature on economic growth and the environment in three ways. First, it makes a theoretical contribution by developing a model of the EKC that explains other features of cross-country pollution data not considered before. Specifically, I explain why, over time: (i) there has been cross-country convergence in pollution emissions, (ii) there has been variation in emission intensities across countries, and (iii) pollution abatement costs have been a small and constant fraction of the GDP in the industrialized world. Most existing theories focus solely on explaining the inverted-U shaped relationship between income and pollution (see for example, Selden and Song (1994), Lopez (1994), John and Pecchenino (1994), Stokey (1998), and Andreoni and Levinson (2001)), but do not match other features in the data.

This paper also contributes to the theoretical literature by developing a simple model of economic growth and the environment that allows for composition effects. Although it has long been recognized economic growth can affect the environment through changes in the scale, composition and techniques of production, most theories have adopted a one good framework, which eliminates the possibility of compositional effects (see for example, Brock and Taylor (2010) or Criado et al. (2011)). While one

---

[8] The time period and the cross-country coverage was determined by data limitations imposed by the Penn World Tables and the World Development Indicators database.

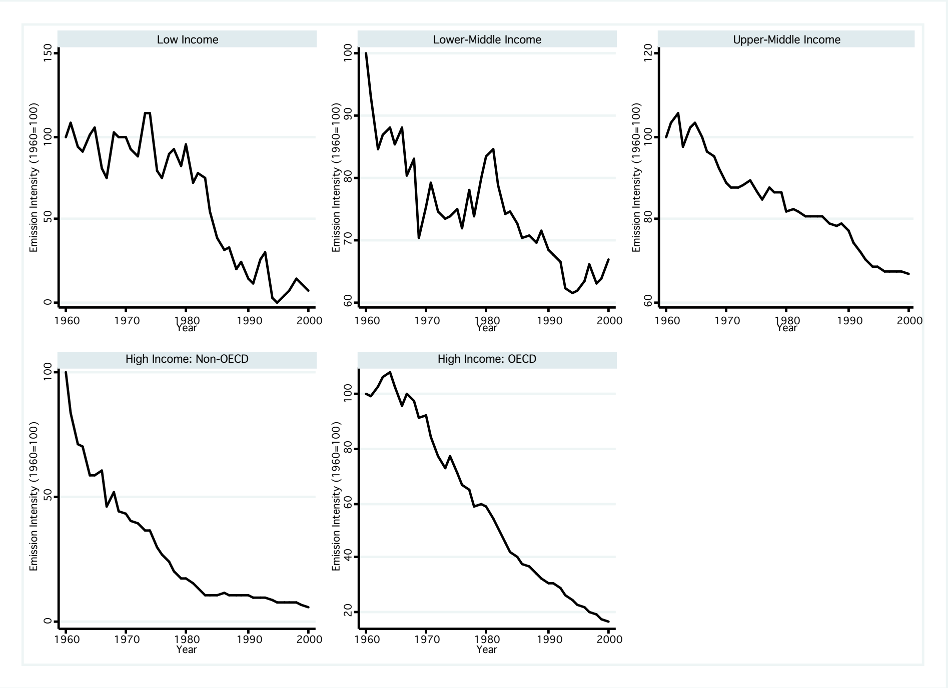
[9] To address the possibility of endogeneity arising from simultaneity or using a lagged dependent variable, I follow the approach taken by Caselli et al. (1996) in the income convergence literature and employ the generalized method of moments estimator of Arellano and Bond (1991).

good models may be useful for studying the behavior of pollutants that are produced by all or most economic activity (such as carbon dioxide), they may not be as useful for studying the behavior of other pollutants which are mainly produced by industrial processes tied to specific sectors. In these cases, sectoral shifts brought about by development may be critical to consider. Importantly, previous two-sector models of economic growth and the environment (such as Bovenberg and Smulders (1995, 1996)) have not explicitly examined how compositional changes affect environmental quality as an economy develops.

The third contribution of this paper is empirical. This paper is the first to examine cross country convergence in sulfur emissions using a dynamic panel model derived from theory. While many authors have previously examined the cross-country sulfur emissions data (see for example, Grossman and Krueger (1995), Stern and Common (2001), Harbaugh et al. (2002)), this study is the first to employ an empirical approach that is tied tightly to theory.

By introducing pollution into a simple neoclassical growth model, this paper bears close resemblance to the work of Brock and Taylor (2010). They develop an augmented version of the Solow model in which the EKC is generated through the interaction of scale and technique effects. In their one good model, emissions intensities decline at a constant rate over time. This means that their model is unable to explain the substantial variation in the emission intensities of industrial pollutants across time and countries, as depicted in Figure 2.1 for the case of sulfur emissions. Figure 2.1 plots sulfur emission intensities by income group over the period 1960-2000. Given that emission intensities are declining at a roughly constant rate for high income countries, and there is significant variation in emission intensities over time for low income countries that are currently in the process of industrializing, this figure suggests that the changes in emission intensity induced by industrialization are

Figure 2.1: Sulfur Emission Intensities by Income Group



an important mechanism driving changes in industrial pollutants.

This paper is also closely related to the work of Smulders et al. (2011). They develop a simple endogenous growth model in which an EKC is generated through changes in the scale, techniques and composition of production. Unlike the model presented here, in which the composition effect arises as capital accumulates, in their work the composition effect arises through changes in technology. This means that their model is unable to explain why there has been a great deal of cross-country convergence in pollution emissions over time or why pollution abatement costs have represented a small constant fraction of GDP over time in the industrialized world.

The rest of this paper proceeds as follows. Section 2 describes the model. Section 3 establishes its equilibrium and discusses pollution in the long run. Section 4 describes how the process of industrialization affects pollution. Section 5 outlines the empirical methodology and results. Section 6 concludes. Proofs to all propositions are included in the appendix.

2.2 A Model of Economic Growth and The Environment in a Small Open Economy

I develop a simple two sector neoclassical model of economic growth and the environment in a small open economy. The model imbeds a variant of the standard Heckscher-Ohlin model of international trade with pollution presented in Copeland and Taylor (2003) within the Solow (1956) model of economic growth. In this setup, there is no intertemporal optimization by agents in the economy; consumers save a fixed fraction of their income and consume the remainder, producers in each sector maximize their current profits at each point in time taking factor supplies as given, and the government collects the revenue from an exogenously set environmental tax which is rebated to consumers as a lump-sum. In this section I first describe the model's equilibrium at a point in time and then discuss growth. For convenience, time indices are suppressed throughout.

2.2.1 The Economy at a Point in Time

Production

The production side of the economy consists of two perfectly competitive sectors: agriculture and industry. The agricultural sector produces a consumption good, Y, while the industrial sector produces an investment good, X. Each good is produced by combining capital and effective labor using a strictly concave and constant returns to scale production function that satisfies the Inada conditions. Moreover, I assume industrial production is capital intensive and agricultural production is labor intensive at all factor prices.

Total agricultural production in the economy at a point in time is given by:

$$Y = H(K_Y, BL_Y) \tag{2.1}$$

where K_Y and L_Y denote the capital and labor used in agricultural production and B denotes the level of labor augmenting technology available in the economy. I assume that labor augmenting technology is common to both sectors.

Industrial production is dirty; that is, pollution, Z, is produced as a joint output. Following Copeland and Taylor (1994), I assume each unit of industrial activity, F, generates Ω units of pollution as a joint output. Industrial producers are, however, able to reduce their emissions by allocating a fraction, $\theta \in [0, 1]$, of their output to abatement activities. Abatement is a constant returns activity with the same factor requirements as the industrial activity F. With abatement, Ω can be interpreted as the level of abatement augmenting technology in the economy. The joint production technology is given by:

$$X = [1 - \theta]F(K_X, BL_X) \tag{2.2a}$$

$$Z = a(\theta)\Omega F(K_X, BL_X) \tag{2.2b}$$

where K_X and L_X denote the capital and labor used in industrial production and $a(\theta)$ is the abatement technology. I assume the abatement technology satisfies $a(0) = 1$, $a(1) = 0$ and $a'(\theta) < 0$, meaning the level of pollution decreases with abatement. In addition, I assume θ is constant, meaning that a constant fraction of industrial production is devoted to mitigating pollution at all points in time; this is the environmental analogue of the fixed saving assumption in the Solow (1956) model. In what follows, I assume the abatement technology takes the form $a(\theta) = [1 - \theta]^{1/\eta}$, with $\eta \in (0, 1)$.

At any point in time, producers in both sectors maximize their current period profits taking factor supplies as given. Hence, equilibrium in production at any point is determined by the full employment of factors and free entry given a set of prices. I assume factor markets are perfectly competitive and producers face prices r and w for capital and effective labor services. In addition, I assume both capital and labor are supplied inelastically and are perfectly mobile across sectors.

Let X be the numeraire and p denote the price of Y. Moreover, assume pollution is costly, so that firms face an environmental tax of $\tau > 0$ per unit of pollution emitted and that τ is sufficiently large for firms to actively abate. With the assumed functional form for abatement activities, the emission intensity of industrial production (the quantity of pollution produced per unit of industrial output) can be written as $e = \eta/\tau$, meaning industrial producers receive a net of abatement price of $1 - \eta$. The equilibrium conditions are then given by:

$$c^Y(w, r) = p \tag{2.3a}$$

$$c^X(w, r) = [1 - \eta] \tag{2.3b}$$

$$K = a_{KX}(w, r)X + a_{KY}(w, r)Y \tag{2.3c}$$

$$BL = a_{BLX}(w, r)X + a_{BLY}(w, r)Y \tag{2.3d}$$

where $c^Y(w, r)$ is the unit cost function for agricultural production, $c^X(w, r)$ is the unit cost function for industrial production, and $a_{KX}(w, r)$, $a_{BLX}(w, r)$, $a_{KY}(w, r)$ and $a_{BLY}(w, r)$ are the unit factor demands in the production of X and Y.[10] These conditions indicate that in equilibrium, unit costs are equal to the effective prices faced by producers in both sectors and all factors are fully employed. Given that X is, by assumption, more capital intensive than Y for all factor prices, equations (2.3a) and (2.3b) will intersect at most once, ensuring the equilibrium is unique.

Together equations (1) to (2.3d) characterize production in the economy at a point in time. For the sake of the analysis it is convenient, however, to re-express the production side of the economy in terms of a revenue function. Given the environmental tax, and the assumptions on markets and production, the production side of

---

[10] For further details on the equilibrium conditions and their derivation, see Copeland and Taylor (2004), chapter 2.

the economy can be represented with the revenue function:

$$R(p, \tau, K, BL) \equiv \max_{X,Y,Z} \{X + pY - \tau Z : (X, Y) \in T(K, BL, Z)\} \tag{2.4}$$

where $T(K, BL, Z)$ denotes the production possibility set given the factor supplies and production technologies available in the economy. The revenue function, $R(p, \tau, K, BL)$, is homogenous of degree one in prices and endowments.

Market Clearing

As in the standard Solow model, I assume a fixed fraction, s, of income is saved by consumers. The remainder is spent on the agricultural consumption good, Y. Consumer savings are used to purchase the industrial investment good X. Consumers own all factors of production within the economy, and the revenue from the environmental tax is rebated by the government to consumers in a lump-sum fashion. Hence, total income in the economy is given by the gross national product (GNP) function:

$$G(p, K, BL) = R(p, \tau, K, BL) + \tau Z \tag{2.5}$$

Like the revenue function, the GNP function $G(p, K, BL)$ is homogenous of degree one in prices and endowments. At any point in time, aggregate consumption and investment are given by:

$$C = (1 - s)G(p, K, BL)/p \tag{2.6a}$$

$$I = sG(p, K, BL) \tag{2.6b}$$

where $s \in (0, 1)$.

I assume that the economy is small and open, meaning that both goods are traded on international markets, but factors are not. Moreover, I assume prices are set by world markets and these prices are fixed, so producers and consumers face a constant relative price of p at all point in time.[11] Given equations (2.3a) to (2.3d), this means

---

[11] By assuming that the economy faces a constant world price, I am ruling out the possibility of changes in trade barriers over time. The effect of such changes on pollution in the current setup are analyzed in Cherniwchan (2010).

factor prices and factor demands are also constant over time when production is diversified and the economy produces both goods. I assume trade is balanced, and any excess demand or supply for X or Y is satisfied through international trade. This means:

$$C = Y + \bar{Y} \tag{2.7a}$$

$$I = X + \bar{X} \tag{2.7b}$$

where $\bar{X}$ and $\bar{Y}$ denote net imports of the agricultural good and industrial good from international markets. Because trade is balanced, equations (2.7a) and (2.7b) enable the economy to specialize in the production of agricultural or industrial goods or to produce output from both sectors; world prices determine the set of factor endowments for which production is diversified or specialized. Given world prices, specialization or diversification in production is determined by the levels of labor and capital available in the economy.

Aggregate Pollution Emissions

In this setup, aggregate pollution emissions at any point in time are determined by relative prices, factor supplies and the current state of technology. Let $\Phi(p, K, BL)$ denote the value share of industrial production in national income.[12] Aggregate emissions can then be written as:

$$Z = \tilde{a}\Omega\Phi(p, K, BL)G(p, K, BL) \tag{2.8}$$

where $\tilde{a} = a(\theta)/[1-\theta] = [1-\theta]^{(1-\eta)/\eta}$ is a constant. Hence, as in previous models of economic growth and the environment, aggregate emissions produced in the economy at any point in time are a function of both the techniques of abatement, $\tilde{a}\Omega$, and the scale of the economy, $G(p, K, BL)$. However, aggregate emissions also depend on the relative shares of agricultural and industrial production in national output,

---

[12] Note, $\Phi(p, K, BL) = X/G(p, K, BL)$, so $\Phi \in (0, 1)$.

$\Phi(p, K, BL)$, meaning pollution also depends on the composition of production in the economy. With fixed world prices, the composition of production is determined by the levels of capital, labor and technology in the economy.

2.2.2 Growth

I assume both population growth and labor-augmenting technological progress are exogenously given, with growth rates of $n > 0$ and $g_B > 0$ respectively. Following Brock and Taylor (2010), I also assume technological progress in abatement is exogenously given and lowers Ω at rate $g_A > 0$.[13]

Capital accumulates through aggregate investment and depreciates at rate δ. Hence, capital accumulation is given by:

$$\dot{K} = sG(p, K, BL) - \delta K \tag{2.9}$$

Given an initial value for K, the fixed world price p and exogenous technological change and population growth, equation (2.9) defines the dynamics of the economy.

2.2.3 The Model in Intensive Form

It is useful to reformulate the model in intensive form to facilitate the analysis. Recall the production and GNP functions are homogeneous of degree one in K and BL,

---

[13] With the assumed functional form for the abatement technology, θ can be written as $\theta = 1 - (\eta/\Omega\tau)^{\eta/(1-\eta)}$. Hence, the assumptions of fixed θ and decreasing Ω imply τ is increasing over time. This is consistent with reality: regulation of industrial pollutants has increased across the world since the early 1970s.

meaning the model can be rewritten as:

$$G(p,k) = x + py \tag{2.10a}$$

$$x = l_x[1-\theta]f(k_x) \tag{2.10b}$$

$$y = [1-l_x]h(k_y) \tag{2.10c}$$

$$k = l_x k_x + [1-l_x]k_y \tag{2.10d}$$

$$\dot{k} = sG(p,k) - [\delta + n + g_B]k \tag{2.10e}$$

$$z = \tilde{a}\Omega\phi(p,k)G(p,k) \tag{2.10f}$$

where $l_x \equiv L_x/L \in [0,1]$ is the share of labor in industrial production, k is capital per effective worker, $k_x \equiv K_X/BL_X$ and $k_y \equiv K_Y/BL_Y$ are the capital to effective labor ratios employed in industrial and agricultural production, x, y, and z are industrial production, agricultural production, and pollution per effective worker, $f(k_x)$, and $h(k_y)$ are the intensive form production functions, $G(p,k)$ is national income per effective worker and $\phi(p,k) \equiv l_x[1-\theta]f(k_x)/G(p,k)$ is the value share of industrial production in income.[14]

As in the Solow model, capital accumulation per effective worker depends on the difference between aggregate savings, $sG(p,k)$, and the effective depreciation rate $[\delta + n + g_B]$. Here, however, national income per effective worker depends on the allocation of factors across sectors. Moreover, given the equilibrium conditions in production, k_x and k_y are fixed by world prices.

---

[14] To see the relationship between ϕ and Φ, note: $\Phi(p,K,BL) = X/G(p,K,BL) = [1-\theta]F(K_x,BL_x)/G(p,K,BL)$. Given $G(p,K,BL)$ is homogenous of degree one in endowments and $F(K_x,BL_x)$ is constant returns to scale, we have $[1-\theta]F(K_x,BL_x)/G(p,K,BL) = [BL_x/BL][[1-\theta]F(K_x/BL_x,1)/G(p,K/BL,1)]$. Define $\phi(p,k) = l_x[1-\theta]f(k_x)/G(p,k)$. Hence $\phi(p,k) \equiv \Phi(p,K,BL)$.

2.3 Pollution and Long-Run Growth

Growth in the economy is determined by capital accumulation, population growth and exogenous technological progress. Moreover, with diminishing returns to capital and fixed world prices, the economy converges to a unique balanced growth path in the long run, regardless of initial conditions.

Proposition 1. *Given any initial stock of capital per effective worker, $k_0 > 0$, and fixed world price, p, the economy converges to a unique stable balanced growth path.*

On the balanced growth path, national income, consumption all grow at rate $n + g_B$. However, the composition of production along the balanced growth path is dependent on the specific features of the economy. Given the correspondence between X and Z, this means the long-run behavior of emissions also depends on the economy's attributes.

For any fixed world price, the composition of production in the long run depends on the level of capital per effective worker in the economy along the balanced growth path. Note that the national income function can be rewritten as:

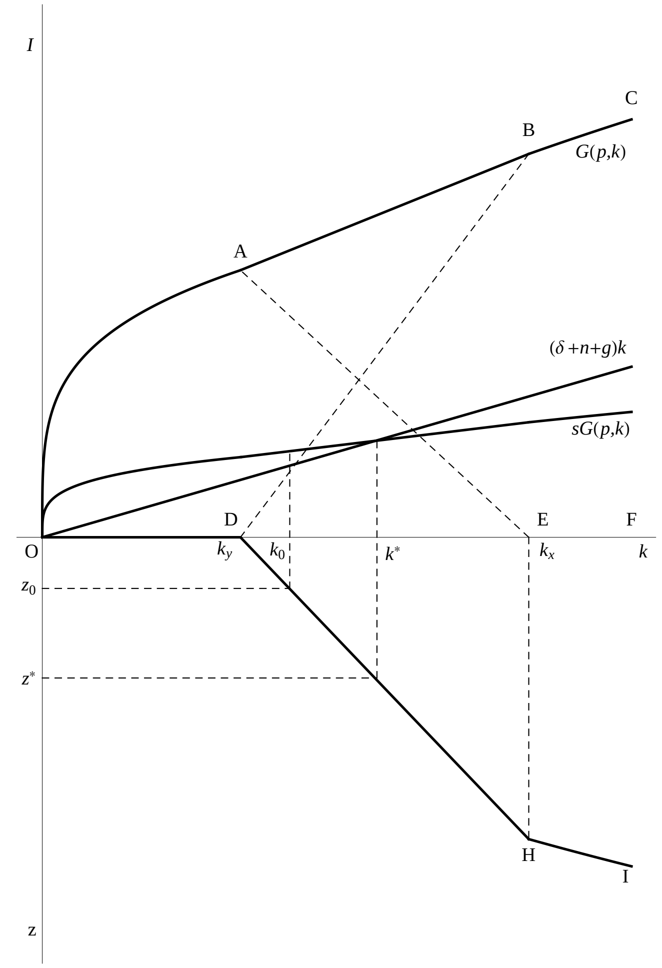
$$G(p,k) = \begin{cases} ph(k) & \text{if } k \leq k_y \\ \gamma_x[1-\theta]f(k_x) + [1-\gamma_x]ph(k_y) & \text{if } k \in (k_y, k_x) \\ [1-\theta]\, f(k) & \text{if } k \geq k_x \end{cases} \tag{2.11}$$

where $\gamma_x = [[k - k_y]/[k_x - k_y]]$ and $k_x > k_y$.[15] Hence, if the capital stock is sufficiently low and $k \leq k_y$ the economy specializes in agricultural production. Similarly, if the capital stock is sufficiently high and $k \geq k_x$ the economy specializes in industrial production. Finally, if $k \in (k_y, k_x)$ production is diversified and the economy produces both goods. Importantly, this means the value share of agriculture in national output is falling and the value share of industrial production is rising as k increases.

---

[15] It is important to note that with a fixed world price, k_x and k_y are constant over time. This occurs because a fixed world price means factor demands are constant over time when the economy is diversified.

Figure 2.2: The Geometry of Growth and Pollution



This can be seen in Figure 2.2, which depicts the relationship between production and the level of capital per effective worker, using the diagrammatic techniques suggested by Deardorff (1974). This diagram summarizes the economy in terms of capital per effective worker for a given p and fixed level of the abatement technology. In the diagram, the GNP function is given by the line $OABC$. The domestic production of x is given by the line $ODBC$ and the domestic production of y valued in terms of x is given by the line $OAEF$. The level of pollution produced for the given level of the abatement technology is given by the line $ODHI$.

Clearly, the production pattern of the economy depends on the level of capital per effective worker. This is governed by capital accumulation. From equation (2.10e), for any level of k, a fraction s of national income is saved and used to purchase industrial output for the creation of new capital, while a portion of the existing capital stock per effective worker depreciates at rate $[\delta + n + g_B]$. The difference between savings and depreciation determines the growth of k. Let k^* denote the equilibrium level of k; that is, let k^* denote the level of k for which the growth rate of k equals zero. If $k < k^*$, investment exceeds the rate of depreciation and the capital stock per effective worker must grow over time; conversely, if $k > k^*$, depreciation exceeds investment and the capital stock per effective worker must be declining. If $k = k^*$, investment equals depreciation, and the economy is on a balanced growth path. This is depicted in Figure 2.2 as the intersection of the savings $(sG(p,k))$ and effective depreciation $([\delta + n + g_B]k)$ curves.

The composition of production in the long run depends on the savings rate and the effective rate of depreciation. If the effective rate of depreciation is sufficiently high, or the savings rate is sufficiently low, $k^* \leq k_y$ and the economy specializes in agricultural production along the balanced growth path. Conversely, if savings are sufficiently high, or depreciation is sufficiently low, $k^* \geq k_x$ and the economy specializes in industrial production along the balanced growth path. If $k^* \in (k_y, k_x)$, the economy will produce both goods in the long run, but the relative shares of agricultural and industrial production in total output depend on parameters. In what follows, I restrict attention to the case where the economy is diversified and assume $k^* \in (k_y, k_x)$. It is important to note the compositional changes associated with industrialization play no role in the long run as the composition of production is fixed on the balanced growth path.

When the economy is diversified on the balanced growth path, the growth rate of aggregate emissions, g_Z, is given by $g_Z = n + g_B - g_A$. In the long run, pollution emissions will increase if output growth outstrips the rate of improvement in abatement technology, that is, if $g_A < n + g_B$. Similarly, pollution emissions will decrease in the long run if $g_A > n + g_B$, and technological progress in abatement occurs faster than output growth. I focus on the case where $g_Z < 0$, meaning growth is sustainable in the long run.[16]

2.4 Industrialization and Pollution

I assume the economy is initially endowed with a level of capital per effective worker that is smaller than its level along the balanced growth path; that is, I assume $k_0 < k^*$ as depicted in Figure 2.2. In this case, saving in the economy exceeds the effective rate of depreciation and growth is generated through a combination of capital accumulation and technological progress as the economy transitions towards the balanced growth path. Moreover, capital accumulation leads to industrialization. As the economy grows and capital is accumulated, the relative supply of capital to labor increases. Given industrial production is more capital intensive than agricultural production and the economy is open, this causes the industrial sector to expand and the agricultural sector to contract.[17] Hence, the value share of industrial output increases as the capital stock increases, and the economy industrializes as the economy grows. This change in the composition of production continues until the economy reaches the balanced growth path.

2.4.1 Industrialization and the EKC

If the economy is on the balanced growth path, the growth rate of aggregate pollution is determined by the underlying fundamentals of the economy (the rate of popula-

---

[16] If $g_Z > 0$, pollution emissions would grow without bound. This is at odds with the available evidence; as indicated by Brock and Taylor (2010), the emissions of NO_X, SO_X, CO and $VOCs$ peaked in the US and much of Europe by the mid 1990s.

[17] This effect is similar to the Rybczynski theorem from the Heckscher-Ohlin model of international trade.

tion growth, and the rates of technological progress for both labor and abatement-augmenting technologies respectively). During the transition to the balanced growth path, deviations from this rate occur as capital accumulates.

When the economy is off the balanced growth path, the growth rate of aggregate pollution emissions can be written as:

$$\frac{\dot{Z}}{Z} = -g_A + \frac{\dot{\phi}(p,k)}{\phi(p,k)} + \left[\frac{\dot{G}(p,k)}{G(p,k)} + n + g_B\right] \tag{2.12}$$

where $\dot{Z}/Z$ is the growth rate of aggregate pollution emissions, g_A is the growth rate of technological progress in abatement, $\dot{\phi}(p,k)/\phi(p,k)$ is the growth rate of the value share of industry in national income and $\dot{G}(p,k)/G(p,k)$ is the growth rate of national income per effective worker.[18] The growth rate of pollution depends on the long run trend, but varies with changes in both the size of the economy and the composition of national output as the economy industrializes. Scale and composition are both functions of the stock of capital per effective worker in the economy; this means the transitional behavior of aggregate emissions will be determined by the growth rate of capital per effective worker.[19] Moreover, the transitional changes in scale and composition depend explicitly on the magnitude of the economy's initial capital stock relative to its level on the balanced growth path. As a result, the time path of aggregate emissions is not necessarily monotonic and the process of industrialization can generate an EKC.

Proposition 2. *Assume growth is sustainable, so $g_Z < 0$. Then there exists some*

---

[18] Using the terminology of Copeland and Taylor (1994), the terms on the left hand side of (2.12) are the *technique effect* (g_A), the *composition effect* ($\dot{\phi}(p,k)/\phi(p,k)$) and the *scale effect* ($\dot{G}(p,k)/G(p,k) + n + g_B$). The technique effect captures the change in pollution that arises from a change in abatement technology. The composition effect reflects the effect of a change in the mix of production on pollution levels. The effect of a change in the size of the economy on emissions is captured by the scale effect. It is useful to note the scale effect is comprised of two elements; the long-run component, ($n + g_B$), which is driven by technical change in production and population growth and the short-run component ($\dot{G}(p,k)/G(p,k)$), which is driven by capital accumulation during the transition to the balanced growth path.

[19] Note (2.12) can be rewritten as $\dot{Z}/Z = g_Z + [\varepsilon_{\phi k} + \varepsilon_{Gk}][\dot{k}/k]$, where $\varepsilon_{\phi k} = [\partial\phi(p,k)/\partial k][k/\phi(p,k)]$ and $\varepsilon_{Gk} = [\partial G(p,k)/\partial k][k/G(p,k)]$ are the elasticities of composition and output, respectively.

$k^p < k^*$ such that for $k_0 < k^p$, aggregate emissions peak necessarily during the transition to the balanced growth path. If $k_0 \geq k^p$, aggregate emissions decline monotonically as the economy approaches the balanced growth path.

To see the intuition for this result, consider an economy that is initially endowed with a very low level of capital (that is, suppose $k_0 < k^p$). With a low level of capital, the economy is relatively labor abundant; with fixed world prices, this means the economy initially has a comparative advantage in the production of agricultural goods. As a result, most factors are employed in agricultural production and little industrial production occurs. Because the economy is open to trade, some of the agricultural production is consumed while the rest is exported. These exports are used to finance purchases of industrial goods from international markets, which increases the capital stock and makes capital relatively more abundant. This stimulates industrialization; with the increase in capital factors are drawn out of agriculture and into industry, increasing the domestic production of industrial goods. As capital accumulates, more factors are drawn out of agriculture and into industry, furthering industrialization.

The process of industrialization increases emissions in two ways: (i) through increases in the scale of production as more output is produced, and (ii) through shifts in the composition of output towards pollution intensive industrial production as capital becomes relatively more abundant. At the same time improvements in the techniques of production from ongoing technological progress in abatement work to lower emissions.

Initially, changes in the scale and composition of production from industrialization overwhelm technological progress in abatement, causing emissions levels to rise. As development proceeds, diminishing returns to capital causes these changes to slow, meaning technological progress in abatement occurs faster than emissions growth, so emissions levels fall. This process yields the EKC.

While it has long been recognized economic growth can affect the environment through changes in the scale, composition and techniques of production, compositional changes have, for the most part, been ignored in the existing theoretical literature.[20] Instead, most theories adopt a one good framework which eliminates the possibility of compositional effects.[21] While one-good models may be useful for the study of pollutants that are produced by most economic activity (such as carbon dioxide), they may not be as useful for studying the behaviors of other pollutants, which are mainly produced by industrial processes tied to specific sectors. In these cases, sectoral shifts brought about by development are critical to consider; a one good framework will obscure the mechanisms driving changes in emissions.

It is also important to note the EKC is not a necessary result; the existence of the EKC depends both on the particulars of technology and the initial endowment of capital per effective worker. Moreover, even when an EKC is produced, it is not unique path.[22] This is consistent with the empirical evidence; as Stern and Common (2001) and Harbaugh et al. (2002) demonstrate, the EKC is not a robust feature of the data.

---

[20] The exceptions to this are the "Sources of Growth" analysis presented in Copeland and Taylor (2003), Ch. 3, where compositional changes are driven by changes in the factor that is accumulated and the work of Smulders et al. (2011) where compositional changes are driven by changes in technology.

[21] See, for example, Lopez (1994), John and Pecchenino (1994), Stokey (1998), Andreoni and Levinson (2001), Brock and Taylor (2010) and Criado et al. (2011).

[22] To see this, consider two countries that differ only in their initial level of the abatement technology. If the two countries differ only in their initial abatement technology, emissions in each country must peak at the same level of capital per effective worker, k^p. However, the peak level of emissions in each country will not be the same; the country with the better initial abatement technology will have lower emissions. If, instead, the two countries share the same initial level of abatement technology, but differ in size, the economy that is larger will have greater emissions everywhere, even though the two countries could have the same level of capital per effective worker at all points in time.

2.4.2 Convergence

While it does not yield an EKC necessarily, the process of industrialization does generate convergence in the level of pollution emissions across countries.

Proposition 3. *Suppose Country A and Country B differ only in their initial endowment of capital per effective worker, and suppose Country A is initially endowed with a higher level of capital per effective worker; that is, suppose* $k_0^A > k_0^B$. *Then, pollution emissions levels in Country A and Country B will converge as economies industrialize.*

This finding offers a simple explanation for observed changes in pollution emissions over time.[23] As capital accumulates, changes in the composition and scale of the economy cause the domestic supply of the industrial good to increase, increasing pollution. Diminishing returns to capital cause these increases to slow, meaning pollution levels approach their long run trend as the economy industrializes.[24] As a result, countries that only differ in their initial endowment of capital per effective worker will exhibit convergence in pollution emissions levels; the growth rate of pollution emissions will change faster in poor countries than in rich countries.

The compositional changes created by industrialization play a key role in determining the path of emissions during convergence because the level of pollution is tied directly to the level of output in the industrial sector. This means the scale effect does not fully capture the effects of growth on pollution; industrial output grows faster than national income during the transition to the balanced growth path, so the emission intensity of production also depends on the composition of national output.

---

[23] A number of authors have documented convergence in pollution: see, for example, Strazicich and List (2003), Lee and List (2004), Aldy (2006), Bulte et al. (2007) and Brock and Taylor (2010).

[24] Convergence occurs regardless of whether pollution levels are increasing or decreasing on the balanced growth path.

The emission intensity of production in the economy is given by:

$$\frac{Z}{G} = \tilde{a}\Omega\phi(p,k) \tag{2.13}$$

Given the production functions in each sector and world prices, $\phi(p,k)$ is determined by the saving rate, the rate of effective depreciation and the initial levels of labor-augmenting technology and the capital stock. Similarly, Ω is determined by the initial level and growth rate of the abatement technology and $\tilde{a}$ is determined by the fraction of output allocated to abatement. If economies differ in these parameters or in their initial conditions, then the emission intensity of industrial production will vary across time and countries, which matches a key feature of the data.

Convergence also implies that pollution abatement costs will account for a constant fraction of output as an economy industrializes and approaches its balanced growth path. As an economy grows and domestic industrial production increases, pollution abatement expenditures increase. However, because of diminishing returns to capital, the growth rate of pollution abatement costs falls as industrialization occurs. This means the growth rate of pollution abatement costs and national income are roughly the same once an economy is industrialized. This corresponds with the available data: in the OECD, pollution abatement costs have been a small and constant fraction of GDP over time.

2.4.3 Trade, Industrialization, and Pollution

Given that the economy is small and open, international trade facilitates the industrialization process by allowing the composition of production to change as the economy develops. This occurs because the pattern of trade is determined by the stock of capital per effective worker. As growth occurs and the economy transitions to the balanced growth path, national income increases resulting in an increase in the domestic demand for industrial production. At the same time, capital accumulation causes the industrial sector to expand and the agricultural sector to contract, increasing the domestic supply of industrial goods. The growth of the industrial sector outpaces the increase in the domestic demand for its products, meaning that net exports of the industrial good increase. Hence, for a sufficiently low level of capital, the economy can transition from an importer to an exporter of industrial goods as it develops.

To see this, suppose that the economy is initially endowed with the stock of capital per effective worker given by k_0 in Figure 2.2. At this point, the domestic demand for industrial production (given by the line $sG(p, k)$) exceeds the domestic supply (given by the line $ODBC$), meaning the economy is initially importing industrial goods. Moreover, because $k_0 < k^*$, the economy is growing and the capital stock per effective worker is increasing over time. As the economy grows, it remains an importer of industrial products until domestic demand equals domestic supply (given by the intersection of $sG(p.k)$ and $ODBC$ in Figure 2.2). After this point, domestic supply exceeds domestic demand and the economy becomes an exporter of industrial production.

While international trade facilitates the industrialization process, changes in the pattern of trade are not a necessary condition for changes in environmental quality as a country industrializes. When the economy is diversified, capital accumulation increases the domestic supply of industrial goods more than domestic demand. This means the trade pattern can only change via industrialization in cases when the economy is endowed with a low level of capital per effective worker and initially imports industrial goods; if the economy is initially a net exporter of industrial production, capital accumulation simply increases the net exports of the industrial good. However, even if the economy initially imports industrial goods, a change in the trade pattern does not affect capital accumulation. Given that pollution emissions are determined by the offsetting forces of capital accumulation and technological progress in abatement, this means that a change in the trade pattern will not affect pollution. Although international trade is often viewed as means to improve environmental quality by allowing dirty domestic production to be replaced with imports from international markets (Copeland and Taylor, 2004), this suggests that trade need not function as an abatement mechanism for pollution to fall as economies develop if technological progress in abatement is sufficiently high.

2.4.4 Discussion

In the model, growth increases emissions by shifting the composition of production from agriculture to industry. This means the composition effect always leads to an increase in emissions. In reality, this effect may be offset by further compositional changes as the economy transitions from industrial production to cleaner sectors such as services or finance. This transition could be captured in the model by allowing for a third sector that is more capital intensive than industrial production at all factor prices, but does not pollute (or pollutes less). With the addition of this third sector, a second compositional effect would arise that would work to offset the compositional changes induced by industrialization. However, since my focus is on the transition between agricultural and industrial production, modeling an additional sector is beyond the scope of this paper.

2.5 Empirical Evidence

The model contains two empirical predictions about convergence in emissions. If all countries share parameter values (and share balanced growth paths), then all countries converge to the same level of pollution emissions per capita and the model predicts *Absolute Convergence in Emissions per capita* (ACE). If, instead, countries are heterogeneous, the model predicts *Conditional Convergence in Emissions per capita* (CCE), meaning that any two countries will converge to the same level of pollution emissions per capita only if they share the same parameter values. In either case, convergence will also depend on the extent of industrialization.

2.5.1 Estimating Equation

To evaluate the theory's predictions about convergence, I log-linearize the model around the balanced growth path to derive an estimating equation linking emissions per capita in any period to emissions per capita in the previous period and additional controls. Doing so yields the following:[25]

$$\begin{aligned}
\ln z^c(t_1) = {} & \left[1 - \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1 - e^{-\lambda[t_1 - t_0]}]\right] \ln z^c(t_0) \\
& + \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1 - e^{-\lambda[t_1 - t_0]}] \ln \phi(t_0) \\
& + \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1 - e^{-\lambda[t_1 - t_0]}] \ln G^* \\
& + \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1 - e^{-\lambda[t_1 - t_0]}][\ln \tilde{a} + \ln \Omega(0) + \ln B(0)] \\
& + [t_1 - t_0]\left[-g_A + g\left[1 + \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1 - e^{-\lambda[t_1 - t_0]}]t_0\right]\right]
\end{aligned} \tag{2.14}$$

where $z^c(t)$ denotes emissions per capita in period t, $\phi(t)$ is the value share of industrial production in national output, $\varepsilon_{\phi k}$ and ε_{Gk} are the elasticities of composition and output with respect to the capital stock, G^* is the level of income per effective worker on the balanced growth path, $B(0)$ and $\Omega(0)$ are the initial levels of the production and abatement technologies, and $\lambda = [1 - \varepsilon_{Gk}][\delta + n + g]$ is the speed of convergence.

From equation (2.14), it is readily apparent that pollution emissions per capita are increasing in the level of pollution emissions per capita in the previous period. However, $\left[1 - [(\varepsilon_{\phi k} + \varepsilon_{Gk})/\varepsilon_{Gk}]\,[1 - e^{-\lambda[t_1 - t_0]}]\right] < 1$, meaning that pollution emissions are converging, ceteris paribus. This convergence occurs as the economy industrializes;

---

[25] The derivation is given in the appendix.

the level of pollution emissions per capital is increasing in the initial value share of industrial output in national income.

Equation (2.14) also indicates how differences in both initial conditions and endpoint affect emissions during convergence. Clearly, an increase in an economy's endowment of the production technology (an increase in $B(0)$), or a decrease in the initial effectiveness in the abatement technology (an increase in $\Omega(0)$) increases the level of emissions. Similarly, a decrease in the economy's level of income per effective worker on the balanced growth path (a decrease in G^*) will lower the level of emissions.

If it is assumed all countries share the same balanced growth path and there is ACE, $[[\varepsilon_{\phi k}+\varepsilon_{Gk}]/\varepsilon_{Gk}]\,[1-e^{-\lambda[t_1-t_0]}][\ln G^*+\ln\tilde{a}+\ln\Omega(0)+\ln B(0)]$ is a time-invariant individual country effect. In the conventional notation of the panel data literature, this equation can be rewritten as:

$$\ln z^c_{i,t} = \beta_1 \ln z^c_{i,t-\tau} + \beta_2 \ln \phi_{i,t-\tau} + \eta_i + \mu_t + \epsilon_{i,t} \tag{2.15}$$

where

$$\begin{aligned}
\beta_1 &= \left[1-\left[\frac{\varepsilon_{\phi k}+\varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1-e^{-\lambda[t-\tau]})\right] < 1\\
\beta_2 &= \left[\frac{\varepsilon_{\phi k}+\varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1-e^{-\lambda[t-\tau]}] > 0\\
\eta_i &= [[\varepsilon_{\phi k}+\varepsilon_{Gk}]/\varepsilon_{Gk}]\,[1-e^{-\lambda[t-\tau]}][\ln G^*+\ln\tilde{a}+\ln\Omega(0)+\ln B(0)]\\
\mu_t &= [t-\tau]\left[-g_A+g\left[1+\left[\frac{\varepsilon_{\phi k}+\varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1-e^{-\lambda[t-\tau]}]\tau\right]\right]
\end{aligned}$$

and ϵ_{it} is a transitory error term with mean zero. These conditions imply $\beta_1+\beta_2=1$

If instead countries are assumed to be heterogenous and there is CCE, the time-invariant individual country effect is given by $[[\varepsilon_{\phi k}+\varepsilon_{Gk}]/\varepsilon_{Gk}]\,[1-e^{-\lambda[t_1-t_0]}][\ln\tilde{a}+\ln\Omega(0)+\ln B(0)]$. In this case, equation (2.14) can be rewritten as:

$$\ln z^c_{i,t} = \beta_1 \ln z^c_{i,t-\tau} + \beta_2 \ln \phi_{i,t-\tau} + \beta_3 \ln G^*_{i,t-\tau} + \eta_i + \mu_t + \epsilon_{i,t} \tag{2.16}$$

where

$$\begin{aligned}
\beta_1 &= \left[1 - \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1 - e^{-\lambda[t-\tau]}]\right] < 1 \\
\beta_2 = \beta_3 &= \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1 - e^{-\lambda[t-\tau]}] > 0 \\
\eta_i &= [[\varepsilon_{\phi k} + \varepsilon_{Gk}]/\varepsilon_{Gk}]\,[1 - e^{-\lambda[t-\tau]}][\ln\tilde{a} + \ln\Omega(0) + \ln B(0)] \\
\mu_t &= [t-\tau]\left[-g_A + g\left[1 + \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right][1 - e^{-\lambda[t-\tau]}]\tau\right]\right]
\end{aligned}$$

and ϵ_{it} is again a transitory error term with mean zero.

With data on G^*, equation (2.16) could be estimated directly. Unfortunately, such data is not available. To circumvent this problem, I proxy for G^* using observable determinants of the balanced growth path: the savings rate, s, and the rate of population growth, n.[26] The model can then be rewritten as:

$$\ln z^c_{i,t} = \beta_1 \ln z^c_{i,t-\tau} + \beta_2 \ln\phi_{i,t-\tau} + \beta_3 \ln s_{i,t} + \beta_4 \ln(\delta + n + g_B)_{i,t} + \eta_i + \mu_t + \epsilon_{i,t} \quad (2.17)$$

where β_1, β_2, β_3, η_i, μ_t, and $\epsilon_{i,t}$ are defined as before, $\beta_1 + \beta_2 = 1$, and $\beta_3 = -\beta_4$.

By rewriting (2.14) in the form of (2.15) or (2.17), it is natural to think of the time-invariant individual country effect as a fixed effect. While many approaches are available to estimate panel models with fixed effects, here I borrow from the income convergence literature and follow the approach of Islam (1995) and use a Least Squares with Dummy Variables (LSDV) estimator.[27]

---

[26] Strictly speaking, G^* also depends on the depreciation rate, δ, the rate of technology, g_B and the world price p, which are unobserved. To deal with the unobservability of δ and g_B, I follow Mankiw et al. (1992) and assume $\delta + g_B = 0.05$. In principle, G^* may also depend on unmodeled determinants of the balanced growth path, such as human capital levels, inequality or openness to trade. I test the robustness of my findings to such factors in section 5.4.

[27] Caselli et al. (1996) are critical of this approach in the context of income convergence because of possible problems arising from having a lagged dependent variable or endogenous regressors on the right hand side. To address these issues, they advocate using the generalized methods of moments estimator of Arellano and Bond (1991). In section 5.4, I employ this estimator to test the robustness of my findings.

2.5.2 Data

I estimate equations (2.15) and (2.17) using data on sulfur emissions. There are two reasons for doing so. First, while sulfur has been studied extensively in the context of the EKC, there is little support for an EKC type relationship in the data (Stern and Common, 2001; Harbaugh et al., 2002). Hence, little is known about what forces are driving changes in sulfur pollution across countries. The second reason for doing so is data availability. Sulfur is one of two pollutants (carbon dioxide being the other) for which there is data on emissions for a large number of countries over a substantial period of time.

The data set was constructed by combining the sulfur emissions data from Stern (2006) with data from the Penn World Tables (Heston et al., 2009) and the World Bank's World Development Indicators. The data set is an unbalanced panel that includes annual data on real income, investment, population, sectoral composition and sulphur emissions for 157 countries over the period 1970-2000.[28] I measure s as the average share of real investment in real GDP, n as the annual population growth rate, z^c as the level of sulphur emissions divided by population size, and ϕ as the value share of industrial output in GDP.[29]

2.5.3 Results

To test whether sulfur dioxide emissions are converging as economies industrialize, I estimate various specifications of both equation (2.15) and equation (2.17). These estimation results are presented in Table 1.

Table 2.1 reports estimates of equations (2.15) and (2.17). Columns (1) and (2) report estimates of ACE, while columns (3) and (4) report estimates of CCE. In each case, the first specification ignores compositional changes, while the second includes

---

[28] The time period and the cross-country coverage was determined by data limitations imposed by the Penn World Tables and the World Development Indicators database.

[29] Summary statistics are given in the appendix.

Table 2.1: Industrialization and Convergence

Variable	(1)	(2)	(3)	(4)
$\ln z^c_{t-1}$	0.8565^a	0.8487^a	0.8563^a	0.8488^a
	(0.0546)	(0.0567)	(0.0545)	(0.0565)
$\ln \phi_{t-1}$	-	0.1211^b	-	0.1177^b
	-	(0.0501)	-	(0.0493)
$\ln s_t$	-	-	0.0327^b	0.0236^c
	-	-	(0.0141)	(0.0140)
$\ln(\delta + n + g_B)_t$	-	-	0.0416	0.0492
	-	-	(0.0589)	(0.0608)
Observations	3625	3625	3625	3625
Countries	157	157	157	157
R^2	0.9705	0.9708	0.9708	0.9709

Note: Robust standard errors are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the 1%, 5% and 10% levels respectively. In all cases, the dependent variable is the level of sulfur dioxide emissions in the current period. In all cases, the entire sample was used. All specifications also include time dummies.

the lagged value share of industrial output in GDP. These results support the theory's prediction of convergence as industrialization occurs. In all four specifications, the coefficient on lagged emissions per capita is less than one, which is consistent with convergence in per capita pollution emissions. More importantly, in columns (2) and (4), the lagged share of industrial production in GDP is statistically significant and has the sign predicted by theory. This means convergence coincides with changes in the sectoral composition of the economy. Moreover, the restriction $\beta_1 + \beta_2 = 1$ cannot be rejected in either case, providing further support for the model.

These results also provide evidence on the nature of convergence. If convergence in emissions per capita is absolute and countries are homogeneous, determinants of the balanced growth path level of income per capita should not be statistically significant. Given columns (3) and (4), this is not the case; the coefficient on the savings rate is statistically significant and of the expected sign and magnitude. While effective depreciation is not statistically significant because it is imprecisely measured, the restriction $\beta_3 = -\beta_4$ cannot be rejected and the coefficients are jointly significant.

This indicates convergence is conditional on country specific characteristics, meaning two countries will converge to the same level of emissions per capita only if they have the same savings rate, s, and effective depreciation rate, $(\delta + n + g_B)$.

All together, the magnitudes and significance of the estimated coefficients on lagged pollution per capita and the lagged share of industrial production in GDP, and the joint significance of savings and effective depreciation indicate the model fits the data well. This suggests the process of industrialization posited here is a key driver of cross country variation in sulfur dioxide emissions.

The importance of industrialization in determining emissions can be seen clearly from column (4). These coefficient estimates indicate industrialization has a much larger effect on pollution levels than either savings or effective depreciation. For example, a 1% increase in industry's share of total output is associated with a 11.8% increase in the level of emissions per capita, whereas a 1% increase in the savings rate is only associated with a 2.4% increase in the level of emissions per capita. This suggests policies that alter the composition of production (such as industrial subsidies) will have much larger direct effects on the environment than policies that affect economic growth (such as increases in savings rates).

2.5.4 Robustness

Taken together, the estimates presented in Table 2.1 are indicative of CCE as economies industrialize. Tables 2.2-2.4 document the robustness of this finding to omitted variable bias, endogeneity arising from using a lagged dependent variable as a regressor, endogeneity caused simultaneity, and outliers in the sample.

While the estimates reported in Table 2.1 include the observable determinants of the balanced growth path suggested by the model, G^* may also depend on unmodeled factors, leading to omitted variable bias. This may be a valid concern given that previous studies of economic growth and the environment have shown that charac-

Table 2.2: Conditional Convergence in Emissions: Other Determinants of the Balanced Growth Path

Variable	(1)	(2)	(3)	(4)	(5)	(6)
$\ln z^c_{t-1}$	0.8488^a	0.8478^a	0.8206^a	0.8053^a	0.7969^a	0.8339^a
	(0.0565)	(0.0550)	(0.0699)	(0.0682)	(0.0630)	(0.0698)
$\ln \phi_{t-1}$	0.1177^b	0.1286^a	0.1429^b	0.1126^b	0.2318^a	0.2062^a
	(0.0493)	(0.0468)	(0.0577)	(0.0466)	(0.0885)	(0.0764)
$\ln s_t$	0.0236^c	0.0505^a	0.0377^b	0.0305^b	0.0338^c	0.0356^c
	(0.0140)	(0.0194)	(0.0175)	(0.0138)	(0.0177)	(0.0191)
$\ln(\delta + n + g_B)_t$	0.0492	0.0388	-0.0365	0.0098	-0.0933^c	-0.0594
	(0.0608)	(0.0621)	(0.0663)	(0.0364)	(0.0491)	(0.0802)
$Openness_t$	-	-0.0014^b	-	-	-	
	-	(0.0006)	-	-	-	-
$No\ School_t$	-	-	-0.0032	-	-	-
	-	-	(0.0022)	-	-	-
$School\ Years_t$	-	-	0.0275	-	-	-
	-	-	(0.0233)	-	-	-
$PolityIV_t$	-	-	-	0.0010	-	-
	-	-	-	(0.0014)	-	-
$Gini_t$	-	-	-	-	0.0016	-
	-	-	-	-	0.0012	-
$Hardcoal\ Supply_t$	-	-	-	-	-	0.0486
	-	-	-	-	-	(0.0726)
Observations	3625	3625	3139	3287	2324	2808
Countries	157	157	129	141	131	124
R^2	0.9709	0.9685	0.9616	0.9736	0.9751	0.9674

Note: Robust standard errors are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the 1%, 5% and 10% levels respectively. In all cases, the dependent variable is the level of sulfur dioxide emissions in the current period and the entire sample was used. All specifications also include time dummies.

teristics such as education and inequality (Torras and Boyce, 1998), and openness to trade (Frankel and Rose, 2005) are significant determinants of pollution emissions as countries develop. Furthermore, previous studies have also shown that the political system (Farzin and Bond, 2006) and domestic coal supply (Antweiler et al., 2001) are significant determinants of sulfur emissions. If they are significant determinants of the balanced growth path, omitting any of these factors will mean the estimates reported in Table 2.1 are biased.

To investigate this possibility, Table 2.2 reports estimates of equation (2.17) that include other possible determinants of the balanced growth path. Column (2) includes a measure of trade openness, while column (3) includes two measures of education. Column (4) includes a measure of the political regime and column (5) includes a measure of inequality. Finally, column (6) includes a measure of the domestic supply of coal per capita. For ease of comparison, column (1) restates the estimates for the full sample reported previously in column (4) of Table 2.1.[30]

Adding additional controls does not appear to affect the results significantly. With the exception of openness in column (2), the estimated coefficients for the additional controls are statistically insignificant in all specifications.[31] More importantly, the additional controls do not affect the estimated effect of industrialization. The estimated coefficient on the lagged value share of industry in national output is statistically significant and the expected sign in all specifications. The estimated coefficient increases in magnitude in columns (5) and (6), but the number observations drops substantially for these specifications, suggesting this is attributable to sample selection. Furthermore, the restriction $\beta_1 + \beta_2 = 1$ cannot be rejected in any specification. Altogether, the results presented in Table 2.2 suggest that omitted factors are not driving the results.

---

[30] See the appendix for further details on the source and construction of each determinant.

[31] While the individual coefficients are insignificant, the measures of education presented in column (3) are jointly significant at the 10% level.

Two other concerns related to omitted variable bias are the issues of endogeneity arising from using a lagged dependent variable as a regressor and endogeneity arising from simultaneity. As shown by Nickell (1981), within group estimates from dynamic panel models (such as those from the LSDV approach) can be biased because of endogeneity arising from having a lagged dependent variable on the right hand side of equation (2.17). Moreover, it is possible that some regressors, such as the rate of population growth, are simultaneously determined with the level of pollution emissions per capita, causing the estimates to be biased. To address these issues, I follow the approach taken by Caselli et al. (1996) in the income convergence literature and employ the generalized method of moments estimator of Arellano and Bond (1991).[32]

The results from this approach are presented in Table 2.3. For comparison, Column (1) restates the main results previously reported in Table 2.1. Column (2) reports results using triple lags as instruments for the lagged dependent variable in equation (2.17).[33] In this case, the estimated effect of industrialization increases by just over 7 percentage points, suggesting industrialization may have a larger effect than previously reported. Furthermore, the estimated coefficient on lagged per capita pollution emissions decreases by nearly ten percentage points, but the restriction $\beta_1 + \beta_2 = 1$ cannot be rejected. The estimated coefficients on savings and effective depreciation become statistically insignificant, but they are imprecisely estimated and the restriction $\beta_3 + \beta_4 = 0$ still holds. Together, these findings suggest that endogeneity arising from using a lagged dependent variable as a regressor may be influencing the results and causing the effect of industrialization to be understated.

This conclusion hinges on the lagged dependent variable being the only source

---

[32] This approach uses a combination of first-differencing and instrumental variables within a GMM framework to deal with the endogeneity problems described above.

[33] It is important to note that the p-values from the Arrelano-Bond test for second-order autocorrelation in the differenced residuals are less than 0.1 in the specifications reported in columns (2) and (3). This is evidence of first-order autocorrelation in levels and it suggests that double lags are not valid instruments. Hence, I employed triple lags as instruments in both cases.

Table 2.3: Conditional Convergence in Emissions: Addressing Endogeneity

Variable	(1)	(2)	(3)
$\ln z^c_{t-1}$	0.8488^a	0.7369^a	0.8233^a
	(0.0565)	(0.0949)	(0.1176)
$\ln \phi_{t-1}$	0.1177^b	0.1915^a	0.1170^c
	(0.0493)	(0.0748)	(0.0640)
$\ln s_t$	0.0236^c	-0.0057	0.0119
	(0.0140)	(0.0711)	(0.0559)
$\ln(\delta + n + g_B)_t$	0.0492	-0.0064	-0.1523
	(0.0608)	(0.1322)	(0.1749)
Hansen J Test		[0.16]	[0.13]
AR(2) Test		[0.08]	[0.09]
AR(3) Test		[0.28]	[0.27]
Observations	3625	3463	3463
Countries	157	156	156
R^2	0.9709		

Note: Robust standard errors are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the 1%, 5% and 10% levels respectively. In all cases, the dependent variable is the level of sulfur dioxide emissions in the current period and entire sample was used. All specifications also include time dummies.

of endogeneity. If other regressors are simultaneously determined with the level of pollution emissions per capita, the estimates in column (3) will still be biased. To deal with this issue, the specification reported in column (3) repeats the exercise reported in column (2), but also instruments for the savings rate and effective depreciation rate to account for endogeneity arising from simultaneity between per capita pollution emissions and the determinants of the balanced growth path. In this case, the estimated effects of industrialization and lagged pollution emissions per capita are similar to those reported in column (1). The estimated coefficient on savings decreases by one percentage point, while the estimated coefficient decreases by twenty percentage points. Although the coefficients on savings and effective depreciation are insignificant because they are imprecisely estimated, these results indicate that simultaneity between population growth and pollution per capita, and not dynamic panel bias, is affecting the results. This is unsurprising given that dynamic panel bias

Table 2.4: Conditional Convergence in Emissions: Outliers

Variable	(1)	(2)	(3)	(4)	(5)
$\ln z^c_{t-1}$	0.8488^a	0.8498^a	0.7296^a	0.6259^a	0.9671^a
	(0.0565)	(0.0599)	(0.0757)	(0.0818)	(0.0170)
$\ln \phi_{t-1}$	0.1177^b	0.1201^b	0.1976^b	0.1721^b	-0.0169
	(0.0493)	(0.0532)	(0.0766)	(0.0710)	(0.0724)
$\ln s$	0.0236^c	0.0271^c	0.0381^c	0.0630^b	0.0786^b
	(0.0140)	(0.0153)	(0.0216)	(0.0254)	(0.0321)
$\ln(\delta + n + g_B)$	0.0492	0.0613	0.0256	0.0789	-0.2434^b
	(0.0608)	(0.0643)	(0.0565)	(0.0668)	(0.0964)
Observations	3625	2246	2563	1873	690
Countries	157	146	108	83	25
R^2	0.9709	0.9704	0.9665	0.9535	0.9860

Note: Robust standard errors are reported in parentheses. ^{a}, ^{b}, and ^{c} indicate significance at the 1%, 5% and 10% levels respectively. In all cases, the dependent variable is the level of sulfur dioxide emissions in the current period. All specifications also include time dummies. Column 1 employs the entire sample. Column 2 eliminates OPEC members. Column 3 excludes OPEC members, countries with a population less than a million and countries that received a grade of D from the PWT. Columns 4 and 5 divide the sample from column 3 into Non-OECD and OECD members, respectively.

becomes small with many periods of data. Moreover, it suggests that the estimates presented in Table 2.1 may be overstating the effect of savings but understating the effect of effective depreciation on pollution emissions per capita.

A final concern is whether the results are driven by outliers in the sample. To address this, I constructed 4 subsamples using common restrictions from the income convergence literature and re-estimated equation (2.17) using each sample.[34] These results are presented in columns (2)-(5) of Table 2.4. Column (2) eliminates OPEC members from the sample as oil extraction is the primary source of income in these countries. Column (3) excludes countries with a population less than one million as well as countries that received a grade of "D" from the Penn World Tables as measurement error is likely to be a greater problem for these countries. Column (4) limits the sample from column (3) to Non-OECD countries while column (5) limits

---

[34] See, for example, Mankiw et al. (1992). The countries in each sample are listed in the appendix.

it to members of the OECD. Column (1) restates the estimates for the full sample reported previously in Table 2.1.

From Table 2.4, it appears that restricting the sample to exclude certain country groups does not affect the results significantly. As shown in column (2), eliminating OPEC members from the same has little effect on the estimates, suggesting the results are not driven by oil producing countries. Restricting the sample further to exclude small countries and countries with poor data reporting (column (3)) increases the estimated coefficient on the lagged value share of industrial production in GDP. This suggests that the main finding reported in column (1) may understating the true effect of industrialization on pollution.

The results of further dividing the sample from column (3) into developing Non-OECD (column (4)) and highly industrialized OECD (column (5)) countries are also consistent with the predictions of the theory. The theory predicts changes in the composition of output will have the largest effect on pollution emission at the start of industrialization. This means compositional changes will have the largest effect in developing countries, but little to no effect when countries are highly developed. Hence, the finding that the coefficient on the lagged value share of industrial output in GDP is statistically significant for Non-OECD countries (column (4)), but insignificant for OECD countries (column (5)) is unsurprising.[35]

2.6 Conclusion

This paper presented a simple two-sector model of neoclassical growth in a small open economy to investigate the relationship between growth and environmental outcomes. Most existing research in this area has come through the lens of the EKC, but existing

---

[35] A similar pattern emerges if the sample is divided into low income and high income countries using standard classifications from the World Bank. In this case, compositional changes are a significant determinant of emissions per capita for low income countries, but not for high income countries.

theories have not come to grips with three relevant features of the data: (i) there has been a great deal of cross-country convergence in pollution emissions over time, (ii) there is substantial variation in the emission intensities of industrial pollutants across both over time and across countries, and (iii) pollution abatement costs have been a small and constant fraction of GDP in the industrialized world. This paper provides a theory of growth and the environment that also explains these other features.

The theory showed how the EKC can arise during the transition from agricultural production to industrial production as economies develop. As countries develop and accumulate capital, pollution levels increase as a result of increases in the scale of production as more output is produced, and through shifts in the composition of output towards pollution intensive industrial production. Initially these increases overwhelm the pollution reducing effect of technological progress. As development proceeds and diminishing returns to capital set in, growth and compositional changes slow; as a result technological progress in abatement occurs faster than emissions growth and emissions levels fall. Such changes in scale, composition and technique as countries industrialize generate an EKC.

Although the theory showed why an EKC could arise through industrialization, it is not a necessary result. Instead the theory predicted cross country convergence in emissions as economies industrialize. To evaluate this prediction I derived an estimating equation directly from the theory by log-linearizing the model around the balanced growth path. The empirical results showed that the process of industrialization is a significant determinant of observed changes in sulfur emissions, supporting the theory's prediction: a 1% increase in industry's share of total output is associated with an 12% increase in the level of emissions per capita.

Chapter 3

Tariff Structure, Trade Expansion and Canadian Protectionism from 1870-1910

Joint with Eugene Beaulieu

3.1 Introduction

The conventional view among economic historians is that Canada's trade policy became protectionist and had large efficiency costs following the National Policy tariff of 1879. Pomfret (1993) suggests that the welfare losses associated with the Canadian tariff were greater than 4%-8% of GDP during this period. There are two important problems with the evidence supporting this view. First, it relies almost exclusively on the import-weighted average tariff (AWT) as a measure of protection.[1] This is problematic because the AWT does not accurately reflect the true level of protection or capture the structure of the tariff, meaning the case for protectionism may be overstated.[2] Second, the welfare implications of the tariff are not directly measured from data, but are instead inferred from estimates from later periods based on changes in the AWT over time.[3] As a result, we do not know how restrictive, or how costly,

---

[1] Other measures that have been employed include the effective rate of protection, the coefficient of variation of tariffs and the non-tariff-barrier coverage ratio. Of these, the AWT is the most commonly employed because it is easily calculated from aggregate data by dividing the value of total duties collected by the value total imports.

[2] As Irwin (2010) points out, the AWT suffers from four key limitations that make it a poor measure of the level and welfare costs of protection: (i) it is downward biased; (ii) it ignores dispersion in duties across goods, causing welfare costs to be understated; (iii) it lacks any economic interpretation; and (iv) it does not reflect the impact of non-tariff barriers on trade. For further discussion of the problems associated with using the AWT and other common measures of protection, see Anderson and Neary (2005).

[3] Young (1957), Wonnacott and Wonnacott (1967) and Harris and Cox (1984) estimate the costs of trade policy in the 1950s, 1960s and 1980s respectively. These estimates provide the basis for inference in earlier periods. The typical logic used in this inference is as follows: the AWT was

Canadian trade policy was at the end of the 19th century.

The purpose of this paper is to analyze the level and costs of Canadian trade policy at the turn of the 19th Century using theoretically consistent measures of protection and welfare loss. To do so, we employ the Anderson-Neary Trade Restrictiveness Index (TRI) to measure protection.[4] The TRI is an index measure equal to the uniform tariff, that if applied to all goods, would yield the same welfare level as the existing tariff structure. Moreover, it provides us with a simple means for calculating the static welfare losses associated with trade policy. This makes it possible compare the level, and costs of trade policy across time using an approach that is consistent with theory.

The conventional view of history, based on the AWT, also posits that the National Policy tariff established the protectionist structure of the tariff for the next 50 years. Although this interpretation may be correct, it is difficult to reconcile this view with the continued importance of the tariff as the main source of government revenue. Moreover, it is impossible to infer how protectionist a given trade policy is based on the AWT because a high AWT is consistent both with high levels of protection for certain commodities and high tariffs on non-competing import goods meant to maximize government revenue. In order to make inferences about how protectionist the tariff policy is, we compute the TRI for broad commodity classes and show how the structure of protection changed over time.

The shift to protectionism at this time was not a uniquely Canadian phenomenon. Indeed, the end of the 19th century witnessed a shift to higher tariffs around the globe as many countries moved from revenue tariffs to protectionist trade policies in an effort to protect domestic producers from foreign competition.[5] At the same time, the

---

higher between 1870-1910 than between 1950-1980, thus the welfare losses during this period must also be higher.

[4] The TRI was pioneered by Anderson and Neary (1994). For a detailed overview of the theory underlying the TRI, see Anderson and Neary (2005).

[5] For a discussion of the transition to protectionism around the world during this period, see

world was in the midst of one of the largest trade booms in history, with tremendous increases in both the volume and variety of goods traded internationally.[6] Together, these changes led to significant revisions in tariff schedules around the industrializing world as governments changed policy in an effort to protect domestic producers and account for new varieties of products. Unfortunately, little is known about how these changes affected the level, structure and welfare consequences of protection offered by trade policy because existing analyses are based on average tariff measures.

This paper provides the first evidence of how the shift to protectionism and expansion of trade during the first wave of globalization affected the level, structure and welfare costs of trade policy. By employing the TRI methodology to examine changes in Canadian trade policy between 1870 and 1910, we have a simple means to identify the channels through which changes in the tariff structure and the expansion of trade led to changes in the level of protection. We follow Kee et al. (2009) and Irwin (2010) and employ Feenstra's (1995) simplification of the TRI to measure protection. This approach has the advantage that it allows us to construct the index using observable data on imports, ad-valorem tariff rates and elasticities of import demand. Employing disaggregate data allows us to document changes in the structure of protection in response to the shift to protectionist trade policies and increases in the number of products traded. We compute TRIs for agricultural, manufacturing and exotic goods industries as defined by Lehmann and O'Rourke (2011). They show that the tariff structure across these goods is key for understanding the impact of tariff policy on economic growth.

We find that the AWT understates the restrictiveness of trade policy measured by the TRI by as much as 13 percentage points, so in this sense, the tariff was more restrictive than previously understood. We compute the first estimates of the welfare

---

O'Rourke (2000).

[6] For an overview of the expansion of world trade during this period, see Estevadeordal et al. (2003).

costs associated with protection in Canada during our period of study and find that the static welfare losses arising from protectionism amounted to 0.7-1.5% of GDP. Although they have not been measured previously, these estimates are drastically lower than the conventional view of welfare losses found in the literature. From 1875 to 1880, the higher level of trade restrictiveness was primarily driven by an increase in the average tariff across goods. After 1880, the changing structure of the tariff across goods resulted in a higher variance of the tariff and this became the main factor that increased the TRI. Although the TRI increased after the National Policy, the structure of the tariff continued to be restrictive with low deadweight loss because the highest tariffs tended to be applied to goods with inelastic demand. Tariffs on agricultural and industrial goods increased but most of the tariff increases were on exotic goods - goods that were not produced in Canada and were primarily taxed for revenue purposes.

These results suggest a re-evaluation of the typical history of Canadian trade policy at the end of the 19th century. Based on the TRI, Canadian trade policy was more restrictive than previously understood and the measured static welfare losses are much lower than previously inferred. Moreover, contrary to the conventional view of history, we find that Canadian tariff revisions after the National Policy had significant effects on trade restrictiveness. Previous research has focused on the National Policy tariff as the key driver of protectionism in Canada at this time because it corresponds to the largest increase in the AWT prior to the Great Depression. Later revisions to the tariff schedule are ignored because they do not lead to similar changes in the AWT. We show that these tariff revisions did indeed play an important role in determining the level of protection because they affected the variance of the tariff structure. In particular, the Tariff Amendment Act of 1887 and Fielding's Tariff of 1897 altered the level of protection similar in magnitude to the National Policy tariff. Hence, while the

National Policy was the beginning of higher Canadian tariffs, subsequent revisions to the tariff schedule also had a large impact on the level of protection offered by trade policy.

Our results imply that Canadian trade policy at this time is not as protectionist as is generally believed. Although agricultural and industrial goods received higher levels of protection during our period of study, the level of protection we measure with the TRI is driven by high tariffs on exotic goods. This implies that the tariff structure was not protectionist in the sense that the highest tariffs were not primarily protecting domestically produced goods as policy statements at the time suggest. Instead, high tariffs on inelastically-demanded exotic goods are a means to maximize revenue, which is consistent with the fact that tariff revenue continued to be the largest component of government revenue during this period. This also suggests that welfare costs are lower than would have occurred under a more protectionist trade policy.

This paper illustrates the importance of using a theoretically consistent measure of protection when examining how revisions to trade policy affect the economy. Our analysis also highlights the importance of employing disaggregated trade data to measure protection because the structure of the tariff is the crucial factor. We show that, although the AWT understates the restrictiveness of trade policy, it is accurate when revisions to the tariff schedule are relatively uniform across all goods, such as the case of the increase in tariffs following the National Policy. In contrast, we find that the AWT significantly understates the level of protection when tariff changes are designed to increase protection for some products more than others, such as the change in protection resulting from the Tariff Amendment Act of 1887 and Fielding's Tariff of 1897. Hence, research relying on the AWT understates the effects of trade policy reforms that alter the structure of the tariff across goods.

Our paper contributes to an emerging literature documenting the extent of protection and the welfare costs of trade policy using the TRI. This method for measuring the restrictiveness of trade policy has been employed to examine trade policy across time and countries. The TRI has been used to examine protection in France and the UK in the 19th century (O'Rourke, 1997), in the US between 1859 and 1961 (Irwin, 2010), and various other countries around the world from the 1980s onward (Anderson and Neary, 2005; Kee et al., 2008, 2009; Lloyd and MacLaren, 2010). We add to this literature by constructing the TRI for a historic period and by demonstrating the importance of using disaggregate data to calculate the simplified TRI.

By constructing the TRI using historical data, our paper is closely related to the work of Irwin (2010). He constructs an annual TRI for the United States over the period 1859-1961 using data for up to 21 import categories. Our analysis differs from Irwin in three important respects. First, we examine how changes in the tariff schedule designed to alter trade barriers and to account for expansion in the number varieties traded affect the level and cost of protection. Although the United States underwent a shift to protectionism and a large expansion in trade during our period of study, these features are not examined by Irwin. Second, we employ customs data that is reported at the product level. This allows us to account for detailed changes in the tariff structure. As we show below, employing aggregated data will understate the effect of changes in tariff structure. Finally, we examine the robustness of our results to our choice of elasticities. Given that historical elasticity estimates are not available during our period of study, we follow Irwin's approach and calculate the TRI using modern import demand elasticity estimates in the place of historical estimates. We employ the delta method and simulations to examine the robustness of our results and find that they are not being driven by our elasticities.

The rest of this paper proceeds as follows. Section two provides a brief overview of Canadian Tariff Policy between Confederation and World War I. Section three outlines the TRI, and the data used in this study. Section four presents the results. Section five presents the results of two robustness checks examining how our results are affected by our choice of elasticities and aggregation. Section six concludes.

3.2 Canadian Trade Policy Through the Lens of the AWT

Canadian trade policy at the end of the 19th century is commonly viewed by both economists and historians as protectionist. This view traces back to the 'National Policy' tariff enacted by the Macdonald Conservatives in 1879 following a prolonged stagnation of the economy. The National Policy and many of the subsequent tariff policies implemented in the following 30 years had the stated intent of providing Canadian producers with protection from foreign competition. Public proclamations stated that Canada started actively protecting domestic industry in 1879 with the enactment of the National Policy. The Canadian Finance Minister at the time declared that trade policy was set 'to select for higher rates of duty those [goods] that are manufactured or can be manufactured in the country' (McDiarmid, 1946, p. 161).[7] These revisions to tariff policy correspond to increases in the AWT, leading many to conclude that protection was the both the intent and the result of tariff reform.[8] This can be seen in Figure 3.1, which presents the import-weighted average tariff in Canada from 1870 to 1910. As shown in the figure, the average tariff increased from approximately 14 percent in 1875 to over 20 percent by 1880, following the enactment of the National Policy.

This increase is often viewed as laying the foundation for the tariff schedule for the next 50 years. The AWT remained relatively stable after the National Policy, leading to the conclusion that the National Policy legislation was the main determinant of

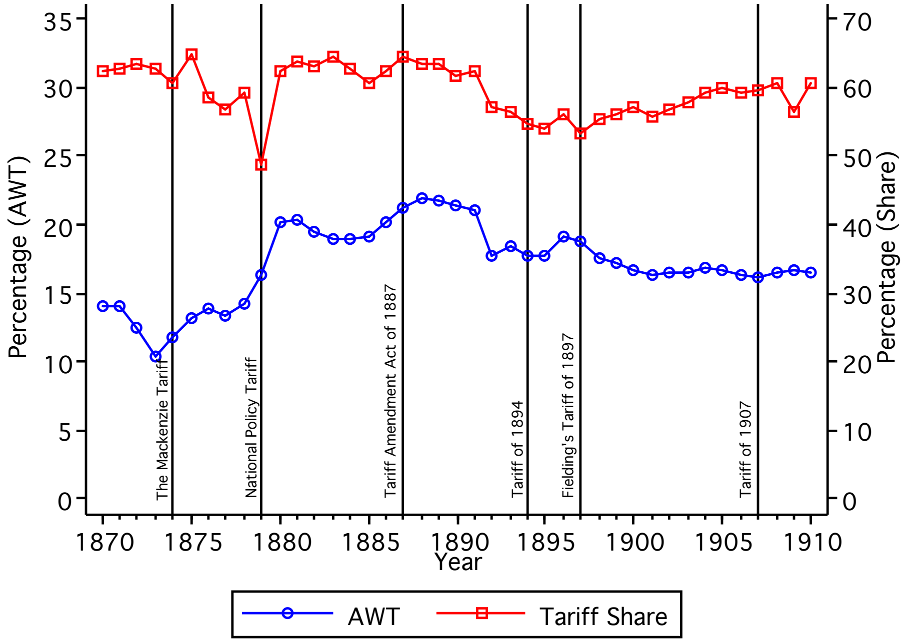
---

[7] See Pinchin (1970).

[8] See, for example, Easterbrook and Aitken (1965) or Norrie and Owram (1991).

protection for years to come. For example, Taylor (1939) writes, "The general level of protection was essentially unchanged until 1930, with only minor changes to the tariff schedule." The tariff schedule was modified in 1887 and 1894, with a major revision in 1897 when a preferential tariff for Great Britain was introduced. There was further revision to the tariff in 1904 and in 1907, by which time the government had established three levels of duties, the lowest being the British preferential, then scaling up to the intermediate and general tariffs. The intermediate tariff served as the basis for the negotiation of treaties with non-British countries. Given that these later revisions did not affect the AWT tariff by as much as the National Policy, they are viewed as secondary determinants of Canadian protectionism during this time.

Figure 3.1: Protection and Revenue from Canadian Tariffs: 1870-1910



Note: Import-weighted average tariff constructed using data from Leacy, ed (1983). Data on tariff share in government revenue obtained from Gillespie (1991).

Altogether, the evidence based on the AWT gives the typical view of Canadian history: the National Policy set the stage for Canadian protectionism over the next

50 years. But is this the right conclusion? There are two key reasons to dispute this view. First, the average tariff does a poor job of measuring the level of protection, particularly when tariffs are non-uniform (Anderson and Neary, 2005). Given that many of the tariff revisions following the National Policy appear to have affected the structure of the tariffs rather than the average tariff, the AWT presented in Figure 3.1 may be giving a misleading view of Canadian tariff history. The raw data suggests that the National Policy and later revisions changed the tariff structure to a greater extent than is reflected by examining the AWT in Figure 3.1. For example, in their first session of parliament in 1879, Macdonald's Conservative Party almost doubled the rates of protection for the textile sector and iron and steel industry, but only increased the general rate from 17.5 percent to 20 percent. In the textile industry, cotton duties increased from 17.5 percent to rate of about 30 percent, while primary iron and steel went from a range of free to 5 percent to a range of 12.5 percent to 17.5 percent. Given the economic importance of textiles and iron and steel at the time, these revisions may have had a larger effect on the level of protection and the welfare costs of the tariff than implied by the AWT.

Second, protection is not the only possible motive for the observed changes in trade policy. Tariff revenue was the primary source of government revenue in the early post-confederation period. As Figure 3.1 shows, customs duties provided on average almost 70 percent of the total Canadian government revenues up until 1887 and declined but still represented about 60 percent of revenue as late as 1910. With the large transportation development debts assumed by the Dominion during this period the revenue from import duties was essential to the government's nation-building objective, which suggests the Canadian government may have structured protection to maximize revenue rather than primarily protectng domestic industry. This means that the observed changes in trade policy are consistent with two competing explanations;

differentiating between them is largely an empirical question that we examine below.

The tariff regime observed in Canada following the National Policy is also considered to have led to large welfare losses. This conclusion is not based on direct evidence, but inferred using estimates from later periods. Various studies have suggested that the welfare costs of protection in Canada ranged between \$1 billion or 4 % of GNP in the 1950s (Young, 1957) to 10 % of GNP in the 1960s (Wonnacott and Wonnacott, 1967), to 4-8% of GDP in the 1980s (Harris and Cox, 1984). Pomfret (1993) comments that the welfare costs of protection in Canada were likely higher from 1859-1939 than this because levels of protection were higher. However, this conclusion relies on changes in the AWT which may not accurately reflect changes in protection over time. As described in the following section, using the TRI method, we will directly measure the static welfare costs of the tariff during this period.

3.3 Measuring Protection and Welfare Loss

To measure protection, we follow the approach of Kee et al. (2009) and Irwin (2010) and employ Feenstra's (1995) simplification of the Anderson-Neary Trade Restrictiveness Index.[9] With his simplification, the TRI can be written:

$$TRI = \left(\frac{1/2 \sum_{i=1}^{n} (\partial I_i / \partial p_i)(p_i t_i)^2}{1/2 \sum_{i=1}^{n} (\partial I_i / \partial p_i)(p_i)^2} \right)^{1/2} \tag{3.1}$$

where n is the number of goods, p_i is the price of good i, t_i is the ad-valorem tariff rate on good i, and $(\partial I_i / \partial p_i)$ is the change in import expenditures on good i resulting from a small change in the price of i.

---

[9] It is important to note that by employing the simplified version of the TRI, we are focusing on the first-order effects of trade policy and ruling out cross-price effects and other general equilibrium interactions. In principle, this means our estimates may understate the true level of protection (Lloyd and MacLaren, 2010). General equilibrium interactions could be captured using a computable general equilibrium (CGE) model, but Canadian data from the period of our study does not provide sufficient detail to allow for CGE modelling. More importantly, when calculated using CGE methods, the TRI is highly sensitive to the specification of the model (O'Rourke, 1997), meaning any second-order effects will depend explicitly on our modelling choices. By using the simplified TRI and focusing on the first-order effects of trade policy, we are able to abstract from this issue.

Direct calculation of the TRI based on equation (3.1) is not possible, as $(\partial I_i/\partial p_i)$ is unobserved. Kee et al. (2009) show that equation (3.1) can be re-written and expressed solely in terms of observables:

$$TRI = \left(\frac{\sum_i^n m_i \varepsilon_i t_i^2}{\sum_{i=1}^n m_i \varepsilon_i} \right)^{1/2} \tag{3.2}$$

where m_i denotes total imports of good i and ε_i is the own-price elasticity of import demand for good i. By re-expressing equation (3.1) in this manner, it is possible to calculate the TRI directly using data on imports, ad-valorem tariff rates and elasticities of import demand.

This approach also provides a simple means for identifying the channels through which changes in tariff policy led to changes in the level of protection. As Kee et al. (2008) show, the TRI given by (3.2) can be rewritten as:

$$TRI = \left(\bar{t}^2 + \sigma^2 + \rho \right)^{1/2} \tag{3.3}$$

where $\bar{t}$ is the AWT, $\sigma^2 = \sum_{i=1}^n s_i (t_i - \bar{t})^2$ is the import-weighted variance in the tariff rate, and $\rho = \sum_{i=1}^n s_i (\tilde{\varepsilon}_i - 1)(t_i^2 - \bar{t}^2)$ is the import-weighted covariance between tariffs and elasticities, where $s_i = m_i / \sum_{i=1}^n m_i$ is the share of good i in total imports and $\tilde{\varepsilon}_i = \varepsilon_i / \bar{\varepsilon}$ is the import-weighted average elasticity. This decomposition makes it easy to identify whether changes in protection are being brought about primarily through changes in the average level of tariffs $(\bar{t})$, through changes in the set of goods high tariffs are applied to (σ^2), or by placing tariffs on goods with relatively inelastic demand (ρ).

In addition, employing the simplified TRI provides a method for calculating the static welfare loss associated with trade policy. As Kee et al. (2008) indicate, the numerator in equation (3.2) is equal to twice the static deadweight loss (DWL) arising from protection. Hence, an approximate value of the welfare loss associated with protection can be calculated using:

$$\frac{DWL}{GDP} = \frac{1}{2}\sum_{i=1}^{n} \tilde{m}_i \varepsilon_i t_i^2 \tag{3.4}$$

where $\tilde{m}_i = m_i/GDP$ is the ratio of imports of good i to GDP. Like the TRI given in (3.2), this equation can be calculated directly using observable data.

Equation (3.4) can also be manipulated so that the channels driving welfare losses can be identified. Again following Kee et al. (2008), DWL/GDP can be rewritten as:

$$DWL/GDP = \frac{1}{2} \times \bar{\varepsilon} \times (\bar{t}^2 + \sigma^2 + \rho) \tag{3.5}$$

Like the decomposition presented in equation (3.3), this equation makes it possible to determine how changes in the level, dispersion and placement of tariffs affect welfare.

3.3.1 Data

The computation of the TRI and welfare loss measures given by (3.2) and (3.4) require data on GDP, imports, ad-valorem tariff rates and elasticities of import demand. Estimates of Canadian GDP used to calculate static welfare loss were obtained from Urquhart (1993), Table 1.1. The trade data are detailed customs data from the *Tables of the Trade and Navigation of the Dominion of Canada*. These tables report Canadian imports and duties at the product level throughout our period of study. Using product-level customs data is important because it allows us to observe changes to the tariff schedule that might be missed at higher levels of aggregation. Our trade data was taken from these tables at five-year intervals for the years 1870-1910.

We also employ the customs data to calculate the ad-valorem tariffs that were applied to each product in each year. These tariff rates were calculated by dividing the value of duties collected by the value of imports for each product that was imported. We employ the calculated ad-valorem tariff rates from customs data for two reasons. First, it is computationally necessary to calculate ad valorem rates from the customs

Table 3.1: Data Overview

Year	Imports ($1000)	Duty ($1000)	GDP ($1000)	Price Index (1900 =100)	Import Weighted Average Tariff (%)	Average Import Elasticity	Number of Products (HS6)	Number of Customs Categories
1870	69,670	9,289	363,194	104	13.33	-2.20	255	308
1875	117,166	15,344	429,876	108	13.10	-2.13	299	378
1880	68,808	14,018	452,082	104	20.37	-2.23	559	819
1885	97,689	19,106	528,170	100	19.58	-2.13	680	1027
1890	109,697	23,897	665,293	104	21.78	-2.20	790	1283
1895	101,680	17,877	609,921	91	17.58	-2.15	847	1354
1900	176,550	28,807	867,201	100	16.41	-2.20	922	1412
1905	250,554	41,766	1,306,322	109	16.67	-2.21	947	1372
1910	364,409	60,828	1,947,358	122	16.69	-2.17	964	1467

Note: Imports, duty and GDP are in nominal values. The Price Index was obtained from Urquhart (1993), Table 1.6.

data because the Canadian government employed a combination of specific and ad-valorem tariffs and we do not have sufficient data to separately incorporate specific tariffs into our measurement of protection.[10] Second, employing the calculated ad-valorem tariff rate allows us to capture trade policy as it was actually applied on imported goods at the product level.

Table 3.1 provides an overview of the data used in our analysis. As can be seen in the table and in Figure 3.1, the import-weighted average tariff rate in Canada remained relatively constant until the implementation of the National Policy. The AWT increased from just over 13% in 1875 to just over 20% by 1880. Tariffs remained high throughout the 1880s, peaking again at just under 22% in 1890, before falling to 17.5% in 1895. The AWT fell to just over 16% by 1900 and remained relatively constant throughout the rest of the period studied.

Two features of Canadian trade flows that stand out in the data summarized in

---

[10] Although this approach is common practice, it means that changes in tariff levels for some goods will reflect changes in import prices in addition to changes in trade policy. Price changes have been shown to have large effects when specific tariffs are widely used (Irwin, 1998), however, in our case their effects should be small. Canada employed specific duties sparingly throughout our period of study.

Table 3.1 are the dramatic increases in both the value of imports and the number of different products imported. These features are illustrated in Figure 3.2. As the figure shows, the number of goods imported increased exponentially starting in 1875 but the value of imports did not increase dramatically for another twenty years.

Since the expansion of trade along the extensive margin is such a prominent feature of the data it is important that we are clear about how we measure the number of goods. We have been careful to ensure that we are documenting an actual increase in the number traded products rather than an expansion in the number of categories included in customs records. Rather than relying on the categories of goods used by customs officials of the period, we mapped the products into the Harmonized Commodity Description and Coding System (HS) at the 6-digit level on the basis of descriptor, and treat each HS6 category as a unique product or good. This ensures we are using a consistent classification in all years that is not affected by the whims of customs agents of the period. Columns 8 and 9 in Table 3.1 compare the expansion in products and customs categories. During our period of study, there was a similar pattern of expansion in both customs categories and products. However, our approach ensures we are documenting an expansion in goods and not simply capturing the splitting of customs categories.[11] This means the expansion at the extensive margin reflects an expansion across the static 6-digit HS categories.[12]

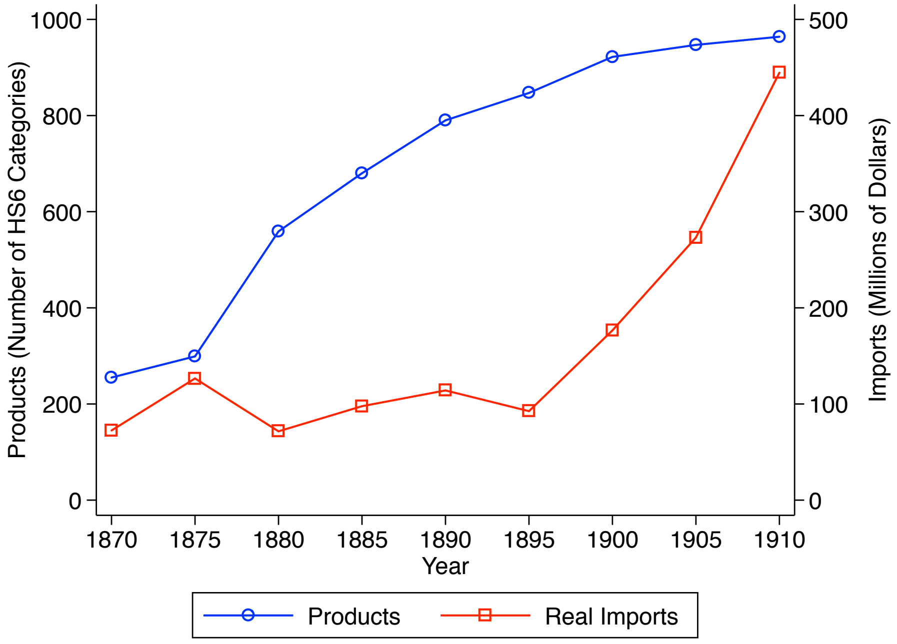
Although the growth in trade along the extensive margin is dramatic, it should not be considered surprising. As Jacks et al. (2010) point out, economic growth and the reduction in trade costs contributed to a dramatic increase in trade between 1870 and 1913. This expansion of tradable goods is also reflected in the expansion of production along the extensive margin. Inwood (1995) indicates there was a rapid expansion of

---

[11] For example, in 1870 the customs data contains one line for carriages, which we classified in HS category 871680. In 1910, the customs data contains nine lines for carriages, which were all classified in the HS category 871680.

[12] In section 4 we discuss the robustness of our results to aggregating our data to the HS6 category.

Figure 3.2: Value of Imports and Number of Goods Imported into Canada: 1870-1910



Note: Real imports were computed by deflating nominal imports using a GDP price deflator. The number of goods imported is given by the number of distinct HS-6 categories traded in each year.

entirely new products in Canada during this period. For example, electrical goods did not exist, while rubber and paper products were a very small share of production in Canada in the 1870s. Products in these industries grew significantly over the next 40 years and were becoming widely produced by 1910. With respect to our import data, the types of industries with most of the expansion in the numbers of goods during this period were metals, textiles, chemicals, and vegetable products. Machinery and electrical products also saw a large increase in the number of goods imported. Given falling transport costs, strong economic growth and the expansion in production along the extensive margin during this period, it is not surprising to find the dramatic growth of tradable goods along the extensive margin depicted in Figure 3.2. We examine the number of goods by industry in more detail in the results section and present the TRI and number of goods by broad industry grouping.

The TRI and welfare loss measures given by equations (3.2) and (3.4) also require estimates of the elasticity of demand for each product. Unfortunately, no such estimates exist for this period and cannot be calculated with available data. Hence, throughout most of the analysis we follow the approach of Irwin (2010) and calculate the TRI using modern import demand elasticity estimates in the place of historical estimates.

We obtain our estimates of import price elasticities from Kee et al. (2008), who estimate elasticities for a wide range of goods and countries (including Canada) for the period 1988-2001. It is classified according to the HS6 classification scheme, making it possible to match Canadian elasticity estimates to our re-classified import data. If a Canadian estimate is not available for a particular HS6 category or the existing estimate is an outlier[13], the average estimate for that category from the rest of the world was used. Products that could not be assigned to an HS6 category (due to poor or non-existent correspondence between the data and the HS6 classification scheme) were treated as miscellaneous products and assigned the average elasticity value from the Kee et al. (2008) data.

Using the data from Kee et al. also provides us with a simple means to examine the robustness of our results to changes in elasticity values. In addition to reporting elasticity estimates, Kee et al. also report estimated standard errors. The estimated standard errors allow us to construct a confidence interval for both the TRI and DWL/GDP using the delta method. Let $\boldsymbol{\varepsilon}$ denote the vector of estimated elasticities that we use in our analysis. Applying the delta method to equations (3.2) and (3.4) yields:

$$\widehat{\text{Var}}(TRI) = \mathbf{T}\widehat{\text{Var}}(\boldsymbol{\varepsilon})\mathbf{T}' \tag{3.6}$$

$$\widehat{\text{Var}}(DWL/GDP) = \mathbf{D}\widehat{\text{Var}}(\boldsymbol{\varepsilon})\mathbf{D}' \tag{3.7}$$

---

[13] We consider elasticity estimates to be outliers if they are greater than two standard deviations away from the average value in the Kee et al. (2008) data.

where $\widehat{\mathrm{Var}}(\boldsymbol{\varepsilon})$ is an $n \times n$ diagonal matrix containing the variance of each estimated elasticity from Kee et al., $\widehat{Var}(\varepsilon_i)$, as elements, $\mathbf{T}$ is a vector of length n with typical element $\partial TRI/\partial\varepsilon_i$, and $\mathbf{D}$ is a vector of length n with typical element $\partial(DWL/GDP)/\partial\varepsilon_i$. We employ equations (3.6) and (3.7) to construct 95% confidence intervals for our estimates. Because these confidence intervals capture how variation in our elasticities affect our estimates, they allow us to identify how changes in the elasticities influence our results.[14]

3.4 Results

3.4.1 The Level and Cost of Protection

Our main results for the TRI are presented in Table 3.2. This table also includes the AWT and other commonly employed measures of protection for comparison. Our results indicate that the AWT understates the level of protection offered by trade policy in all years and that Canada's trade policy at the end of the 19th century was more protectionist than previously believed. Moreover, the correlation between the TRI and AWT is only 0.65 in our sample, meaning that changes in the TRI do not correspond perfectly to changes in the average tariff. Importantly, other commonly employed measures of protection, such as the average tariff on dutiable goods and the share of duty free imports, also fail to capture these changes.

The difference in protection as measured by the AWT and the TRI can be seen clearly in Figure 3.3. This figure displays the AWT, the TRI, and the confidence interval (based on equation 6) around the TRI (the dashed lines) in each year. Clearly, the AWT is less than the TRI in all years, meaning that previous studies have understated protection. Notice that the import-weighted average tariff is a relatively

---

[14] In section 4 we present additional evidence documenting the robustness of our results to employing modern elasticity estimates.

Table 3.2: Average Tariffs, Trade Restrictiveness and Welfare Losses

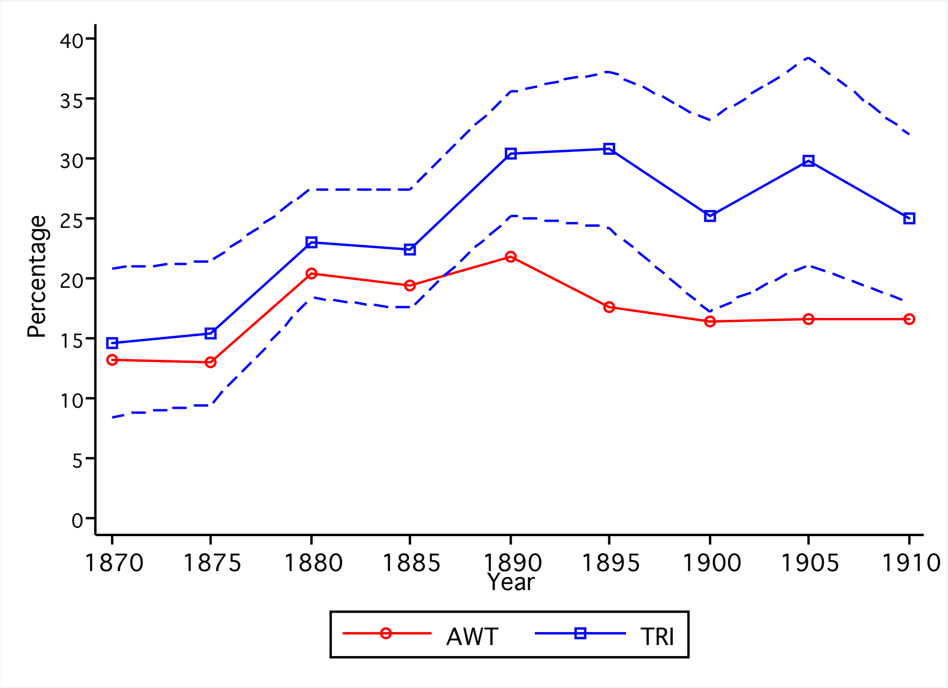
Year	Average Tariff on Total Imports	Average Tariff on Dutiable Imports	Share of Imports Duty Free	Imports /GDP	TRI		DWL/GDP	
1870	13.33	20.58	35.23	19.18	14.72	(3.08)	0.37	(0.14)
1875	13.09	19.64	33.31	27.26	15.51	(2.98)	0.54	(0.18)
1880	20.37	25.94	21.47	15.22	22.97	(2.27)	0.76	(0.17)
1885	19.56	26.08	25.01	18.50	22.56	(2.50)	1.07	(0.24)
1890	21.78	31.02	29.77	16.49	30.47	(2.58)	1.36	(0.21)
1895	17.58	30.58	42.51	16.67	30.82	(3.27)	1.24	(0.17)
1900	16.41	27.68	40.73	20.24	25.23	(3.99)	1.24	(0.25)
1905	16.67	27.68	39.78	19.18	29.86	(4.31)	1.50	(0.39)
1910	16.69	26.72	37.54	18.71	25.13	(3.50)	1.00	(0.27)

Note: All values in percentages. Standard errors for both the TRI and DWL/GDP are reported in parentheses. These standard errors were calculated by applying the delta method to equation (3.2).

accurate measure of the restrictiveness of trade policy up to 1885 suggesting that the tariff was relatively uniform up to then. The AWT tracks the TRI quite closely until the Tariff Amendment Act of 1887, when there was a large increase in the TRI but the AWT levels off. Moreover, the AWT lies within the TRI confidence interval in every year up to (and including 1885), but lies outside the confidence interval in the years that follow, meaning the two measures are distinct. This suggests that the structure of the tariff may be changing and that the variance of the tariff across industries my be getting larger. Figure 3.3 reveals that tariff revisions enacted after the National Policy had a much larger effect on the level of protection than previously thought. This is important because most previous studies of Canada have focused on the National Policy as the long term determinant of the level of protection available in the Canadian economy. When the AWT is used to measure protection, the National Policy appears to have the largest effect on protection. Our results show that the Tariff Amendment Act of 1887 and Fielding's Tariff of 1897 altered the level of protection by a similar magnitude.

Unlike the National Policy, which largely increased protection through changes in

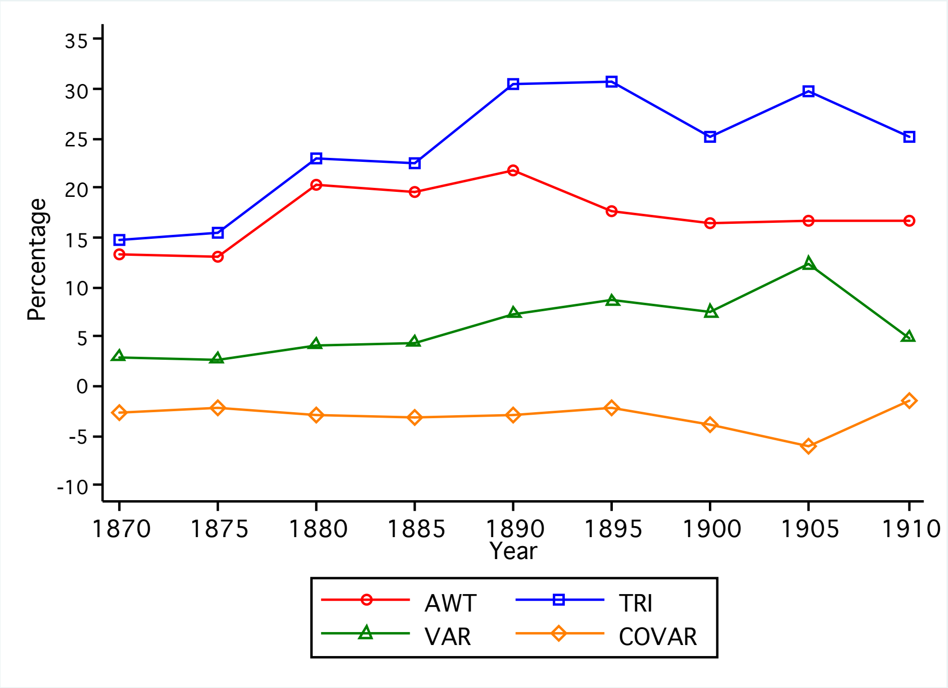
Figure 3.3: Measures of Trade Restrictiveness



the level of tariffs, later revisions primarily increased protection through changes to the dispersion of tariffs across goods. This can be seen by employing the decomposition of the TRI given in equation (3.3) presented in Figure 3.4. From this figure it is readily apparent that the increase in protection resulting from the National Policy was driven primarily by changes in the level of tariffs. The changes in protection resulting from the Tariff Amendment Act of 1887 and Fielding's Tariff of 1897, on the other hand, were driven primarily by changes in tariff rates for a subset of goods. This can be seen from the increase in the variance in the tariff rate; such changes only occur as the set of goods subject to high tariffs changes. Such changes fit the historical record. As Pinchin (1970) indicates, the Tariff Amendment Act of 1887 and Fielding's Tariff of 1897 largely consisted of revisions to the tariff rates applied to some goods as opposed to schedule-wide changes in tariff rates. Moreover, the covariance between tariffs and elasticities are nearly constant for the entire period.

Table 3.2 also includes the first estimates of the welfare loss associated with Cana-

Figure 3.4: Sources of Protection



dian tariff policy during this period. Our results indicate that Canadian protectionism led to substantial welfare losses. Losses were less than 0.6% prior to the National Policy, and ranged between $0.76 - 1.50\%$ of GDP thereafter. Like the TRI, the change in welfare loss was highest following the implementation of the National Policy, but later revisions to the tariff schedule, particularly the Tariff Amendment Act of 1887 also had big effects on welfare. The ratio of static deadweight loss to GDP (the solid line) and the confidence interval (the dashed lines) are plotted in Figure 3.5.

Like the TRI, the sources of welfare loss vary by year. Figure 3.6 presents the results of a decomposition based on equation (3.5). This figure shows that changes in welfare are primarily driven by changes in the set of goods tariffs are applied to, rather than changes in the level of protection. This can be seen from the large changes in the variance of the tariffs and the covariance between import elasticities and tariffs after 1880; such changes only occur as the set of goods subject to tariffs changes.

Figure 3.5: Welfare Loss

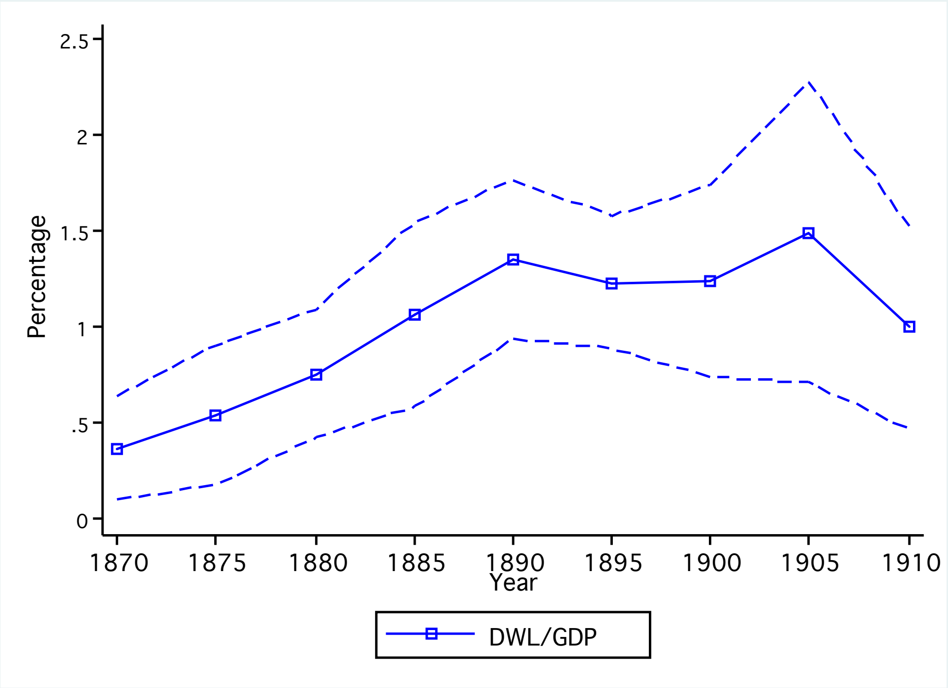
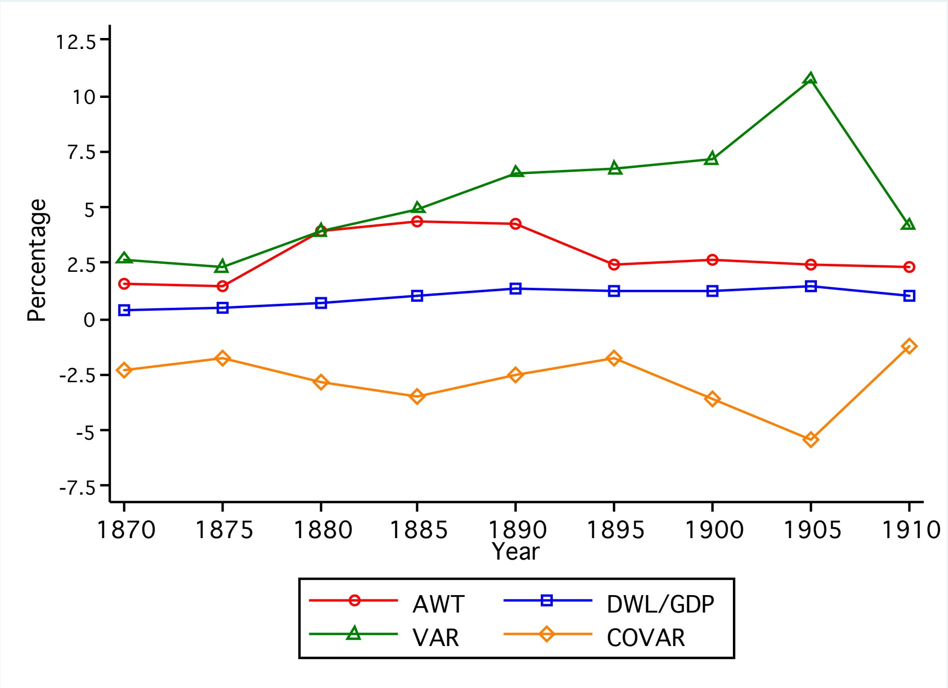


Figure 3.6: Sources of Welfare Loss



3.4.2 The Structure of Protection

At first glance, the results presented above suggest that Canada was much more protectionist than previously thought. Moreover, this protectionism appears to be consistent with the idea that tariffs were extended to protect vulnerable Canadian producers that is prevalent in the literature (see Easterbrook and Aitken (1965) or Dales (1966) for classic references). Most of the changes in the level and costs of protection result from increases in the variance of the tariff rates across goods which would arise from preferential tariffs being extended to certain industries to foster domestic production. However, the validity of this conclusion hinges on the exact structure of protection, which we turn to examine now.

First, consider how the structure of protection was affected by the expansion of trade along the extensive margin. Recall that the number of goods imported into Canada quadrupled during our period of study as a result of technological progress and falling trade costs. The first three rows of Table 3.3 show that the expansion of trade along the extensive margin was an important component of the overall value of imported goods. In fact, by 1890, goods that were not imported at all in 1870 (new goods), comprised nearly half of the value of imports. Although it is not shown in this table, new goods and old goods were approximately equal shares of imports until 1900, when new goods became a larger share of the value of imports than goods that were already imported in 1870. During this period there was very little attrition along the extensive margin; that is, most of the goods that were imported in 1870 continued to be imported in 1910.

Table 3.3 also shows that old goods generally received systematically higher levels of protection than new goods. This structure of protection is what one might expect from a political-economy perspective as older, more established producers were able to obtain protection that was not available to those competing with imports of new

Table 3.3: The Expansion of Trade: Old vs. New Goods

	Year								
	1870			1890			1910		
Category	N$_j$	M$_j$	TRI$_j$	N$_j$	M$_j$	TRI$_j$	N$_j$	M$_j$	TRI$_j$
Overall									
Old Goods	255	67.02	14.72	249	54.13	35.27	253	135.25	30.48
New Goods	-	-	-	541	51.12	25.26	711	163.93	21.20
Total	255	66.99	14.72	790	105.48	30.47	964	298.70	25.13
Agriculture									
Old Goods	67	14.13	7.56	52	11.06	25.15	49	23.03	13.35
New Goods	-	-	-	151	8.15	22.79	161	19.26	17.15
Total	67	14.13	7.56	203	19.23	24.04	210	42.30	15.56
Industry									
Old Goods	167	46.92	11.06	126	32.12	25.18	131	88.52	20.33
New Goods	-	-	-	424	47.02	22.49	585	154.10	19.80
Total	167	46.92	11.06	550	79.13	23.27	716	242.62	19.96
Exotic									
Old Goods	21	5.95	55.29	18	3.29	133.55	19	7.05	112.21
New Goods	-	-	-	19	3.90	58.73	19	6.76	51.29
Total	21	5.95	55.29	37	7.19	97.58	38	13.77	90.18

Note: N$_j$ is the number of goods traded in category j, M$_j$ is category j's real imports in millions of 1900 dollars, and TRI$_j$ is the TRI for goods category j. Real imports were calculated using the deflators reported in Table 1. Column totals may not equal overall value due to rounding.

varieties. However, when we examine the expansion of trade by commodity type using the classification scheme from Lehmann and O'Rourke (2011), it appears that this pattern is driven primarily by protection on old exotic commodities, as similar levels of protection were granted to old and new goods in both agriculture and industry. This suggests the Canadian government was not enacting protection for old established producers, but instead setting tariffs primarily for revenue purposes.

To analyze how the structure of protection changed over time, we calculated the TRI for a number of broad commodity classes and grouped them into agricultural, industrial and exotic commodities using the categorization of Lehmann and O'Rourke (2011).[15] These results are presented in Table 3.4, which presents the TRI, number

---

[15] We assigned the broad commodity classes to the three categories on the basis of descriptor using the classification scheme from the appendix of Lehmann and O'Rourke (2011).

Table 3.4: The Expansion of Trade

					Year				
		1870			1890			1910	
Category	N$_j$	M$_j$	TRI$_j$	N$_j$	M$_j$	TRI$_j$	N$_j$	M$_j$	TRI$_j$
Agriculture									
Animals/ Animal Products	16	1.59	9.01	62	3.61	21.64	58	4.98	16.91
Vegetable Products	39	7.98	2.42	107	8.54	20.27	110	22.46	13.57
Foodstuffs	12	4.57	35.78	34	7.03	45.07	42	14.92	22.79
Total Agriculture	67	14.13	7.56	203	19.23	24.04	210	42.30	15.56
Share of Total	26%	21%	-	26%	18%	-	22%	14%	-
Industry									
Mineral Products	21	2.48	11.57	38	9.71	27.30	43	31.64	17.92
Chemicals	24	1.58	12.45	97	3.39	26.56	123	9.51	20.26
Plastics and Rubbers	3	0.33	10.64	13	1.30	21.28	15	6.75	10.34
Hides, Skins, Leather, Fur	7	2.57	12.86	19	4.22	18.73	20	15.25	14.67
Wood and Wood Products	20	1.92	9.32	48	4.48	22.66	63	16.48	18.48
Textiles	22	19.04	13.43	96	28.65	22.89	113	63.93	21.10
Footwear and Headgear	4	0.65	7.90	13	1.70	26.04	13	3.93	25.80
Stone and Glass	12	5.72	7.39	48	4.38	24.48	54	15.57	19.48
Metals	24	6.09	6.58	95	15.38	22.13	124	47.92	16.21
Machinery and Electrical	10	0.02	12.94	30	1.12	27.61	62	13.11	23.26
Transportation	4	0.96	10.17	10	0.49	24.68	21	4.16	29.22
Miscellaneous	16	5.35	14.28	43	4.27	23.29	65	14.67	25.30
Total Industry	167	46.92	11.06	550	79.13	23.27	716	242.62	19.96
Share of Total	65%	70%	-	70%	75%	-	74%	81%	-
Exotics									
Total Exotics	21	5.95	55.29	37	7.19	97.58	38	13.77	90.18
Share of Total	8%	9%	-	5%	7%	-	4%	5%	-
Overall	255	66.99	14.72	790	105.48	30.47	964	298.70	25.13

Note: N$_j$ is the number of goods traded in category j, M$_j$ is category j's real imports in millions of 1900 dollars, and TRI$_j$ is the TRI for goods category j. Column totals may not equal overall value due to rounding. Shares may not add to 100% because of rounding. Goods categories were created by aggregating data to HS2 as follows: Animal & Animal Products: 01-05, Vegetable Products: 06-08, & 10-15, Foodstuffs: 16-17, 19-21, & 23, Mineral Products: 25-27, Chemicals: 28-38, Plastics & Rubbers: 39-40, Hides, Skins, Leather & Furs: 41-43, Wood & Wood Products: 44-49, Textiles: 50-63, Footwear & Headgear: 64-67, Stone & Glass: 68-71, Metals: 72-83, Machinery & Electrical: 84-85, Transportation: 86-89, Miscellaneous: 90-99, Exotic goods: 09, 18, 22, & 24.

of goods traded, and value of imports by industry for 1870, 1890, and 1910. As we showed in the previous section, there was an increase in protection as measured by the overall TRI from 1870 to 1890, and some decline by 1910. However, there are substantial differences in the level of protection across commodities. Agricultural and industrial commodities had much lower protection than exotic commodities. Given that exotics are goods such as coffee and tobacco with limited domestic production that were primarily taxed for revenue purposes, this suggests that the observed changes in the level protection were not driven by tariffs favouring specific domestic producers but by tariffs designed to increase government revenue.

This conclusion holds even for narrower commodity classifications. Most commodities had similar levels of protection throughout our period of study. Moreover, commodities such as textiles and metals that are typically viewed as facing the highest level of foreign competition because of the high level of imports of these commodities do not have systematically higher levels of protection. This provides further support for the idea that trade policy was primarily motivated by revenue considerations, and not the protection of producers of favoured commodities.

3.4.3 The Magnitude of Canadian Protection: Some Context

While the results presented above outline the patterns of protection and welfare loss in Canada from 1870-1910, it is natural to ask whether the level of protection and welfare losses obtained from Canadian trade policy are high. To get a sense of the magnitudes of these estimates, we compare our results to estimates from other studies. Table 3.5 compares our estimates to those for Canada for later periods. These results show that Canada's recent trade policy was much less restrictive and much less costly that that at the turn of the 20th century when Canada's trade policy was less restrictive and tariff revenue was of much lower importance. Our estimates of welfare loss are much lower than estimates from mid-century, but this is likely attributable to differences in methodology.

Table 3.5: Canada's Protection over Time

Year	Import-weighted Average Tariff	Anderson-Neary TRI	DWL/GDP
1870-1910	17.28	24.14	1.01
1950s	10.06	-	4.00*
1960s	8.57	-	10.00*
1976†	5.61	-	4.13*
1980s	3.93	-	4.00-8.00
1990	6.95	9.55	-
1988-2001	2.92	7.54	0.08

Note: All values reported in percentages. * Reported estimate indicates welfare loss as a fraction of GNP. † Estimate for 1975 using data from Leacy, ed (1983). Import-weighted average tariff values for 1950s and 1960s also constructed using data from Leacy, ed (1983). Import-weighted average tariff values for 1980s constructed using data from CANSIM tables 227-0002 and 380-0034. DWL/GDP estimate for the 1950s from Young (1957). DWL/GDP estimate for the 1960s from Wonnacott and Wonnacott (1967). DWL/GDP estimate for 1976 taken from Cox and Harris (1985). DWL/GDP estimate for the 1980s from Harris and Cox (1984). Estimates for 1990 taken from Anderson and Neary (2005). Estimates for 1988-2001 taken from Kee et al. (2008).

Table 3.6: Canada versus the United States

Year	Import-weighted Average Tariff		Anderson-Neary TRI		DWL/GDP	
	CAN	US	CAN	US	CAN	US
1870	13.3	44.9	14.7	49.9	0.37	1.33
1875	13.1	29.4	15.5	39.6	0.54	1.02
1880	20.4	29.1	23.0	40.4	0.76	0.93
1885	19.6	30.8	22.6	43.8	1.07	0.96
1890	21.8	29.6	30.5	40.9	1.36	0.81
1895	17.6	20.4	30.8	34.0	1.24	0.51
1900	16.4	27.6	25.2	52.2	1.24	0.56
1905	16.7	23.8	29.9	37.0	1.50	0.46
1910	15.7	21.1	25.1	33.8	1.00	0.46

Note: All values in percentages. US figures taken from Irwin (2010).

Table 3.6 presents protection and welfare loss estimates for both Canada and the United States between 1870-1910. From the table it can be seen that Canada's TRI is much lower than that of the United States during this period, meaning that although Canada's tariff structure was more restrictive than previously understood, it was still less restrictive than other countries at this time. More importantly, even though Canada's trade policy was less restrictive, it had higher welfare losses than the United States during much of this period. This is likely driven by the size of the two economies and by the fact that imports were a smaller share of the US economy.

Overall, our results show that Canada's trade policy at the turn of the 20th century was more restrictive than previously thought. While the extent to which the average tariff understates protectionism varies with time used, the TRI is higher than the average tariff in all cases. This suggests that previous studies that have relied on the average tariff for inference are understating the case for protection, particularly in years when tariff revisions primarily consisted of revisions for some goods, instead of changing the tariff level faced by all goods. Moreover, the results show that the average tariff does not move in perfect correspondence with the TRI; inference based on changes on the AWT alone will be invalid.

3.5 Robustness Checks

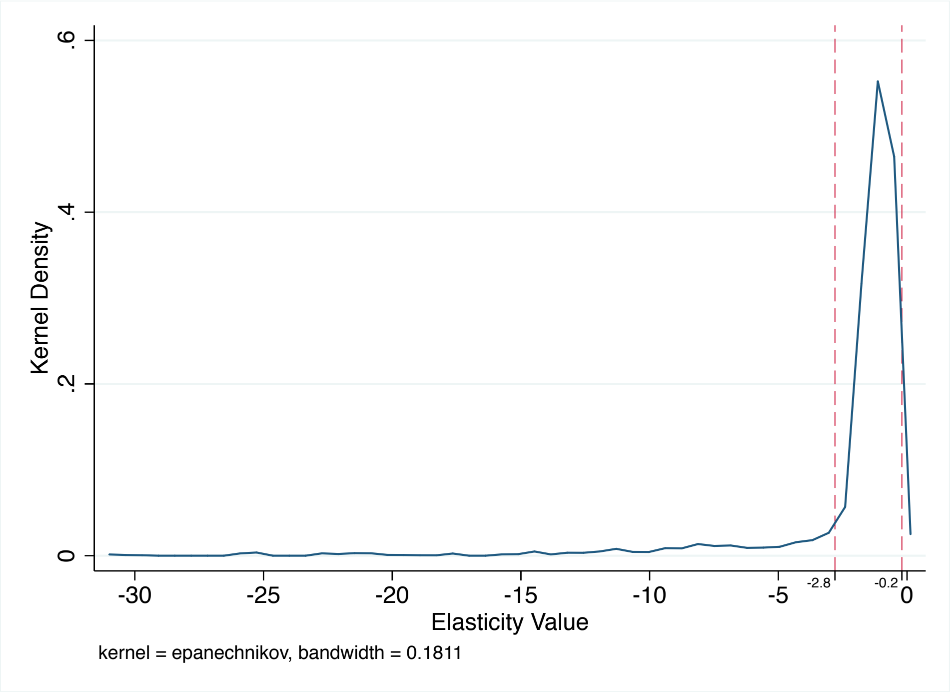
3.5.1 Elasticities

Throughout the analysis presented above, we employed modern elasticity estimates because disaggregated period elasticities are unavailable and cannot be calculated using existing data. While this allows us to match elasticities to each product in our data, it means that some of our elasticities lie outside the range of historical elasticity estimates for Canada: -2.8 to -0.2 (Marquez, 1999). This can be seen in Figure 3.7, which plots the distribution of modern elasticities and range of elasticity estimates. Clearly, most of our elasticities fall within the historical range, but there are a number of outliers which may be driving our results. Moreover, most of our elasticities are at the upper end of the historical range of elasticities, meaning the distribution of elasticities across HS6 categories may be driving our results.

To address these issues, we proceeded in two ways. First, we examined the robustness of our estimates to outliers in the modern data, by recalculating both the TRI and DWL/GDP using truncated elasticity data from Kee et al. (2008), where the data was truncated to ensure that all of the elasticities lie within the historical range. That is, we truncated the elasticities for each HS6 category so that the maximum value in the data is -0.2 and the minimum value in the data is -2.8. Second, we examined the robustness of our results to an alternative distribution of elasticities across HS6 categories using simulations based on the historical range of elasticities. The simulation procedure we employ is inspired by Irwin (2010) who suggests that estimated trade elasticities are relatively stable over time. Hence, a reasonable estimate of the TRI should be similar to a TRI calculated with a random draw of elasticities from the historical interval. Given that we do not know the shape of the historical distribution of elasticities, for our simulations we assumed that all historical elasticities are uniformly distributed over the interval $(-2.8, -0.2)$. Each product was assigned a random elasticity drawn from the interval and the corresponding TRI was calculated. This procedure was repeated 10,000 times to create 10,000 distinct measures of TRI and welfare loss for each year. The results of these procedures are displayed in Figures 3.8 and 3.9.

Figure 3.8 displays the AWT, the original TRI and associated confidence interval as calculated above, the truncated TRI, and the mean simulated TRI. Like the original estimates, both the truncated and simulated TRIs are higher than the AWT in all years, and are imperfectly correlated with the AWT. Moreover, the Tariff Revision of 1897 still leads to a large increase in protection and Fielding's Tariff of 1897 leads to a decrease in protection in both cases, meaning our finding that later tariff revisions were important determinants of protection is robust to our choice of elasticities. How-

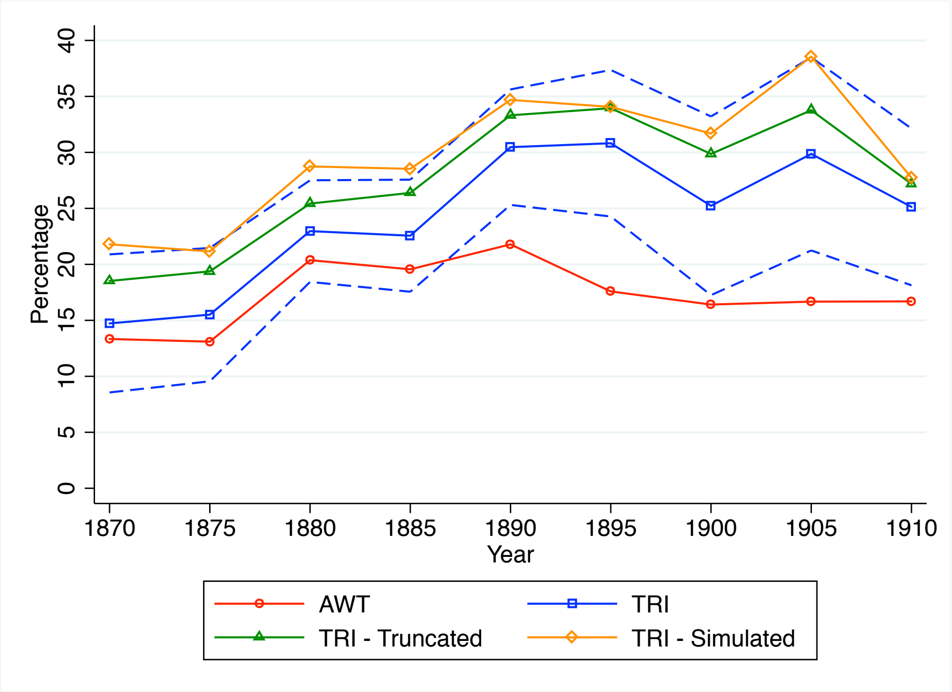
Figure 3.7: The Distribution of Elasticities



ever, both the truncated and simulated TRIs are much higher than the calculated TRI in all years because we have reduced the imported weighted covariance between tariffs and elasticities by restricting the data to the historical range. Hence, while our choice of elasticities does not affect the pattern of protection over time, it does influence our estimate of the level of protection. As such, our calculated TRI may be considered a lower bound on the true level of protection.

The results of our welfare loss simulations paint a similar picture. Figure 3.9 displays the original welfare loss estimates and confidence interval presented above, the welfare estimates using the truncated Kee et al. (2008) data, and the mean simulated results. Our results using the truncated data display a similar trend to our original results, but are lower in nearly every year. This is unsurprising given that our welfare loss estimates depend explicitly on the average elasticity in the data (recall equation (3.5)); the truncated data has a lower average elasticity than the original data by construction. Our simulated results display a similar general trend to our calculated

Figure 3.8: TRI Robustness

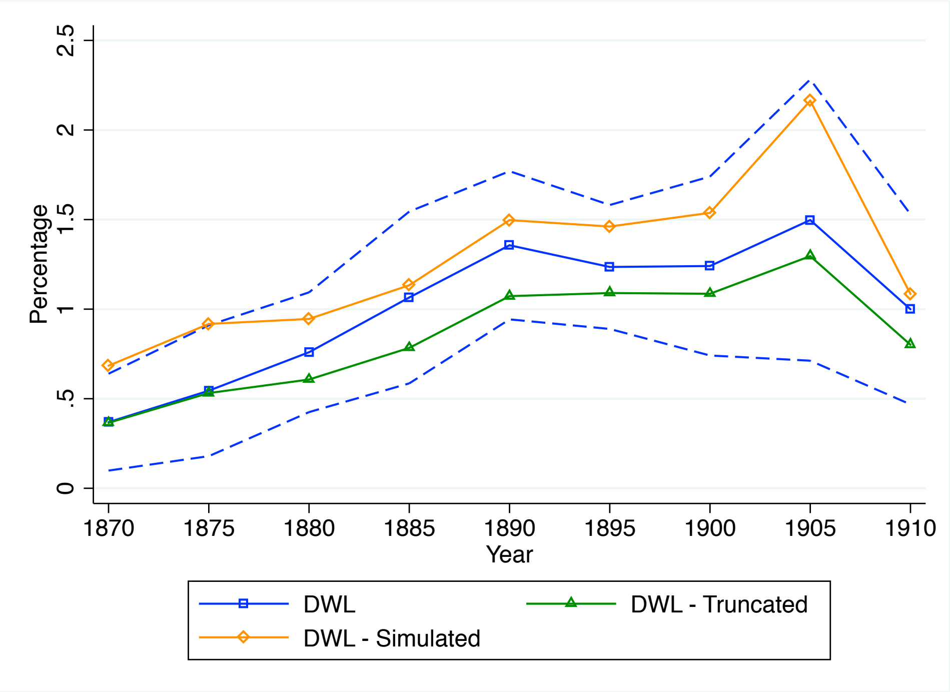


results, but are higher in every year because that the average of the simulated elasticities is higher than the average elasticity in our original data. However, both the truncated and simulated estimates lie within the original confidence interval, suggesting that our original estimates reflect the true welfare losses arising from Canadian Protectionism.

3.5.2 Aggregation

In order to ensure we use a consistent definition of products in all years, we were forced to aggregate the raw trade data from the *Tables of the Trade and Navigation of the Dominion of Canada* to the HS6 level. As we discussed previously, this involved matching our data to each HS6 category on the basis of descriptor. As can be seen in Figure 3.10, this leads to a substantial reduction in the number of goods reported in all years. This leads to a natural concern: the reduction may drive our results by artificially manipulating the variance in the tariff rate in all years. To investigate whether

Figure 3.9: Welfare Loss Robustness



aggregation is driving our results, we recalculated TRI and DWL/GDP using both disaggregated and aggregated data for all years. Throughout, we assume a constant elasticity of import demand for all goods; doing so allows us to focus on differences in protection created solely from differences in how the trade data is aggregated.

Figures 3.11 and 3.12 show how aggregation changes our measurement of protection and welfare loss. In Figures 3.11 and 3.12, the measures for disaggregated data and data aggregated to HS6 are nearly identical. This means our main analysis is not a product of aggregation.

One other aspect of Figures 3.11 and 3.12 is worth noting. While the TRI and DWL/GDP are nearly identical when calculated using disaggregated or HS6 data, higher levels of aggregation (HS3 and HS1) clearly understate the true level of protection and welfare loss. While this point has been made previously by Irwin (2010), our results show that the degree to which calculations using highly aggregated data understate protection or welfare loss is not constant. This means that studies using

Figure 3.10: Aggregation and Varieties Traded

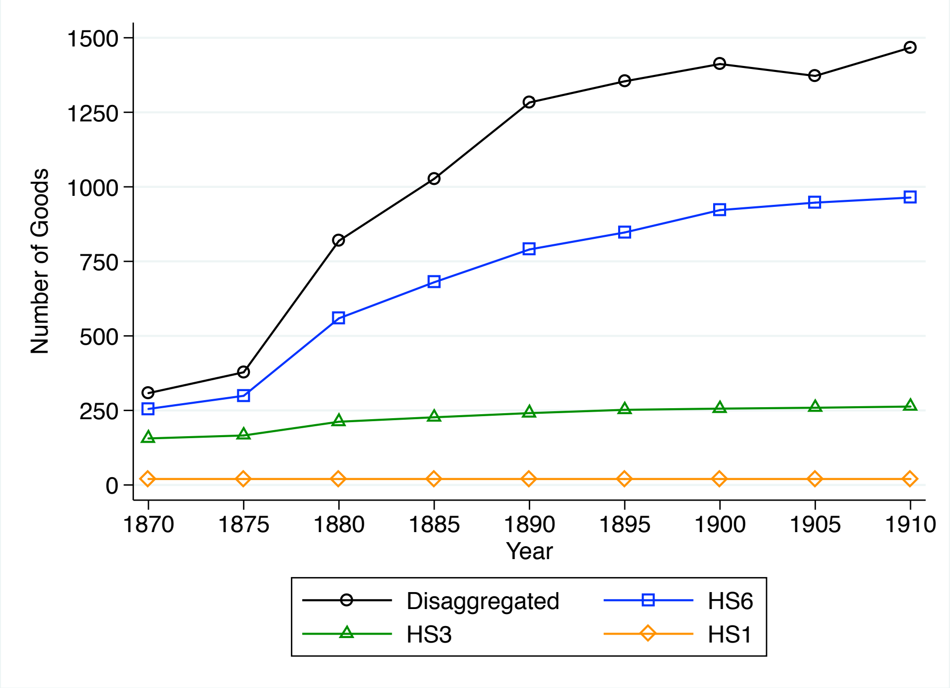


Figure 3.11: Aggregation and The Measurement of Protection

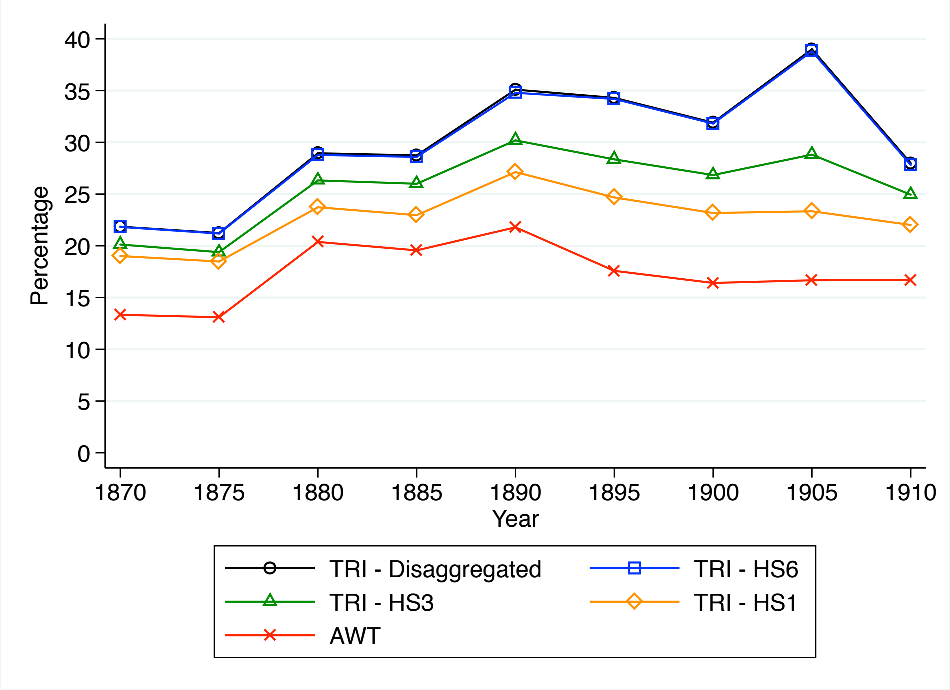
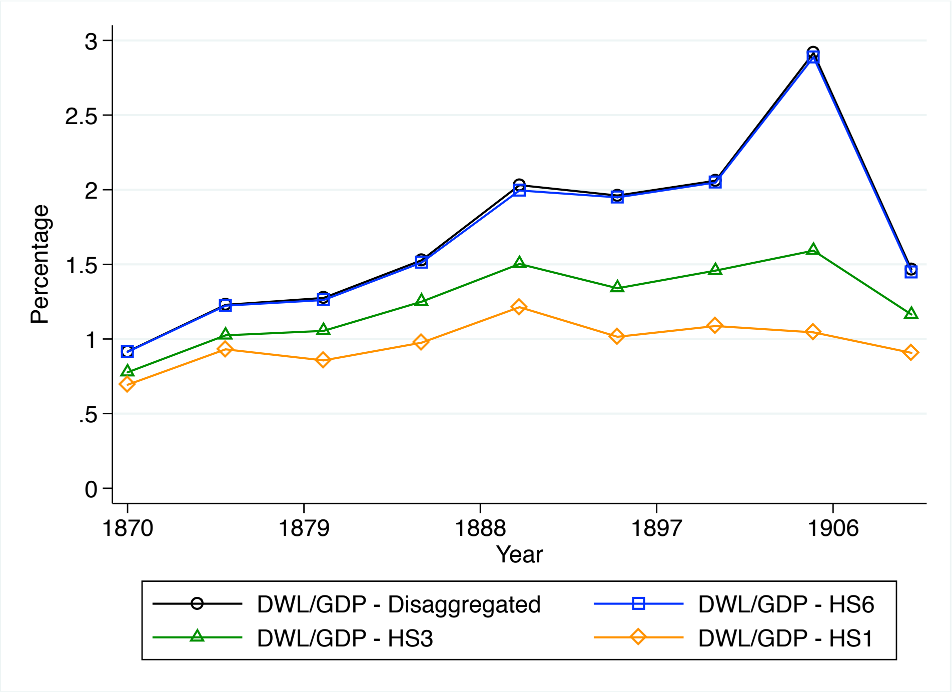


Figure 3.12: Aggregation and The Measurement of Welfare Loss



highly aggregated data in their analysis may fail to capture the full effect of the tariff structure on protection and welfare loss.

3.6 Conclusion

We examine the trade restrictiveness and welfare consequences of trade policy in a small open economy during the first wave of globalization (1870-1913) - a time of an historic transformation of trade policy from revenue- to protectionist-based policy and a time of unprecedented growth in trade. To examine the effects of trade policy on protection and welfare we construct a simplified version of the Anderson-Neary Trade Restrictiveness Index for Canada at the end of the 19th and beginning of the 20th century. We find that the historiography of Canada's trade policy is very different when considered through the lens of the TRI than when only the AWT is considered. The evidence based on the TRI reveals that Canada's trade policy at this time was more restrictive than previously thought. The AWT understates the level of protection by as much as 13 percentage points when compared to the TRI. However, we show that the AWT does a reasonable job of measuring the restrictiveness of trade policy when changes in the tariff are relatively uniform across products as was the case in Canada up to 1885. Thereafter, as the variance of the tariff grew, the AWT became a poor measure of the restrictiveness of trade policy. Moreover, we compute the first estimates of the static welfare losses associated with tariff policy at this time and find the deadweight losses from protectionism amounted to be $0.7 - 1.5\%$ of GDP. These welfare costs based on the TRI are dramatically lower than found in the literature where the welfare costs are inferred from estimates based on later periods.

We present compelling evidence suggesting a re-evaluation of the typical history found in the literature on Canadian protectionism at the end of the 19th century. Most studies focus on the National Policy tariff as the key driver of protectionism because it corresponds to the largest increase in the AWT prior to the Great Depression; later revisions to the tariff schedule are ignored because they do not lead to similar changes in the AWT. The evidence presented here leads one to conclude that these revisions also played an important role in determining the level of protection. In particular, the Tariff Amendment Act of 1887 and Fielding's Tariff of 1897 altered the level of protection a similar amount. Hence, while the National Policy was the beginning of Canadian protectionism, subsequent revisions to the tariff schedule also had a large impact on the level of protection offered by trade policy.

Moreover, we find that most of the increase in trade restrictiveness is from high tariffs on exotic goods with little to no domestic production. From 1875 to 1880, the higher level of trade restrictiveness was primarily driven by an increase in the average tariff across goods. After 1880, tariffs on agricultural and industrial goods increased but most of the observed increase in the TRI is due to increased tariffs on exotic goods - goods that were not produced at home and had inelastic demand. This is not the protectionist trade policy that is presumed based on examining the average tariff. The tariff structure appears to have been designed to maximize revenue and is consistent with the observation that the tariff continued to be the most important revenue source throughout the period.

Our results are robust to the elasticities used in our analysis. While the elasticities we employed were estimated for a much later period, our robustness results show that the trends in protection and welfare loss are not sensitive to changes in the distribution of elasticities. However, the level of both the TRI and DWL/GDP depend on the distribution; our calculated results are less than our simulated results in all years. This suggests that our calculated results represent plausible lower bounds for the magnitudes of protection and welfare loss.

Bibliography

Aldy, Joseph E., "Per Capita Carbon Dioxide Emissions: Convergence or Divergence?," *Environmental and Resource Economics*, 2006, *33*, 533–555.

Amiti, Mary and Jozef Konings, "Trade Liberalization, Intermediate Inputs, and Productivity," *The American Economic Review*, 2007, *97* (05), 1611–1638.

Anderson, James E. and Eric van Wincoop, "Gravity With Gravitas: A Solution to the Border Puzzle," *The American Economic Review*, March 2003, *93* (1), 170–192.

_ **and** _ , "Trade Costs," *Journal of Economic Literature*, 2004, *42* (3), 691–751.

_ **and J. Peter Neary**, "Measuring the Restrictiveness of Trade Policy," *The World Bank Economic Review*, 1994, *8* (2), 151–169.

_ **and** _ , *Measuring the Restrictiveness of International Trade Policy*, The MIT Press, 2005.

Andreoni, James and Arik Levinson, "The Simple Analytics of the Environmental Kuznets Curve," *Journal of Public Economics*, 2001, *80* (2), 269 – 286.

Antweiler, Werner, Brian R. Copeland, and M. Scott Taylor, "Is Free Trade Good for the Environment?," *The American Economic Review*, 2001, *91* (4), 877–908.

Arellano, Manuel and Stephen Bond, "Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equation," *Review of Economic Studies*, 1991, *58* (2), 277–297.

Barbier, Edward B., "Introduction to the Environmental Kuznets Curve Special Issue," *Environment and Development Economics*, 1997, *2*, 369–381.

Barro, Robert J. and Jong-Wha Lee, "A New Data Set of Educational Attainment in the World, 1950–2010," Working Paper 15902, National Bureau of Economic Research April 2010.

Bartelsman, Eric J. and Wayne Gray, "The NBER Manufacturing Productivity Database," Technical Working Paper 205, National Bureau of Economic Research October 1996.

Beaulieu, Eugene, "The Stolper-Samuelson Theorem Faces Congress," *Review of International Economics*, 2002, *10* (2), 343–360.

Bernard, Andrew B., Stephen J. Redding, and Peter K. Schott, "Multiple-Product Firms and Product Switching," *The American Economic Review*, 2010, *100* (1), 70–97.

_ , _ , and _ , "Multiproduct Firms and Trade Liberalization," *The Quarterly Journal of Economics*, 2011, *126* (3), 1271–1318.

Bloom, Nicholas, Mirko Draca, and John Van Reenen, "Trade Induced Technical Change? The Impact of Chinese Imports on Innovation, IT and Productivity," Working Paper 16717, National Bureau of Economic Research January 2011.

Bolle, Mary Jane, "NAFTA: Estimated U.S. Job Gains and Losses by State Over 5-1/2 Years," Report 98-782, Congressional Research Service 2000.

Bovenberg, A. Lans and Sjak Smulders, "Environmental Quality and Pollution-Augmenting Technological Change in a Two-Sector Endogenous Growth Model," *Journal of Public Economics*, 1995, *57*, 369–391.

_ and _ , "Transitional Impacts of Environmental Policy in an Endogenous Growth Model," *International Economic Review*, 1996, *37* (4), 861–893.

Brock, William A. and M. Scott Taylor, "Economic Growth and the Environment: A Review of Theory and Empirics," in Phillipe Aghion and Steven N. Durlauf, eds., *Handbook of Economic Growth*, Vol. 1B, North Holland, 2005, chapter 28, pp. 1749–1821.

_ **and** _ , "The Green Solow Model," *The Journal of Economic Growth*, 2010, *15* (2), 127–153.

Bruvoll, Annegrete and Hege Medin, "Factors Behind the Environmental Kuznets Curve: A Decomposition of the Changes in Air Pollution," *Environmental and Resource Economics*, 2003, *24*, 27–48.

Bulte, Erwin, John A. List, and Mark C. Strazicich, "Regulatory Federalism and the Distribution of Air Pollutant Emissions," *Journal of Regional Science*, 2007, *47* (1), 155–178.

Burfisher, Mary E., Sherman Robinson, and Karen Thierfelder, "The Impact of NAFTA on the United States," *The Journal of Economic Perspectives*, 2001, *15* (1), 125–144.

Bustos, Paula, "Trade Liberalization, Exports and Technology Upgrading: Evidence on the Impact of MERCOSUR on Argentinian Firms," *The American Economic Review*, 2011, *101* (1), 304–340.

Caliendo, Lorenzo and Fernando Parro, "Estimates of the Trade and Welfare Effects of NAFTA," April 2011. Mimeo.

Cameron, Maxwell A. and Brian W. Tomlin, *The Making of NAFTA: How the Deal Was Done*, Cornell University Press, 2000.

Caselli, Francesco, Gerardo Esquivel, and Fernando Lefort, "Reopening the Convergence Debate: A New Look at Cross-Country Growth Empirics," *The Journal of Economic Growth*, 1996, *1*, 363–389.

Cherniwchan, Jevan, "Trade Liberalization, Economic Growth and the Environment," May 2010. Mimeo.

Chintrakarn, Pandej and Daniel L. Millimet, "The Environmental Consequences of Trade: Evidence from Subnational Trade Flows," *Journal of Environmental Economics and Management*, 2006, *52* (1), 430–453.

Cole, Matthew A., "US Environmental Load Displacement: Examining Consumption, Regulations and the Role of NAFTA," *Ecological Economics*, 2004, *48* (4), 439–450.

Copeland, Brian R. and M. Scott Taylor, "North-South Trade and the Environment," *The Quarterly Journal of Economics*, 1994, *109* (3), 755–787.

_ **and** _ , *Trade and the Environment: Theory and Evidence*, Princeton University Press, 2003.

_ **and** _ , "Trade, Growth and the Environment," *Journal of Economic Literature*, 2004, *42* (1), 7–71.

Cox, David and Richard Harris, "Trade Liberalization and Industrial Organization: Some Estimates for Canada," *The Journal of Political Economy*, 1985, *93* (1), 115–145.

Criado, Carlos Ordas, Simone Valente, and Thanasis Stengos, "Growth and the Pollution Convergence Hypthesis: A Nonparametric Approach," *Journal of Environmental Economics and Management*, 2011, *62* (2), 199–214.

Cui, Jingbo, Harvey Lapan, and GianCarlo Moschini, "Are Exporters More Environmentally Friendly than Non-Exporters? Theory and Evidence," 2012. Mimeo.

Dales, J.H., *The Protective Tariff in Canada's Development: Eight Essays on Trade and Tariffs When Factors Move, With Special Reference to Canadian Protectionism, 1870-1955*, University of Toronto, 1966.

Davis, Donald and Carsten Kowalczyk, "Tariff Phase-Outs: Theory and Evidence from GATT and NAFTA," Working Paper 5421, National Bureau of Economic Research January 1996.

Davis, Lucas W. and Matthew E. Kahn, "International Trade in Used Vehicles: The Environmental Consequences of NAFTA," *American Economic Journal: Economic Policy*, 2010, *2* (4), 58–82.

Dean, Judith M., "Does Trade Liberalization Harm the Environment? A New Test," *The Canadian Journal of Economics*, 2002, *35* (4), 819–842.

Deardorff, Alan V., "A Geometry of Growth and Trade," *The Canadian Journal of Economics*, 1974, *7* (2), 295–306.

Easterbrook, W.T. and Hugh G. Aitken, *Canadian Economic History*, The Macmillan Company of Canada Limited, 1965.

Edwards, Sebastian, "The Mexican Peso Criss: How Much Did We Know? When Did We Know It?," *The World Economy*, January 1998, *21* (1), 1–30.

Estevadeordal, Antoni, Brian Frantz, and Alan M. Taylor, "The Rise and Fall of World Trade, 1870-1939," *The Quarterly Journal of Economics*, 2003, *118* (2), 359–407.

Farzin, Y. Hossein and Craig A. Bond, "Democracy and Environmental Quality," *Journal of Development Economics*, 2006, *81* (1), 213–235.

Feenstra, Robert C., "Estimating the Effects of Trade Policy," Working Paper 5051, National Bureau of Economic Research March 1995.

_ , "U.S. Exports, 1972-1994: With State Exports and Other U.S. Data," Working Paper 5990, National Bureau of Economic Research April 1997.

_ **, John Romalis, and Peter K. Schott**, "U.S. Imports, Exports, and Tariff Data, 1989-2001," Working Paper 9387, National Bureau of Economic Research December 2002.

Fernandes, Ana M., "Trade Policy, Trade Volumes and Plant-Level Productivity in Columbian Manufacturing Industries," *Journal of International Economics*, 2007, *71* (1), 52–71.

Frankel, Jeffrey A. and Andrew K. Rose, "Is Trade Good or Bad for the Environment? Sorting Out the Causality," *The Review of Economics and Statistics*, 2005, *87* (1), 85–91.

Gamper-Rabindran, Shanti, "NAFTA and the Environment: What Can the Data Tell Us?," *The Journal of Economic Development and Cultural Change*, 2006, *54* (3), 605–634.

Gawande, Kishore and Usree Bandyopadhyay, "Is Protection for Sale? Evidence on the Grossman-Helpman Theory of Endogenous Protection," *The Review of Economics and Statistics*, 2000, *82* (1), 139–152.

Gillespie, W. Irwin, *Tax, Borrow and Spend: Financing Federal Spending in Canada, 1867-1990*, Ottawa, Canada: Carleton University Press, 1991.

Goldberg, Pinelopi Koujianou, Amit Khandelwal, Nina Pavcnik, and Petia Topalova, "Imported Intermediate Inputs and Domestic Product Growth: Evidence From India," *The Quarterly Journal of Economics*, 2010, *125* (4), 1727–1767.

_ **and Giovanni Maggi**, "Protection for Sale: An Empirical Investigation," *The American Economic Review*, 1999, *89* (5), 1135–1155.

Goldsborough, James O., "California's Foreign Policy," *Foreign Affairs*, 1993, *72* (2), 88–96.

Greenstone, Michael, "Estimating Regulation-Induced Substitution: The Effect of the Clean Air Act on Water and Ground Pollution," *American Economic Review Papers and Proceedings*, 2003, *93* (2), 442–448.

Grossman, Gene and Alan Krueger, "Environmental Impacts of a North American Free Trade Agreement," Working Paper 3914, National Bureau of Economic Research 1991.

_ **and Elhanan Helpman**, "Protection for Sale," *The American Economic Review*, 1994, *84* (4), 833–850.

_ **and** _ , "The Politics of Free-Trade Agreements," *The American Economic Review*, 1995, *85* (4), 667–690.

Grossman, Gene M. and Alan B. Krueger, "Economic Growth and the Environment," *The Quarterly Journal of Economics*, 1995, *110* (2), 353–377.

Gutierrez, Emilio and Kensuke Teshima, "Import Competition and Environmental Performance: Evidence from Mexican Plant-level and Satellite Imagery Data," Discussion Paper 11-01, Instituto Tecnologico Autonomo de Mexico 2011.

Hanson, Gordon H., "Market Potential, Increasing Returns and Goegraphic Concentration," *Journal of International Economics*, 2005, *67*, 1–24.

Harbaugh, William T., Arik Levinson, and David Molloy Wilson, "Reexamining the Empirical Evidence for an Environmental Kuznets Curve," *The Review of Economics and Statistics*, 2002, *84* (3), 541–551.

Harris, R.G. and D. Cox, *Trade, Industrial Policy, and Canadian Manufacturing*, Toronto: Ontario Economic Council, 1984.

Head, Keith and John Ries, "Increasing Returns Versus National Product Differentiation as an Explanation for the Patter of U.S.-Canada Trade," *The American Economic Review*, 2001, *91* (4), 858–876.

Heston, Alan, Robert Summers, and Bettina Aten, "Penn World Table 6.3," August 2009.

Hillberry, Russell and David Hummels, "Intranational Home Bias: Some Explanations," *The Review of Economics and Statistics*, November 2003, *85* (4), 1089–1092.

_ and _ , "Trade Responses to Geographic Frictions: A Decomposition Using Micro-Data," *European Economic Review*, 2008, *52* (3), 527–550.

Holladay, J. Scott, "Are Exporters Mother Nature's Best Friends?," Mimeo 2010.

Holmes, Thomas J. and John J. Stevens, "Exports, borders, distance, and plant size," *Journal of International Economics*, 2012.

Inwood, Kris, "The Representation of Industry in the Canadian Census, 1871-1891," *Histoire Sociale/Social History*, November 1995, *28* (56), 347–374.

Irwin, Douglas A., "Changes in U.S. Tariffs: The Role of Import Prices and Commercial Policies," *The American Economic Review*, 1998, *88* (4), 1015–1026.

_ , “Trade Restrictiveness and Deadweight Losses from U.S. Tariffs,” *American Economic Journal: Economic Policy*, 2010, *2*, 111–133.

Islam, Nazrul, “Growth Empirics: A Panel Data Approach,” *The Quarterly Journal of Economics*, November 1995, *110* (4), 1127–1170.

Jacks, David S., Christopher M. Meissner, and Dennis Novy, “Trade Costs in the First Wave of Globalization,” *Explorations in Economic History*, 2010, *47*, 127–141.

John, A. and R. Pecchenino, “An Overlapping Generations Model of Growth and the Environment,” *The Economic Journal*, 1994, *104* (427), 1393–1410.

Karp, Larry, “The Environment and Trade,” *Annual Review of Resource Economics*, 2011, *3*, 397–417.

Kee, Hiau L., Alessandro Nicita, and Marcelo Olarreaga, “Import Demand Elasticities and Trade Distortions,” *The Review of Economics and Statistics*, November 2008, *90* (4), 666–682.

_ , _ , and _ , “Estimating Trade Restrictiveness Indices,” *The Economic Journal*, 2009, *119*, 172–199.

Khandelwal, Amit and Petia Topalova, “Trade Liberalization and Firm Productivity: The Case of India,” *The Review of Economics and Statistics*, 2011, *93* (3), 995–1009.

Kijima, Masaaki, Katsumasa Nishide, and Atsuyuki Ohyama, “Economic Models for the Environmental Kuznets Curve: A Survey,” *Journal of Economic Dynamics and Control*, 2010, *34*, 1187–1201.

Kim, Sukkoo, "Expansion of Markets and the Geographic Distribution of Economic Activities: The Trends in U.S. Regional Manufacturing Structure, 1860-1987," *The Quarterly Journal of Economics*, November 1995, *110* (4), 881–908.

Kumar, Anil, "Did NAFTA Spur Texas Exports?," *Southwest Economy*, 2006, pp. 3–7.

Leacy, F.H., ed., *Historical Statistics of Canada*, 2 ed., Statistics Canada, 1983.

Lee, Junsoo and John A. List, "Examining Trends of Criteria Air Pollutants: Are the Effects of Governmental Intervention Transitory?," *Environmental and Resource Economics*, 2004, *29*, 21–37.

Lehmann, Sibylle H. and Kevin H. O'Rourke, "The Structure of Protection and Growth in the Late Nineteenth Century," *Review of Economics and Statistics*, 2011, *93* (2), 606–616.

Leonhardt, David, "The Politics of Trade in Ohio," *The New York Times*, February 27 2008.

Levinson, Arik, "Technology, International Trade, and Pollution from US Manufacturing," *The American Economic Review*, 2009, *99* (5), 2177–2192.

_ **and M. Scott Taylor**, "Unmasking the Pollution Haven Effect," *International Economic Review*, 2008, *49* (1), 223–254.

Li, Zhe and Shouyong Shi, "Emission Tax or Standard? The Role of Productivity Dispersion," 2012. Mimeo.

Lileeva, Alla and Daniel Trefler, "Improved Access to Foreign Markets Raises Plant-Level Productivity…For Some Plants," *The Quarterly Journal of Economics*, 2010, *125* (3), 1051–1099.

Liu, Runjuan, "Import Competition and Firm Refocusing," *Canadian Journal of Economics*, 2010, *43* (2), 440–466.

Lloyd, Peter and Donald MacLaren, "Partial- and General-Equilibrium Measures of Trade Restrictiveness," *Review of International Economics*, 2010, *18* (5), 1044–1057.

Lopez, Ramon, "The environment as a factor of production: The effects of economic growth and trade liberalization," *Journal of Environmental Economics and Management*, September 1994, *27* (2), 163–184.

Mankiw, N. Gregory, David Romer, and David N. Weil, "A Contribution to the Empirics of Economic Growth," *The Quarterly Journal of Economics*, May 1992, *107* (2), 407–437.

Marquez, Jaime, "Long-Period Trade Elasticities for Canada, Japan, and the United States," *Review of International Economics*, 1999, *7* (1), 102–116.

Martin, Leslie A., "Efficiency Gains from Trade: Greenhouse Gas Emissions and India's Manufacturing Firms," Mimeo 2012.

McDiarmid, Orville John, *Commercial Policy in the Canadian Economy*, Cambridge MA: Harvard University Press, 1946.

McLaren, John and Shushanik Hakobyan, "Looking for Local Labor Market Effects of NAFTA," Working Paper 16535, National Bureau of Economic Research November 2010.

Neumark, David, Brandon Wall, and Junfu Zhang, "Do Small Businesses Create More Jobs? New Evidence for the United States From the National Establishment Time Series," *The Review of Economics and Statistics*, 2011, *93* (1), 16–29.

Nickell, Stephen, "Biases in Dynamic Models With Fixed Effects," *Econometrica*, 1981, *49* (6), 1417–1426.

Norrie, Kenneth and Douglas Owram, *A History of the Canadian Economy*, Harcourt Brace Jovanovich Canada Inc., 1991.

O'Rourke, Kevin H., "Measuring Protection: A Cautionary Tale," *Journal of Development Economics*, 1997, *53*, 169–183.

_ , "Tariffs and Growth in the Late 19th Century," *The Economic Journal*, 2000, *110* (463), 456–483.

Pavcnik, Nina, "Trade Liberalization, Exit, and Productivity Improvements: Evidence From Chilean Plants," *The Review of Economic Studies*, January 2002, *69* (1), 245–276.

Pierce, Justin R. and Peter K. Schott, "A Concordance Between Ten-Digit U.S. Harmonized System Codes and SIC/NAICS Product Classes and Industries," Working Paper 15548, National Bureau of Economic Research November 2009.

Pinchin, Hugh McAlester, "Canadian Tariff Levels 1870-1959." PhD dissertation, Yale University 1970.

Pomfret, Richard, *The Economic Development of Canada*, Nelson Canada, 1993.

Romalis, John, "NAFTA's and CUSTFA's Impact on International Trade," *The Review of Economics and Statistics*, 2007, *89* (3), 416–435.

Sachs, Jeffrey, Aaron Tornell, and Adres Velasco, "The Collapse of the Mexican Peso: What Have We Learned?," *Economic Policy*, 1996, *11* (22), 15–56.

Scheve, Kenneth F. and Matthew J. Slaughter, "What Determines Individual Trade-Policy Preferences?," *Journal of International Economics*, 2001, *54*, 267–292.

Schmitz, James A., "What Determines Productivity? Lessons from the Dramatic Recovery of the U.S. ad Canadian Iron Ore Industries Following Their Early 1980s Crisis," *Journal of Political Economy*, 2005, *113* (3), 528–625.

Scott, Robert E., "Heading South: U.S.-Mexico Trade and Job Displacement after NAFTA," EPI Briefing Paper 308, Economic Policy Institute May 2011.

Selden, Thomas M. and Daqing Song, "Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions?," *Journal of Environmental Economics and Management*, 1994, *27*, 147–162.

_ **, Anne S. Forrest, and James E. Lockhart**, "Analyzing the Reductions in U.S. Air Pollution Emissions: 1970 to 1990," *Land Economics*, 1999, *75* (1), 1–21.

Smulders, Sjak, Lucas Bretschger, and Hannes Egli, "Economic Growth and the Diffusion of Clean Technologies: Explaining Environmental Kuznets Curves," *Environmental and Resource Economics*, 2011, *49*, 79–99.

Solow, Robert M., "A Contribution to the Theory of Economic Growth," *The Quarterly Journal of Economics*, 1956, *70* (1), 65–94.

Stern, David I., "The Rise and Fall of the Environmental Kuznets Curve," *World Development*, 2004, *32* (8), 1419–1439.

_ , "Revesal of the Trend in Global Anthropogenic Sulfur Emissions," *Global Environmental Change*, 2006, *16*, 207–220.

_ , "The Effect of NAFTA on Energy and Environmental Efficiency in Mexico," *Policy Studies Journal*, 2007, *35* (2), 291–322.

_ **and Michael S. Common**, "Is There an Environmental Kuznets Curve for Sulfur?," *Journal of Environmental Economics and Management*, 2001, *41* (2), 162–178.

Stokey, Nancy L., "Are There Limits to Growth?," *International Economic Review*, February 1998, *39* (1), 1–31.

Strazicich, Mark C. and John A. List, "Are CO2 Emissions Levels Converging Among Industrial Countries?," *Environmental and Resource Economics*, 2003, *24* (3), 263–271.

Taylor, K.W., "The Commercial Policy of Canada," in H.R. Kemp, ed., *Canadian Marketing Problems*, Toronto: University of Toronto Press, 1939.

Taylor, M. Scott, "Unbundling the Pollution Haven Hypothesis," *Advances in Economic Analysis and Policy*, February 2004, *4* (2), 1–26.

Torras, Mariano and James K. Boyce, "Income, Inequality and Pollution: A Reassessment of the Environmental Kuznets Curve," *Ecological Economics*, 1998, *25*, 147–160.

Trefler, Daniel, "Trade Liberalization and the Theory of Endogenous Protection: An Econometric Study of U.S. Import Policy," *Journal of Political Economy*, 1993, *101* (1), 138–160.

_ , "The Long and Short of the Canada-U.S. Free Trade Agreement," *The American Economic Review*, 2004, *94* (4), 870–895.

Urquhart, M.C., *Gross National Product, Canada, 1870-1926: The Derivation of the Estimates*, McGill-Queen's University Press, 1993.

Verhoogen, Eric A., "Trade, Quality Upgrading, and Wage Inequality in the Mexican Manufacturing Sector," *The Quarterly Journal of Economics*, 2008, *123* (2), 489–530.

Wolf, Holger C., "Intranational Home Bias in Trade," *The Review of Economics and Statistics*, November 2000, *82* (4), 555–563.

Wonnacott, R.J. and P. Wonnacott, *Free Trade Between the United States and Canada: The Potential Economic Effects*, Cambridge MA: Harvard University Press, 1967.

Xepapadeas, Anastasios, "Economic Growth and the Environment," in Karl-Goran Maler and Jeffrey R. Vincent, eds., *Handbook of Environmental Economics*, Vol. 3, North Holland, 2005, chapter 23, pp. 1217–1271.

Yilmazkuday, Hakan, "Understanding Interstate Trade Patterns," *Journal of International Economics*, January 2012, *86* (1), 158–166.

Young, J.H., *Canadian Commercial Policy*, Ottawa, Canada: Royal Commision on Canada's Economic Prospects, 1957.

Appendix A

Appendix to Chapter 1

This appendix describes additional details of the data construction and cleaning required to create the pollution data used in the analysis presented in Chapter 1.

A.1 Data Construction

My emissions data comes from the Toxic Release Inventory (TRI) that is maintained by the Environmental Protection Agency. This data set contains detailed information on emissions of all TRI-listed toxic chemicals from plants that are required to report under the EPCRA of 1986. While this data contains detailed information on pollution emissions, several steps must be taken before the data can be utilized.

I begin by creating a dataset of plant-level pollution emissions by linking the annual datasets available from the Toxic Release Inventory. In its raw form, this dataset contains information on the emissions of every chemical reported by each plant in every year it is required to report. However, there have been numerous changes in the list of covered chemicals since the TRI's inception, meaning that changes the total level of emissions reported by any one plant may be due to changes in the list of chemicals that the plant is required to report rather than a change in economic activity. To address this, I exclude any chemicals that are not listed on the TRI throughout my period of study.

For each plant, I also exclude any chemicals that are reported under the Alternate Threshold for Facilities With Low Annual Reportable Amounts in any year. This threshold was enacted on November 30, 1994, and established an alternative reporting requirement for chemicals with annual releases of less than five hundred pounds (under this threshold, plants are required to report if they manufacture, process or otherwise use a regulated substance in excess of one million pounds per year). In practice, this means some plants were no longer required to report their emissions of some chemicals in the middle of my period of study. Excluding these chemicals for each plant ensures that I am not capturing decreases in emissions due to the change in reporting threshold.

Lastly, I exclude any chemicals for which releases are reported using range codes in any year. In the TRI reporting forms, plants can document pollution releases using range codes for reports of less than one thousand pounds. In these cases, emissions are reported using a range (either 1-10, 11-499 or 500-1000 pounds) and then recorded in the TRI data using the midpoint of the range. However, most plants do not use range codes, making it impossible to use standard approaches to deal with censoring. As such, I drop these chemicals from the data.

After these restrictions, I am left with a dataset that contains information on the annual emissions of various chemicals by plant. These substances come from a variety of sources and production methods, meaning the toxic chemicals produced at each plant may not share similar characteristics. To deal with this, I classify these chemicals as volatile organic compounds, particulate matter, lead and other toxic chemicals using the correspondence developed by Greenstone (2003) and create a separate dataset for each pollutant. Given my focus on emissions to air, land and water, I then restrict the data further to only include plants with positive emissions to at least one of these media. I also exclude plants with unrealistically large spikes in the data by dropping the first and ninety-ninth percentiles of the distribution of plant-level emissions growth.

Appendix B

Appendix to Chapter 2

This appendix includes the proofs to the propositions, additional derivations and details of the data used in the analysis presented in Chapter 2.

B.1 Proofs to Propositions

Proposition 1

To begin, recall that the growth rate of capital,

$$\frac{\dot{k}}{k} = \frac{sG(p,k)}{k} - (\delta + n + g_B) \tag{B.1}$$

is the difference between two terms: the savings curve, $[s/k]G(p,k)$, and the depreciation curve, $[\delta + n + g_B]$.

Existence. Note that:

$$\lim_{k \to 0} \frac{G(p,k)}{k} = \lim_{k \to 0} \frac{ph(k)}{k} = \lim_{k \to 0} ph'(k) = \infty \tag{B.2}$$

where the second equality follows from L'Hopital's rule and the third follows from the Inada conditions. Similarly:

$$\lim_{k \to \infty} \frac{G(p,k)}{k} = \lim_{k \to \infty} \frac{[1-\theta]f(k)}{k} = \lim_{k \to \infty} [1-\theta]f'(k) = 0 \tag{B.3}$$

Again, the second equality follows from L'Hopital's rule and the third follows from the Inada conditions. The savings curve must intersect with the depreciation curve and a balanced growth path must exist.

Uniqueness. The savings curve can be rewritten as $(G(p,k)/k) = p(h(k)/k)$ if $k \leq k_y$. Hence:

$$\frac{\partial (G(p,k)/k)}{\partial k} = -\frac{1}{k}\left[\frac{ph(k)}{k} - ph'(k)\right] \tag{B.4}$$

Given $ph(k)/k - ph'(k) = w > 0$, $\partial(G(p,k)/k)/\partial k < 0$. Similarly if $k \geq k_x$, the savings curve can be rewritten as $(G(p,k)/k) = (1-\theta)(f(k)/k)$ and

$$\frac{\partial(G(p,k)/k)}{\partial k} = -\frac{[1-\theta]}{k}\left[\frac{f(k)}{k} - f'(k)\right] \tag{B.5}$$

As before, $f(k)/k - f'(k) = w > 0$, so $\partial(G(p,k)/k)/\partial k < 0$. To find $\partial(G/k)/\partial k$ for $k \in (k_y, k_x)$, note that gross national product must be equal to the total wages paid to all of the factors plus the lump-sum transfer of environmental tax revenue back to consumers: $G(p,k) = rk + w + \tau z$. Differentiating the savings curve yields:

$$\frac{\partial(G/k)}{\partial k} = \frac{G(p,k)}{k}\left[\frac{\partial G(p,k)}{\partial k}\frac{k}{G(p,k)} - 1\right] \tag{B.6}$$

Note that $\partial G(p,k)/\partial k = r$ and $rk/G(p,k) < 1$, so $\partial(G(p,k)/k)/\partial k < 0$. This means $\partial(G(p,k)/k)/\partial k < 0$ for all $k > 0$ and the balanced growth path is unique.

Stability. The conditions for existence and uniqueness ensure that the savings curve only cuts the depreciation curve from above. This ensures the stability of the balanced growth path. □

Proposition 2

To begin, note that the growth rate of aggregate emissions can be written as:

$$\frac{\dot{Z}}{Z} = g_z + \left[\frac{k}{k-k_y}\right]\left[\frac{\dot{k}}{k}\right] \tag{B.7}$$

where $k > k_y$ because the economy is diversified. Substituting for $\dot{k}/k$:

$$\frac{\dot{Z}}{Z} = g_z + \left[\frac{sG(p,k)}{k-k_y}\right] - \left[\frac{k}{k-k_y}\right][\delta + n + g_B] \tag{B.8}$$

Differentiating yields:

$$\frac{\partial(\dot{Z}/Z)}{\partial k} = \frac{[sr - [\delta+n+g_B]][k-k_y] - [sG(p,k) - [\delta+n+g_B]k]}{[k-k_y]^2} \tag{B.9}$$

where $r = \partial G(p,k)/\partial k$. Along the balanced growth path, $\dot{k}/k = 0$. Given that $G(p,k) = rk + w + \eta x$, this means that on the balanced growth path:

$$sr - [\delta + n + g_B] = -\left[\frac{sw}{k^*} + \frac{s\eta x^*}{k^*}\right] \tag{B.10}$$

where k^* and x^* denote the fixed levels of capital and industrial output per effective worker along the balanced growth path. Substituting (B.10) into (B.9) yields:

$$\frac{\partial(\dot{Z}/Z)}{\partial k} = \frac{-[sw/k^* + s\eta x^*/k^*][k - k_y] - [sG(p,k) - [\delta + n + g_B]k]}{[k - k_y]^2} \tag{B.11}$$

Given Proposition 1, if $k < k^*$, $sG(p,k) > [\delta + n + g_B]k$ and $\partial(\dot{Z}/Z)/\partial k < 0$. Thus, the growth rate of aggregate emissions in falling as capital accumulates. Moreover, suppose that the growth rate of aggregate emissions is zero. From (B.7), this implies:

$$\frac{\dot{k}}{k} = -g_z\left[\frac{k - k_y}{k}\right] > 0 \tag{B.12}$$

where $g_Z < 0$ by sustainability. Given the results of Proposition 1, this means $\dot{Z}/Z = 0$ for some $k < k^*$. Denote this k as k^p. Clearly, if $k_0 < k^p$, emissions peak during the transition to the balanced growth path. If instead $k_0 \geq k^p$, emissions decline monotonically as the economy approaches the balanced growth path. □

Proposition 3

To begin, note $\dot{\phi}(p,k)/\phi(p,k) = \varepsilon_{\phi k}[\dot{k}/k]$ and $\dot{G}(p,k)/G(p,k) = \varepsilon_{Gk}(\dot{k}/k)$ (where $\varepsilon_{\phi k}$ and ε_{Gk} denote the elasticities of composition and output). This means equation (2.12) can be written as:

$$\frac{\dot{Z}}{Z} = g_z + (\varepsilon_{\phi k} + \varepsilon_{Gk})\frac{\dot{k}}{k} \tag{B.13}$$

Proposition 1 indicates the economy converges to the balanced growth path given any $k_0 > 0$ and fixed p. Given the above equation, this means that any two countries that differ only in their initial endowments of capital per effective worker will undergo convergence in pollution levels as they industrialize. □

B.2 Derivation of Estimating Equation

To evaluate the theory's predictions about convergence, I derive an estimating equation from the theory. To begin, rewrite equation (2.12) in terms of pollution per effective worker at time t:

$$\frac{\dot{z}(t)}{z(t)} = -g_A + \frac{\dot{\phi}(p, k(t))}{\phi(p, k(t))} + \frac{\dot{G}(p, k(t))}{G(p, k(t))} \tag{B.14}$$

where, as before, $-g_A$ is the technique effect, $\dot{\phi}(p, k(t))/\phi(p, k(t))$ is the composition effect, and $\dot{G}(p, k(t))/G(p, k(t))$ is the scale effect.

Using the fact $\dot{\phi}(p, k(t))/\phi(p, k(t)) = \varepsilon_{\phi k}[\dot{k}(t)/k(t)]$ and $\dot{G}(p, k(t))/G(p, k(t)) = \varepsilon_{Gk}[\dot{k}(t)/k(t)]$ (where $\varepsilon_{\phi k}$ and ε_{Gk} denote the elasticities of composition and output), rewrite equation (B.14) as:

$$\frac{\dot{z}(t)}{z(t)} = -g_A + \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] \frac{\dot{G}(p, k(t))}{G(p, k(t))} \tag{B.15}$$

Next, approximate growth in emissions per effective worker and capital per effective worker over a period $[t_1 - t_0]$. This yields:

$$\frac{\ln[z(t_1)/z(t_0)]}{[t_1 - t_0]} = -g_A + \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] \frac{\ln[G(t_1)/G(t_0)]}{[t_1 - t_0]} \tag{B.16}$$

To obtain a discrete approximation of the growth rate of income per capita, log-linearize the model around the balanced growth path:

$$\ln[G(t_1)/G(t_0)] = [1 - e^{-\lambda[t_1 - t_0]}][\ln G^* - \ln G(t_0)] \tag{B.17}$$

where G^* is the level of income per effective worker on the balanced growth path and $\lambda = [1 - \varepsilon_{Gk}][\delta + n + g]$ is the speed of convergence. Substitute equation (B.17) into equation (B.16), to obtain:

$$\frac{\ln[z(t_1)/z(t_0)]}{[t_1 - t_0]} = -g_A + \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] \frac{[1 - e^{-\lambda[t_1 - t_0]}]}{[t_1 - t_0]}[\ln G^* - \ln G(t_0)] \tag{B.18}$$

Note $G(t_0) = z(t_0)/a\Omega(t_0)\phi(t_0)$, and at any point in time $z(t) = z^c(t)/B(t)$, where $z^c(t)$ denotes emissions per capita at time t. Given $B(t) = e^{g_B t}B(0)$ and $\Omega(t) = e^{-g_A t}\Omega(0)$, where $B(0)$ and $\Omega(0)$ are the initial levels of the production and abatement technologies, rewrite equation (B.18) in per capita terms as:

$$\begin{aligned}\frac{\ln z^c(t_1) - \ln z^c(t_0)}{[t_1 - t_0]} = &- \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] \frac{[1 - e^{-\lambda[t_1 - t_0]}]}{[t_1 - t_0]} \ln z^c(t_0) \\ &+ \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] \frac{[1 - e^{-\lambda[t_1 - t_0]}]}{[t_1 - t_0]} \ln \phi(t_0) \\ &+ \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] \frac{[1 - e^{-\lambda[t_1 - t_0]}]}{[t_1 - t_0]} \ln G^* \\ &+ \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] \frac{[1 - e^{-\lambda[t_1 - t_0]}]}{[t_1 - t_0]}[\ln \tilde{a} + \ln \Omega(0) + \ln B(0)] \\ &+ \left[-g_A + g_B \left[1 + \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] [1 - e^{-\lambda[t_1 - t_0]}) t_0\right]\right]\end{aligned} \tag{B.19}$$

I reformulate (B.19) as a dynamic panel data model, yielding:

$$\begin{aligned}\ln z^c(t_1) = &\left[1 - \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] [1 - e^{-\lambda[t_1 - t_0]}]\right] \ln z^c(t_0) \\ &+ \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] [1 - e^{-\lambda[t_1 - t_0]}] \ln \phi(t_0) \\ &+ \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] [1 - e^{-\lambda[t_1 - t_0]}] \ln G^* \\ &+ \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] [1 - e^{-\lambda[t_1 - t_0]}][\ln \tilde{a} + \ln \Omega(0) + \ln B(0)] \\ &+ [t_1 - t_0] \left[-g_A + g \left[1 + \left[\frac{\varepsilon_{\phi k} + \varepsilon_{Gk}}{\varepsilon_{Gk}}\right] [1 - e^{-\lambda[t_1 - t_0]}] t_0\right]\right]\end{aligned} \tag{B.20}$$

This equation links emissions per capita in any period to emissions per capita in the previous period and additional controls.

B.3 Data

B.3.1 Summary Statistics

Summary statistics for the full sample and selected years are reported in Table 5.

Table B.1: Summary Statistics: Selected Years

Variable	Year 1970	1980	1990	2000	Full Sample
z_t^c	0.0222	0.0242	0.0177	0.0106	0.0171
	(0.0432)	(0.0482)	(0.0297)	(0.0154)	(0.0309)
ϕ_t	0.3054	0.3355	0.3203	0.3077	0.3114
	(0.1295)	(0.1445)	(0.1155)	(0.1256)	(0.1224)
s_t	0.2157	0.2301	0.2005	0.1990	0.2061
	(0.1354)	(0.1210)	(0.1153)	(0.1164)	(0.1181)
$(\delta + n + g)_t$	0.0708	0.0718	0.0695	0.0645	0.0691
	(0.0139)	(0.0185)	(0.0140)	(0.0116)	(0.0165)
Obs.	94	111	133	152	3787

Note: Standard errors are reported in parentheses.

B.3.2 Data Sources

The dataset was compiled from a variety of sources. A listing of each variable and its source are given below.

Sulfur emissions per capita: This variable was created using sulfur emissions data from Stern (2006) and population data from the Penn World Tables.

Value share of industrial production in GDP: This variable was taken from the World Bank's World Development Indicators.

Savings rate: This variable was obtained from the Penn World Tables.

Population growth rate: This variable was constructed using population data from the Penn World Tables.

Openness: This variable was obtained from the Penn World Tables.

No school: This variable measures the percentage of the population with no schooling and was created from the Barro-Lee Educational Attainment Data Set (see Barro and Lee (2010)). The Barro-Lee dataset reports this variable at five year intervals; this was linearly interpolated to create an annual dataset.

School years: This variable measures average years of schooling attained and was created from the Barro-Lee Educational Attainment Data Set. The Barro-Lee dataset reports this variable at five year intervals; this was linearly interpolated to create an annual dataset.

PolityIV: This variable was obtained from the World Bank's World Development Report 2011 and reports the revised combined polity score, Polity2_PolityIV.

Gini: This variable was constructed using data from the UNU/WIDER World Income Inequality Database.

Hardcoal Supply: This variable measures the domestic supply of hard coal and was obtained from the International Energy Agency's statistics available from the OECD.

B.3.3 Countries in the Data

The countries in the data are: ($\star$ indicates OPEC membership, † indicates population less than one million in at least one year, $\diamondsuit$ indicates the country received a grade of "D" from the Penn World Tables)

Low Income Countries: Bangladesh, Benin, Burkina Faso, Burundi, Cambodia$^{\diamondsuit}$, Central African Republic$^{\diamondsuit}$, Chad$^{\diamondsuit}$, Democratic Republic of Congo$^{\diamondsuit}$, Eritrea$^{\diamondsuit}$, Ethiopia, Ghana, Guinea, Guinea-Bissau$^{\diamondsuit}$, Kenya, Kyrgyzstan, Laos$^{\diamondsuit}$, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique$^{\diamondsuit}$, Nepal, Niger$^{\diamondsuit}$, Rwanda, Senegal, Sierra Leone, Somalia, Tajikistan$^{\diamondsuit}$, Tanzania, Togo$^{\diamondsuit}$, Uganda$^{\diamondsuit}$, Uzbekistan$^{\diamondsuit}$, Vietnam, Yemen$^{\diamondsuit}$, Zambia, Zimbabwe

Lower Middle Income Countries: Albania, Angola$^{\star\diamondsuit}$, Armenia, Azerbaijan, Bhutan$^{\dagger\diamondsuit}$, Bolivia, Cameroon, Cape Verde$^{\dagger\diamondsuit}$, China, Congo, Republic of, Cote d'Ivoire, Djibouti$^{\dagger\diamondsuit}$, Ecuador*, Egypt, El Salvador, Georgia, Guatemala, Guyana$^{\dagger\diamondsuit}$, Honduras, India, Indonesia*, Iran*, Iraq*, Jordan, Moldova, Mongolia$^{\diamondsuit}$, Morocco, Nicaragua, Pakistan, Papua New Guinea$^{\diamondsuit}$, Paraguay, Philippines, Sri Lanka, Sudan$^{\diamondsuit}$, Swaziland, Syria, Thailand, Tunisia, Turkmenistan$^{\diamondsuit}$, Ukraine

Upper Middle Income Countries: Algeria$^{\star\diamondsuit}$, Argentina, Belarus$^{\diamondsuit}$, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Chile, Colombia, Costa Rica, Cuba$^{\diamondsuit}$, Dominican Republic, Fiji†, Gabon*, Jamaica, Kazakhstan, Latvia, Lebanon, Lithuania, Macedonia, Malaysia, Mauritius, Mexico, Namibia$^{\diamondsuit}$, Panama, Peru, Poland, Romania, Russia, South Africa, Suriname†, Turkey, Uruguay, Venezuela*

High Income (Non-OECD) Countries: Antigua and Barbuda†, Bahamas†, Bahrain†, Barbados†, Brunei†, Croatia, Cyprus$^{\dagger\diamondsuit}$, Estonia, Hong Kong, Kuwait*, Macao†, Malta$^{\dagger\diamondsuit}$, Oman, Puerto Rico$^{\diamondsuit}$, Saudi Arabia$^{\star\diamondsuit}$, Singapore, Slovenia, Trinidad and Tobago, United Arab Emirates*

OECD Countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland†, Ireland, Italy, Japan, Republic of Korea, Luxembourg†, Netherlands, New Zealand, Norway, Portugal, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom, United States