# ESSAYS ON ENVIRONMENTAL REGULATIONS AND INTERNATIONAL ECONOMICS

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF THE UNIVERSITY OF MINNESOTA
BY

AYSE MUJDE ERDOGAN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

Timothy J. Kehoe

August, 2009

UNIVERSITY OF MINNESOTA

## Acknowledgements

I am grateful to my adviser, Timothy Kehoe, for his continuous encouragement, guidance and tolerance throughout the process of writing this dissertation. I also thank Fabrizio Perri and Cristina Arellano for their valuable suggestions and support. I would like to extend my thanks to Rodney Smith for his feedback and help by serving in my preliminary oral exam and Ph.D. defense committees. I also thank all participants of the Trade and Development Workshop and Minneapolis Federal Reserve Bank Seminar Series for the useful comments that they provided. I gratefully acknowledge that this dissertation is partially funded by the Sandor Fellowship by the Department of Economics and the Graduate Research Partnership Program Fellowship by the CLA at the University of Minnesota.

I am thankful to all friends at the graduate school, especially Turkmen Goksel and Umut Kuzubas, for all the academic and non-academic discussions we shared. I would like to thank my dear friends, Zeynep and Serdar Sezen, Hande and Erkan Tuzel for their warm and genuine friendship that greatly helped me to keep my spirits up during the trying times.

I owe thanks to my parents and grandparents who instilled in me an indelible love for learning and all members of my family who included me in their prayers and gave me strength despite the distance.

Finally, I wish to express my deepest gratitude to my husband, Gurkan, for his unconditional love and endless patience. We started this journey together and I would not have been able to accomplish it without him.

*To my husband, Gurkan Erdogan...*

# Abstract

This dissertation is a collection of three essays that study the links between environmental regulations and international trade and capital flows.

The first essay investigates the relative importance of environmental regulations in shaping trade patterns of manufactured goods with particular reference to the OECD countries. I introduce environmental regulation and factor endowment differentials into a multi-country general equilibrium model of bilateral trade with random productivities and trade barriers along the line of Eaton and Kortum (2002) and Alvarez and Lucas (2007). In this framework, comparative advantage is determined by an interaction of both country and industry characteristics. I calibrate the model for the OECD countries by estimating trade barriers and productivity parameters so as to match bilateral manufacturing trade shares in year 2000. I show that the calibrated model is capable of generating home trade shares and specialization patterns in pollution-intensive and clean manufacturing goods that are consistent with the data. Next, the model is used to analyze trade and pollution impacts of two types of environmental harmonization policies and trade liberalizations. I find that harmonization of environmental taxes across the OECD countries is predicted to be more effective than the harmonization of pollution quotas in reducing aggregate pollution while under both policies trade impacts are relatively small. I also predict that full trade liberalizations not only have substantial impact on trade but also help to lower OECD pollution emissions by 32%, on average and about half of the decline in pollution is due to international productivity differences.

In the second essay, I specifically consider global pollution problems and theoretically investigate the effects of trade liberalization on the level and concentration of world pollution in presence of endogenous and strategic environmental policy making by involved countries. I study a variation of Copeland and Taylor (1995) two-country Heckscher-Ohlin model of trade with global pollution by incorporating an environment where the incentive to trade is based on differential factor endowments rather than differential environmental standards. First, I show that the model's predictions on trade patterns are qualitatively in agreement with the data. Next, I use

the model to analyze the effects of globalization. I find that free commodity trade can actually lead to improvements in global environmental quality when the two countries are sufficiently different. However, when goods are traded freely, allowing international trade of emission permits or international capital mobility can produce harmful effects on the global environment.

The last essay provides a survey of a broad literature on the relationship between foreign direct investment and environmental policy. First, it focuses on empirical studies that analyze the impact of environmental costs on foreign investment locations. Next, the essay reviews main studies that attempt to explain the lack of evidence for the pollution haven hypothesis. Then, it discusses the literature on the impact of foreign direct investment on local environmental regulations by concentrating on two recent political economy models. Finally, it concludes by summarizing the main findings of the literature and suggesting some future research directions.

# Contents

# List of Figures

# List of Tables

# Chapter 1

# Introduction

There is growing concern over the effects of globalization on environmental quality while there are various international and local attempts to control pollution. The relationship between environment and globalization has been receiving a great deal of attention among both policy-makers and economists, especially since the 1990s. This dissertation seeks answers to the following main questions related to the links between international economics and the environment. Do stringent environmental regulations undermine international competitiveness of domestic industries? How large is the role of environmental regulation differences in shaping international trade and investment patterns in the world? What is the impact of globalization on world pollution levels?

In Chapter 2, I attempt to quantify the impact of environmental standard differentials across the OECD countries on bilateral trade patterns relative to some other factors that can potentially affect a country's comparative advantage. I also develop predictions about possible consequences of some important policy issues on pollution and world trade patterns in the OECD, specifically focusing on trade liberalizations and international harmonization of environmental regulations.

To study these questions, I consider an environment where countries have not only different environmental regulation levels but also different capital abundance levels and productivities. The approach in this essay, therefore, significantly differs from the previous papers on the issue and contributes to the literature in at least two ways: It is the first study that emphasizes and quantifies the role of productivity differences in determining the incidence of world pollution. It also develops a new methodology to quantitatively analyze the interaction between pollution and trade.

The calibrated model produces export-import ratios and home trade shares for pollution-intensive and clean manufacturing industries that are in reasonable agreement with the OECD data. Policy experiments show that trade liberalization facilitates a 32% reduction in average pollution emissions. About one half of this reduction is due to productivity differences between countries. More specifically, when countries open up to trade, part of the production in pollution-intensive goods shifts to high productivity countries where regulation levels are higher and this channel substantially contributes to the decline in emissions. The experiments also yield that a greater reduction in pollution emissions can be achieved through harmonization of pollution *taxes* across the OECD countries than under harmonization of pollution *quotas*.

Chapter 3 is motivated by the desire to understand the impact of free international trade and capital mobility on the incidence of global pollution. In this chapter, I find that, when international trade is triggered by both capital abundance and environmental regulation differences between the countries, trade liberalization can help improvements in global environmental quality. I also emphasize that, under free goods trade, further liberalizations of pollution permit or capital markets are likely to cause global environmental degradation.

Previous theoretical literature on the general equilibrium models of global pollution has been restricted to so-called "pollution haven models" where environmental policy difference is the only motive to trade. However, as documented by numerous studies, other factors determining comparative advantage, such as factor endowments, are likely to dominate differences in policy. Therefore, with pollution haven models it is not possible to capture the international trade patterns observed in the data to start with. Moreover, any policy recommendations based on these models should be approached with scrutiny. Although this idea has been used in several empirical papers and in some models of "local" pollution and trade, there are no studies that incorporated the role of capital abundance motive to trade into a general equilibrium model of "global" pollution. The essay in this chapter, therefore, aims at filling this gap in the literature.

The last chapter surveys a broad literature on the relationship between foreign direct investment (FDI) and the environment. According to UNCTAD (2008), FDI inflows into developing countries rose by 21% in 2007 to reach a record level of $500 billion. The rise in the scale of FDI flowing to developing countries which originally gained pace in the early 1990s, has initiated a large debate about FDI's relevance to environmental standards.

The ideas that surround the debate on the link between FDI flows and environmental standards can be classified into three groups. One of them concerns whether or not multinationals would flock to developing countries to take advantage of lax environmental standards. If FDI is sensitive to lower standards, then developing countries are more likely to experience environmental degradation as a consequence. This topic constitutes a large part of the literature and almost all of the research attempts on this issue are empirical. The second group of studies explores the reasons of the lack of consistent evidence on the responsiveness of FDI to environmental standards. This relatively new strand of the literature offers both some empirical and theoretical explanations to the question in hand. The third group investigates the reverse relationship, that is, the possible effects of FDI on environmental regulations, which is a less explored issue in the literature. If feedback from FDI to regulations exists, then any empirical study that fails to take into account this channel will produce spurious results.

The empirical studies that fall into the first group show that for many firms in many industries environmental compliance costs are not found to be a major determinant of FDI, although in some most pollution-intensive industries anecdotal evidence of industrial relocation from developed to developing countries is found.

The second group of papers attempt to provide an explanation to this weakness of empirical evidence. Most of them point to the empirical challenges in showing the possible link between FDI and environmental standards such as correlations between the host country characteristics and its standards or measurement problems regarding environmental regulations. Eskeland and Harrison (2003) is, arguably, the only study that provides a formal model for the analysis of the phenomenon. They argue that due to the complementarity between capital intensity and pollution abatement, the effect of host country environmental regulations in triggering FDI flows is ambiguous and this could be an explanation to the lack of consistent evidence on the issue.

The literature in the third group is relatively sparse and evidence on whether host countries modify their environmental regulation systems to attract FDI is not consistent. Recently, the attention has shifted towards political processes through which local standards are set. Therefore, I concentrate on two papers which provide political economy models to explain the channels through which FDI may affect environmental standards: Cole et al. (2006) and Cole and Fredriksson (2009). Both papers emphasize the importance of host country characteristics that interfere with the environmental policy making. In Cole et al. (2006), government corruptibility and in Cole and Fredriksson (2009), structure of political institutions in the host country play a role in determining the success of lobbying efforts by the foreign firms to modify environmental regulations. The findings in both papers are also shown to be supported by the empirical tests.

# Chapter 2

# Environmental Regulations and Bilateral Manufacturing Trade: The Case of OECD Countries

## 2.1 Introduction

The relationship between trade and environment has received a great deal of attention especially since the early 1990s, among both academics and policy makers. One particular focus of attention has been on the possible influence of environmental regulation differentials on comparative advantage and international trade patterns. Accompanied with a steady decline in global trade barriers, industrialized nations began legislating and enforcing environmental regulations with substantial compliance costs[1] enlarging the gap between developed and developing countries. This observation brought about some concerns on the sustainability of international competitiveness of the industrialized countries especially in the industries that require pollution-intensive production.

One concern that is implied by the coexistence of differential environmental standards and reduced trade barriers in the world is the possible rise of low income countries as "pollution havens". Several authors have studied the possibility that

[1] Levinson (1996a) presents some evidence of increasing environmental regulations in the developed countries.

trade between two countries with sufficiently different levels of environmental regulation will lead low regulation country to specialize in pollution-intensive production causing it to become a "pollution haven"[2]. In most cases, this possible industrial migration will mean an overall increase in the world pollution levels due to lax environmental policy measures in those countries. Other concerns are centered around the idea that intentional environmental degradation by some developing countries (or alternatively, an increasing regulation gap between world countries) could act as trade barriers, undermining the comparative advantage on the part of industrialized countries.

At the international level, the influence of national environmental regulations on world trade has been an issue on the agenda of many international institutions that aim to facilitate global trade such as GATT, NAFTA and the OECD. Among the others, the OECD made the most systematic effort to address interactions between trade and environmental issues. In 1972, OECD published the work titled "*Guiding Principles Concerning the International Economic Aspects of Environmental Policies*" and put forward the "*Harmonization Principle*"[3]. The pros and cons of the harmonization principle have been a topic of debate since then. Despite these efforts, it is important to note that there exist substantial differences in per capita pollution emissions among the OECD countries[4].

In this essay, I analyze the link between national environmental policy and international trade with particular reference to the OECD countries. I specifically address two points. One aims to understand the role of environmental standard differentials in shaping bilateral trade patterns relative to other factors that potentially affect comparative advantage. The second point focuses on developing predictions about pollution and trade impacts of OECD harmonization policies.

[2]Baumol and Oates (1988), Copeland and Taylor (1994), (1995) are well-known examples of such studies among others.

[3]According to the OECD, harmonization principle should be interpreted as follows: Governments should seek to harmonize environmental policies (i.e., make their regulations similar), unless valid reasons for differences exist. (Valid reasons would include differences from country to country of the environment's capacity to absorb pollution, social priorities, degrees of industrialization, and population density.)

[4]The extent of these differences varies with the type of pollution that is being considered. As an example relevant to this study, air pollution emissions per capita differ by a factor of 52.8 as the data from OECD Environmental Compendium (2004) show.

Although a number of authors empirically tested whether environmental regulations affect trade patterns for a more comprehensive set of countries, the results have rather been inconclusive. Tobey (1990), Janicke et al. (1997) find no evidence that differential environmental standards affect global trade patterns to any significant degree. Jaffe et al. (1995) concludes that there is little evidence to suggest that stringent environmental regulations have a significant effect on industrial competitiveness. On the other hand, Mani and Wheeler (1998) studies the export-import ratio for dirty industries and finds evidence consistent with the pollution haven hypothesis although it is found that such havens have been temporary. Birdsall and Wheeler (1993) and Low and Yeats (1992) also claim to find evidence for the existence of pollution havens. Antweiler et al. (2001) examines the impact of trade liberalization on sulphur dioxide concentrations and finds no evidence of pollution haven pressures.

Besides having ambiguous implications, the empirical studies in the relevant literature fail to capture the interactions between different sectors and countries (i.e. general equilibrium effects) which are crucial factors in understanding international trade patterns. A highly influential study, Antweiler et al. (2001), is an exception to this observation in that the authors utilize reduced form equations from a general equilibrium model for estimation purposes; however, the main structural parameters of the model remain hidden under this approach.

There are also studies which examine the relationship between trade liberalizations and environmental regulations from a theoretical perspective. Copeland and Taylor (1994) and (1995) present two general equilibrium models with local and global pollution, respectively, where there are two regions or countries (high income North and low income South) and a continuum of goods with different pollution intensities. Countries aim to control pollution choosing pollution taxes endogenously. The authors show that after trade liberalization, clean industries expand in North and polluting industries in South as high income North chooses higher environmental taxes.

A critical assumption underlying these results is that comparative advantages in the world are determined solely by differences in environmental standards. An alternative approach is to include factor endowment differences as a factor determining comparative advantage assuming such effects could easily dominate the environmental policy-induced differences. This possibility is mentioned by Antweiler et al. (2001), Copeland and Taylor (2003), (2004) and used as a dominant framework in several empirical studies that examine the impact of environmental regulations on trade patterns. However, a pure Heckscher-Ohlin-Samuelson framework would not be sufficient to analyze the problem in hand since that framework could not capture the determinants of trade between similar countries. Therefore, the question requires the use of a richer model of trade to begin with.

There are two main contributions of this essay. First, it presents an alternative approach under which the impact of domestic environmental regulation levels on international trade can be quantitatively analyzed. The framework used in this essay is mainly built on the seminal work by Eaton and Kortum (2002) but further incorporates the role of environmental regulations, capital abundance and sectoral differences in factor shares. In the general equilibrium model utilized, countries have potentially different capital abundance, productivity and environmental regulation levels or in other words, both Ricardian and Heckscher-Ohlin-Samuelson type incentives to trade are incorporated. Eaton and Kortum (2002) framework produces a gravity equation whose estimation yields an estimate of the trade barriers different countries face. In this essay, trade barriers also differ across industries as another divergence from Eaton and Kortum (2002). Hence, comparative advantages are determined by an interaction of both country and industry characteristics. As a result, the model produces export-import ratios and home trade shares for different industries that are in reasonable agreement with the OECD data.

A related contribution of the essay is that it allows an analysis of international policy implications within a multi-country framework. More specifically, using a calibrated version the model, the essay analyzes possible trade and pollution impacts of trade liberalizations and environmental harmonization policies for the OECD countries.

Within the context of the model, it is predicted that free trade is likely to increase net-exports of pollution-intensive goods by the developed countries in the OECD. In other words, pollution haven effects are not predicted to be dominant. Trade liberalizations also facilitate a 32% reduction in average pollution emissions.

Moreover, depending on the type of the environmental harmonization policy chosen, trade implications and achieved levels of pollution reductions will differ. The model predicts that a greater reduction in pollution emissions can be achieved through harmonization of environmental taxes than under harmonization of pollution quotas while both policies aim to reach highest standards prevailing in the OECD. Overall, although neither of these policies are likely to change the group of countries that are net-exporters of pollution-intensive goods, they are predicted to have opposite average impacts on the specialization patterns.

The remainder of this chapter is organized as follows. In section 2.2, I discuss some data for the set of OECD countries regarding the relation between trade patterns and other indicators to motivate the model choice. In section 2.3, I introduce the model and then define and characterize a trade equilibrium. Section 2.4 describes the calibration procedure and presents the main results from the baseline calibration while section 2.5 discusses some findings from the counterfactual experiments and the impact of two alternative environmental harmonization policies. Finally, section 2.6 concludes.

## 2.2 Data

In table 2.6 presented in appendix C, I list several indicators for the OECD countries corresponding to year 2000, namely, export-import ratios in pollution-intensive ("dirty") manufacturing goods, percentage share of a country's GDP in the total GDP of the OECD countries and capital-labor ratios.

The first column of table 2.6 is formed as follows. First, the dirty manufacturing industries are determined by using the data by Hettige et al. (1987) prepared for the World Bank Industrial Pollution Projections Project (IPPP). The data show several measures of pollution emissions in pounds per number of employees in the US manufacturing sector on an ISIC 3-digit level. I particularly focus on air pollution data due to data availability concerns and rank the US manufacturing sectors according to total amount of air pollution emitted and identify the eight most polluting industries as petroleum refineries, miscellaneous petroleum and coal products, non-ferrous metals, iron and steel, industrial chemicals, other non-metallic mineral products, paper and products and other chemicals. Assuming these pollution intensities are common to all countries, I proceed to calculating the export-import ratios in these polluting sectors using the NBER-UN World Trade Data 1962-2000 by Feenstra et al. (2005). The export and import values for the above-mentioned pollution-intensive goods are aggregated for the year 2000 after the concordance between ISIC and SITC was obtained. An export-import ratio that is greater (less) than one shows that the country is a net exporter (net importer) of the polluting goods.

The second column of table 2.6 shows the percentage share of a country's GDP in total GDP of all OECD countries for the year 2000. The data used is GDP in current US dollars by WDI.

Capital-labor ratios were derived using Heston, Summers and Aten (2006) data. Aggregate labor was calculated as the number of workers and aggregate capital using the aggregate investment data, 0.06 depreciation rate and calculating the average geometric growth rate of aggregate investment, following Caselli (2005). Then the ratios are expressed as indices calculated in relation to the OECD average where the average is 100.

We observe that countries that are net exporters of pollution-intensive goods have relatively higher capital-labor ratios on average. This tendency can be more clearly observed in figure 2.1. In the figure, countries that lie above the horizontal line through 1 are mostly developed and capital abundant OECD countries. The exceptions to this pattern are the cases of Korea and Slovakia however, high export-import ratios in those countries can rather be explained with much higher levels of import tariffs. Excluding Korea and Slovakia, net exporters of dirty manufacturing goods in OECD have an average capital-labor ratio of 126.7 while the OECD average is taken as 100.

An opposite tendency is observed for countries who are net importer of pollution-intensive goods with an export-import ratio that is less than 0.8. Many of the developing countries within the OECD, namely, Turkey, Czech Republic, Poland, Mexico, Hungary, Portugal and Greece have capital-labor indices that are below 100 with net export-import ratios below 1. Excluding the United States, these countries have an average capital-labor ratio of 59.1 while the OECD average is 100.

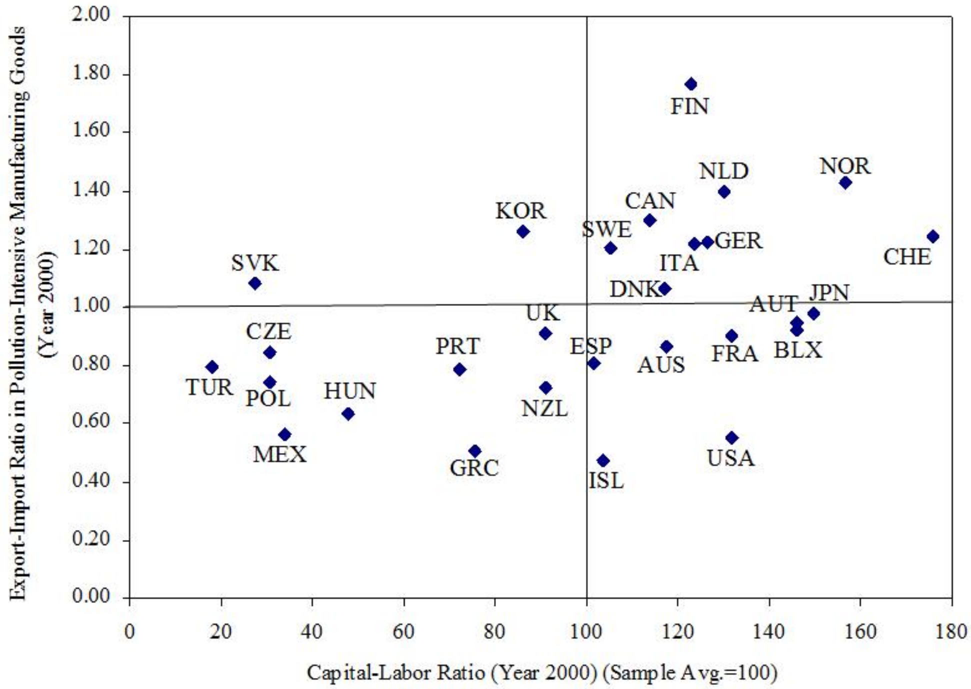


Figure 2.1: Relationship between capital abundance indices and export-import ratios in the pollution-intensive manufacturing industry; Data for the OECD countries, year 2000.

Moreover, these countries also have relatively low incomes; their average percentage share in total OECD income is 0.64% while the value for net exporter countries is about 2%.

Overall, the evidence implies that in an attempt to understand the international trade patterns in dirty manufacturing goods, a pure Ricardian model of trade would not suffice since in that case, the implied positive relation between sectoral pollution intensity and capital abundance of a country could not be captured. On the other hand, "pollution haven models" in which trade incentives solely depend on differential environmental regulations would not be capable of replicating the trend in the data, either. The main prediction of such models is that due to lower regulations, trade leads developing countries to specialize in the pollution-intensive sectors whereas clearly, the evidence presented in this section is in contrast with this prediction. To address these problems, in the next section, I utilize a much richer framework that allows sectoral analysis of trade patterns.

## 2.3 The Model

The multi-country model I employ is a variation of Eaton and Kortum (2002) model of bilateral trade patterns in that it assumes random productivities within a perfectly competitive framework. However, it departs from Eaton and Kortum (2002) in that it further incorporates capital abundance and environmental costs of production as other potential determinants of trade. Furthermore, while Eaton and Kortum (2002) does not differentiate between goods from different sectors, this model assumes that there are a finite number of final good industries that differ in capital and pollution intensities. This multi-industry approach is needed in order to be able to capture the role of environmental regulations in shaping bilateral trade patterns of goods from different industries.

I consider a world with $N$ countries indexed by $n = 1, 2, ..., N$, each of which can potentially have different capital abundance and environmental pollution levels.

### 2.3.1 Production

I assume that in each country there are $M$ (finite) final good industries, indexed by $m = 1, 2, ..., M$. In each country $n$, within each industry, there is a continuum of perfectly competitive goods produced with random inverse productivities, $j_n$. All goods are tradeable final goods and no intermediate goods exist.

Random inverse productivity, $j_n$, is drawn from an exponential distribution with a country-specific parameter $\lambda_n^m$. In other words, $\lambda_n^m$ governs the average level of efficiency of country $n$ in the production such that a relatively higher $\lambda_n^m$ implies that country $n$ is on average more efficient. The vector of technological draws is $j = (j_1, ..., j_N)$ with $j \in R_+^N$ and assuming draws are independent across countries, the joint density of $j$ is found as follows.

$$\psi(j) = \left( \prod_{n=1}^{N} \lambda_n^m \right) \exp \left( - \sum_{n=1}^{N} \lambda_n^m j_n \right) \tag{2.3.1}$$

Hence, "good $j$" is a good that is produced with productivity $j_n$ in country $n$. In any industry in country $n$, there are infinitely many goods, i.e. $j$s.

A good $j$ from industry $m$ is produced in country $n$ according to the Cobb-

Douglas production function:

$$y^m(j_n) = \begin{cases} j_n^{-\theta}[e^m(j_n)]^{s_e^m}[k^m(j_n)]^{s_k^m}[l^m(j_n)]^{s_l^m} & , \text{ if } e^m(j_n) \leq \bar{e}(j_n) \\ \bar{y}^m & , \text{ if } e^m(j_n) > \bar{e}(j_n) \end{cases} \tag{2.3.2}$$

In country $n$ in industry $m$, pollution emissions related to production $e^m$, capital $k^m$, labor $l^m$ are combined to produce quantity $y^m$ while the realization of the productivity, $j_n$, is taken as given.[5] Similarly, $s_e^m$, $s_k^m$, $s_l^m$ denote the pollution, capital and labor intensities of the production process in industry $m$ that are common to all countries. I assume that in each industry $m$, $s_e^m, s_k^m, s_l^m \in [0,1]$ with $s_e^m + s_k^m + s_l^m = 1$. Note that these factor shares are assumed to be common to all countries. Finally, as $m$ increases, $s_l^m$ decreases while $s_e^m$ and $s_k^m$ increases. The main idea behind this assumption is that inherently most polluting industries are among the most capital-intensive sectors of all.[6]

$\theta$ in the production function governs the variability of $\lambda_n^m$, the national idiosyncratic component to productivity. A larger $\theta$ implies higher variation in productivity levels relative to the mean.

### 2.3.2 Incorporating Pollution

The link between pollution endowments and production has been established in a similar fashion to Copeland and Taylor (1994) in that pollution emission is modelled as a by-product of production as the production function formerly introduced implies. More specifically, I assume that each country $n$ has an exogenous aggregate stock of pollution permits issued by the government, $E_n$, which is at the same time equal to the aggregate level of pollution in that country. In other words, the supply of pollution is exogenously given and the demand for pollution is by firms operating in the economy. The price of the permits are thus determined in the market and labelled as $\tau_n$ and any firm that buys one unit of pollution permits paying $\tau_n$ is

[5] It is worth noting that the production function could alternatively be written as a function where pollution emissions are jointly produced with consumption goods. One such constant returns to scale function is $(ye^{-s_e})^{1/(1-s_e)} = (j^{-\theta}k^{s_k}l^{1-s_e-s_k})^{1/(1-s_e)}$ where $y$ and $e$ could be interpreted as joint products.

[6] For more information, see World Trade Organization (1999). In section 2.4 of this essay, additional evidence is also presented.

allowed to emit one unit of pollution. This system is in its nature analogous to a "cap-and-trade" emissions trading that takes place within national boundaries.

At this stage, two points need further explanation. First, the type of pollution that is considered is "production related" or "industrial" and consumption related emission types are ignored. Second, without any restrictions on the firm-level emission levels $e^m$s, production function would imply that quantity produced could be increased indefinitely by increasing pollution. Therefore, in the equation 2.3.2, I impose an upper bound on the firm level pollution emissions, $\bar{e}(j_n)$ chosen sufficiently large to eliminate this theoretical possibility.

### 2.3.3 Consumption

There are $L_n$ units of labor in each country $n$ which is not mobile. A representative consumer in country $n$ owns one unit of labor and $K_n/L_n$ units of capital. Preferences of the consumer in country $n$ are given by the following utility function:

$$U_n = \left( \sum_{m=1}^{M} \left[ \int_0^{\infty} (Q_n^m(j))^{\alpha} dj \right]^{\beta/\alpha} \right)^{1/\beta} - v(E_n), \tag{2.3.3}$$

where $\alpha,\ \beta \in (0,1)$ and $\epsilon = 1/(1-\alpha)$, $\phi = 1/(1-\beta)$ denote elasticities of substitution between same industry goods and goods from different industries, respectively. I assume that these parameters are common to all countries. $Q_n^m(j)$ shows the aggregate consumption level of a good $j$ from industry $m$ by country $n$. $v(E_n)$ is an increasing and convex function which shows the disutility from pollution. Pollution permit revenues raised by governments are assumed to be lump-sum rebated to consumers, equally. Consumer's budget constraint is then written as:

$$\sum_{m=1}^{M} \left[ \int_0^{\infty} p_n^m(j) Q_n^m(j) dj \right] = Y_n, \tag{2.3.4}$$

with $Y_n = w_n + r_n K_n/L_n + \tau_n E_n/L_n$ where $\tau_n$ is the pollution permit price in country $n$, $r_n$, real interest rate and $w_n$, real wage rate. Hence, consumer's problem is to maximize his/her utility function in 2.3.3 choosing $Q_n^m(j)$ for every good $j$ subject to the budget constraint in 2.3.4 given $Y_n$ and $p_n^m(j)$.

### 2.3.4 Trade Equilibrium

I assume that there exist trade barriers between countries denoted by $0 \leq \gamma_{in}^m \leq 1$ which is the fraction of each dollar spent in $i$ on type-m goods made in $n$ that arrives as payment to a seller in $n$. I take $\gamma_{ii}^m$ to be equal to one, that is, intra-country trade is free. It is also worth noting that trade barriers comprise both policy and non-policy related costs of international trade and this property is related to the estimation method of trade barriers explained in section 2.4.

Under trade, consumers in any country are offered a set of prices by producers in all countries. It can be shown that the price of a good offered to sale by country $n$ in $i$ is

$$p_{in}^m(j_n) = B(j_n^{\theta} {\tau_n}^{s_e^m} {r_n}^{s_k^m} {w_n}^{s_l^m})/\gamma_{in}^m, \tag{2.3.5}$$

where $B > 0$ is a constant and the term in paranthesis is simply the unit cost that the firm faces. Note that if $\gamma_{in}^m = 1$ (i.e. if there were no trade barriers), then a producer in country $n$ would offer the good at the same price at home and in country $i$. The country that offers the minimum price sells the good in country $i$ at the actual price $p_i^m(j)$ which is given by:

$$p_i^m(j) = B \min_n [j_n^{\theta} {\tau_n}^{s_e^m} {r_n}^{s_k^m} {w_n}^{s_l^m}/\gamma_{in}^m]. \tag{2.3.6}$$

From the consumer's problem, the aggregate price of a type-$m$ good being sold in country $i$, $P_i^m$, is calculated according to the following equality.

$$P_i^m = \left[ \int p_i^m(j)^{1-\epsilon} \psi(j) dj \right]^{1/(1-\epsilon)} \tag{2.3.7}$$

Solution to the consumer's problem also yields the demand function for a certain good $j$.

$$Q_i^m(j) = \frac{Y_i (P_i^m)^{\epsilon-\eta}}{\sum_{m=1}^{M} (P_i^m)^{1-\eta}} p_i^m(j)^{-\epsilon} \tag{2.3.8}$$

Aggregating demand over different goods, $j$, provides us with the aggregate quantity consumed:

$$Q_i^m = \left[ \int Q_i^m(j)^{(\epsilon-1)/\epsilon} \psi(j) dj \right]^{\epsilon/(\epsilon-1)}. \tag{2.3.9}$$

Next, bilateral trade shares, $D_{in}^m$ are derived. It can be shown that country $i$'s per capita spending on type-$m$ goods from country $n$ is equal to the probabilities that for a particular good $j$, sellers in $n$ offer the lowest price for buyers in $i$. In other words,

$$D_{in}^m = \Pr\{p_{in}^m(j) \leq \min_{k \neq n}[p_{ik}^m(j)]\}. \tag{2.3.10}$$

I also impose trade balance as given in the following equation. The left hand side of the expression shows the amount of expenditures by country $i$ that reaches sellers in all countries and the right hand side shows the amount received by country $i$ from all countries.

$$L_i \sum_{m=1}^{M} P_i^m Q_i^m \sum_{n=1}^{N} D_{in}^m \gamma_{in}^m = \sum_{n=1}^{N} L_n \sum_{m=1}^{M} P_n^m Q_n^m D_{ni}^m \gamma_{ni}^m \tag{2.3.11}$$

Notice that the term capturing country $i$'s spending on home goods appears on both sides of 2.3.11.

I now proceed to defining a trade equilibrium.

**Definition.** *A trade equilibrium is a set of prices* $w_i$, $r_i$, $\tau_i$, $p_i^m(j)$ *and a set of quantities* $l_i^m(j)$, $k_i^m(j)$, $e_i^m(j)$, $y_i^m(j)$, $Q_i^m(j)$ *such that given* $K_i$, $L_i$, $E_i$, $\gamma_{in}^m$, $\lambda_i^m$, $\theta$, $\phi$, $\epsilon$ *in every country* $i$*:*

1. *Consumers choose* $Q_i^m(j)$ *to maximize their utility given by 2.3.3, subject to the budget constraint given in 2.3.4 taking prices* $p_i^m(j)$, $w_i$, $r_i$, $\tau_i$ *as given, for all* $j, m$*;*

2. *Producers of a given good* $j$ *choose* $e_i^m(j)$, $k_i^m(j)$, $l_i^m(j)$ *to maximize their profits given the production function in 2.3.2, taking prices* $p_i^m(j)$, $w_i$, $r_i$, $\tau_i$ *as given, for all* $j, m$*;*

3. *Aggregate prices* $P_i^m$ *satisfy 2.3.7, for all m;*

4. *Aggregate quantities consumed* $Q_i^m$ *satisfy 2.3.9, for all m;*

5. *Bilateral trade shares* $D_{in}^m$ *satisfy 2.3.10, for all m;*

6. *Trade balance condition, 2.3.11, holds;*

7. *Markets clear:*

$$\sum_{m=1}^{M} \int k_i^m(j)dj = K_i \tag{2.3.12}$$

$$\sum_{m=1}^{M} \int l_i^m(j)dj = L_i \tag{2.3.13}$$

$$\sum_{m=1}^{M} \int e_i^m(j)dj = E_i. \tag{2.3.14}$$

### 2.3.5 Characterization of Trade Equilibrium

Under a trade equilibrium, it can be shown that the aggregate prices are described by the following equation[7].

$$P_i^m = AB \left[ \sum_{n=1}^{N} \left( \frac{\tau_n{}^{s_e^m} r_n{}^{s_k^m} w_n{}^{s_l^m}}{\gamma_{in}^m} \right)^{-1/\theta} \lambda_n^m \right]^{-\theta}, \tag{2.3.15}$$

where $A > 0$ is a constant term.

Similarly, calculating the integral given in 2.3.9 yields aggregate quantity of type-$m$ goods consumed in country $i$[8]:

$$Q_i^m = A^{-\epsilon} \frac{Y_n (P_i^m)^{\epsilon-\phi}}{\sum_{m=1}^{M} (P_i^m)^{1-\phi}} \left[ \sum_{n=1}^{N} \left( \frac{\tau_n{}^{s_e^m} r_n{}^{s_k^m} w_n{}^{s_l^m}}{\gamma_{in}^m} \right)^{-1/\theta} \lambda_n^m \right]^{\epsilon\theta}. \tag{2.3.16}$$

[7]See Appendix A for the proof.
[8]See Appendix B for the proof.

Using the expressions for $p_{in}^m(j)$ from equation 2.3.5 in 2.3.10 and using convenient properties of the exponential distribution, $D_{in}^m$ can be written as a function of factor prices and the productivity parameters.

$$D_{in}^m = \left( \frac{{\tau_n}^{s_e^m} {r_n}^{s_k^m} {w_n}^{s_l^m}}{P_i^m \gamma_{in}^m} \right)^{-1/\theta} (AB)^{-1/\theta} \lambda_n^m \tag{2.3.17}$$

Next, I integrate the first order conditions from the firm's optimization problem over all goods in all industries and use the market clearance conditions for the factor markets in those conditions to get:

$$r_n K_n \sum_{m=1}^{M} s_l^m = w_n L_n \sum_{m=1}^{M} s_k^m \tag{2.3.18}$$

$$\tau_n E_n \sum_{m=1}^{M} s_l^m = w_n L_n \sum_{m=1}^{M} s_e^m \tag{2.3.19}$$

At this point, it is important to note that all aggregate prices ($P_i^m$ given in 2.3.15), aggregate quantities ($Q_i^m$ given in 2.3.16), bilateral trade shares ($D_{in}^m$ given in 2.3.17), equations 2.3.18 and 2.3.19 and the trade balance equation (given in 2.3.11) are functions of the factor price vectors, namely, a wage vector, $w = (w_1, ..., w_N)$, an interest rate vector $r = (r_1, ..., r_N)$, a permit price vector $\tau = (\tau_1, ..., \tau_N)$ and they together characterize a trade equilibrium.

An analytical solution does not exist for the set of equations characterizing equilibrium. Therefore, I numerically compute the general equiliibrium values of $w$, $r$ and $\tau$ after I calibrate the model parameters.

## 2.4 Calibration

### 2.4.1 Method

In order to be able to quantify the model and test its predictions against the data for year 2000, I proceed to calibrating the model parameters for the OECD countries whose details are presented in table 2.6. Below, main steps and methods involved

| Parameter | Definition | Method/Data Sources |
|---|---|---|
| K | Aggregate capital endowment | 1990-99 Average<br>Heston-Summers-Aten (2006) |
| L | Aggregate labor endowment | 1990-99 Average number of workers<br>Heston-Summers-Aten (2006) |
| E | Aggregate air pollution emissions | 1990-99 Average<br>OECD Environmental Compendium (2004) |
| $\gamma$ | Trade barriers | Estimation |
| $\lambda$ | Productivity parameter | Calibrated to match bilateral trade shares |

Table 2.1: Summary: Choice of country-specific model parametes

in the calibration process are explained and the procedure with data sources is summarized in tables 2.1 and 2.2.

**Country-specific pollution emission levels:** To the best of my knowledge, it is not possible to find a general measure of the aggregate pollution levels caused in isolation by the manufacturing sector for every country. Therefore, instead, I concentrate specifically on *air pollution* since both industrialization is known to be a significant stimulating factor for this type of pollution and more detailed data sources are readily available.

One of these sources is the OECD Environmental Compendium Data on Air Pollution (2004). The study provides annual country-level data on the amounts of traditional air pollutants emitted in the OECD countries, namely, $SO_x$, $NO_x$, particulates, $CO$, $VOC$ between the years 1990 and 2005. It also presents a decomposition of total air pollution based on several mobile and stationary sources, namely, roads, power stations, industrial combustion, industrial processes and other miscellaneous sources. However, the industrial sources may typically include all sectors including the manufacturing goods sector. To estimate the amount of air pollution that is related to the manufacturing activities alone, I use Hettige et al. (1987) IPPP data on pollution intensities of manufacturing sectors in the US on an ISIC 3-digit level. I first recover the total amount of air pollution by the manufacturing sector in the US in 1987 from this data and this forms my base table. Next, I compare the levels of air pollution caused by the industrial sector between USA and other OECD countries for the year 1990 and scale up or down my base table

| Parameter | Definition | Value | Method/Data Sources |
|---|---|---|---|
| $s_e$ | Share of abatement costs | $s_e^1 = 0.0016$, $s_e^2 = 0.0194$ | Total cost of abatement/Value added Hettige et al. (1994) |
| $s_l$ | Share of labor costs | $s_l^1 = 0.6566$, $s_l^2 = 0.5891$ | Total labor costs (adjusted for self-employment)/Value added OECD STAN (2005), (2006) |
| $s_k$ | Share of capital costs | $s_k^1 = 0.3418$, $s_k^2 = 0.3914$ | Residual |
| $\theta$ | Variance of productivity | 0.15 | Waugh (2007) |
| $\alpha$ | Within-industry curvature | 0.75 | To yield an elasticity: $1/(1-\alpha) = 4$ |
| $\beta$ | Across-industries curvature | 0.50 | To yield an elasticity: $1/(1-\beta) = 2$ |

Table 2.2: Summary: Choice of common model parametes

according to these ratios obtained. This exercise yields a detailed country-level data on the total amounts of specific pollutant types emitted by the manufacturing sector on an ISIC 3-digit level. I choose to use 1990-1999 averages for each country since I test the model against data for year 2000.

**Aggregate capital and aggregate labor endowment levels:** Using Heston, Summers and Aten (2006) data, I calculate aggregate labor as the number of workers. To calculate aggregate investment levels, I use investment shares of real GDP from Heston, Summers and Aten (2006) as well and then follow the perpetual inventory method with 6% depreciation rate and calculating the average geometric growth rate of aggregate investment, following Caselli (2005). The procedure yields aggregate capital and labor levels on an annual basis for the period 1950-2004 and in this study I use 1990-1999 averages.

**Shares of pollution, capital and labor in income:** In the model, I assume that all countries have identical technologies in a certain industry $m$ however, technologies (or more specifically capital and pollution intensities) can potentially be different between any two industries. Due to international data constraints, I recover the shares of pollution, capital and labor using the US data and assume that it is the same for all countries in the sample.

Share of labor in income ($s_l^m$, in the model) is calculated using the OECD STAN Industry Database which provides industry-level data on labor costs (compensation of employees), total employment, total employees and value added. First, I work out concordance problem between the STAN description of industries and ISIC rev.2 categories. Next, I calculate the share of labor as the total labor costs divided by value added while labor costs are adjusted for self-employment assuming that labor costs per employee is the same as in the non-self-employed labor cost data for the years 1989-2001.

Share of pollution abatement costs ($s_e^m$) is derived by using the Hettige et al. (1994) data on abatement cost coefficients expressed as the average cost in US dollars per ton of pollution abated. First, I compute the total cost of abatement and then dividing these figures with value added, I reach at the share of pollution abatement costs. The share of capital ($s_k^m$) is calculated as a residual so as to satisfy $s_e^m + s_k^m + s_l^m = 1$ assumption.

In order to be able to take the model to data, I specify the number of industries ($M$) as being equal to two, namely, "clean" and "dirty" industries. These industries are distinguished based on their average shares of pollution and both the averages and the details of the classification are presented in table 2.7 in appendix C. On average, the dirty industry has higher shares of pollution abatement and capital costs and a lower share of labor costs than the clean industry as in line with the assumptions of the model and supporting the relevant findings in the literature.

**Bilateral trade shares:** The empirical counterparts to bilateral trade shares $D_{ij}^m$ in the manufacturing industries have been derived using the NBER-UN World Trade Data 1962-2000 by Feenstra et al. (2005) and the OECD STAN Industry Database. For each country $i$ in my sample, I calculate the aggregate value of manufacturing imports of type-$m$ goods from country $j$ (with $j \neq i$) using the bilateral trade data by Feenstra et al. for year 2000. Next, I obtain the gross manufacturing production of type-$m$ goods for each country $i$ using the OECD STAN database. Finally, I compute bilateral trade shares $D_{ij}^m$ by dividing the manufacturing imports of country $i$ from $j$ by gross manufacturing production plus total manufacturing exports to world minus total manufacturing imports from sample countries.

**Trade barriers:** I recover unknown trade costs from the pattern of bilateral trade using a type of gravity equation widely used in international trade literature. The method I use is similar to the methods used in Waugh (2007) and Eaton and Kortum (2002).

Using equation 2.3.17 from section 2.3, I divide each country $i$'s trade share from country $j$ ($D_{ij}^m$) by country $i$'s home trade share ($D_{ii}^m$) and obtain the following set of equations.

$$\frac{D_{ij}^m}{D_{ii}^m} = \frac{\lambda_j^m}{\lambda_i^m}\left(\frac{{\tau_j}^{s_e^m}{r_j}^{s_k^m}{w_j}^{s_l^m}}{{\tau_i}^{s_e^m}{r_i}^{s_k^m}{w_i}^{s_l^m}}\right)^{-1/\theta}(\gamma_{ij}^m)^{1/\theta} \tag{2.4.1}$$

Taking logs yield the log-linear Eaton and Kortum (2002)-type gravity equation to be estimated:

$$\log\left[\frac{D_{ij}^m}{D_{ii}^m}\right] = S_j^m - S_i^m + \frac{1}{\theta}\log(\gamma_{ij}^m), \tag{2.4.2}$$

where $S_i^m$ is defined by the following equality:

$$S_i^m = \log\left[\lambda_i^m({\tau_i}^{s_e^m}{r_i}^{s_k^m}{w_i}^{s_l^m})^{-1/\theta}\right]. \tag{2.4.3}$$

I estimate equation 2.4.2 to recover trade barriers while $S_i$'s are estimated as the coefficients on country specific dummy variables. Furthermore, to proxy trade barriers, I assume that trade barriers take the following functional form:

$$\log(\gamma_{ij}^m) = d_k + b_{ij} + x_j^m + \epsilon_{ij}. \tag{2.4.4}$$

Here, trade barriers are assumed to be a logarithmic function of distance where $d_k$ with $k = 1, 2, ..., 6$ are dummy variables that take a value of 1 if the distance between country $i$ and $j$ falls into the $k$th interval and zero otherwise. In other words, there are six distance dummies and the intervals that are expressed in kilometers are formed as follows starting from $k = 1$ in order: [0, 600), [600, 1200), [1200, 2400), [2400, 4800), [4800, 9600) and [9600, maximum].

Similarly, $b_{ij}$ is another dummy variable that captures the effect of two countries sharing the same border by taking a value of 1 if country $i$ and $j$ share a border and zero if they do not.

Finally, exporter fixed effects are captured in the term $x_j^m$ and in total there are 58 dummy variables since there are 29 countries and two sectors.[9] More clearly, $x_j^m$ takes a value of 1 if country $j$ is the exporter of a good from sector $m$ and zero otherwise. So, inherently, the estimates of this term capture the extra cost country $j$ faces when it exports an $m$-type good. Note that it is not necessary to impose an industrial differentiation for the distance and border barriers since these variables do not change with the type of the good.

I estimate the gravity equation given in equation 2.4.2 using ordinary least squares and report the results in table 2.8 in appedix C. For an estimated parameter $\hat{b}$, I also calculate the implied percentage effect on costs using the formula $(\exp^{-\theta\hat{b}} - 1) \times 100$. As expected, as the distance between any two countries increases the percentage impact on costs increases, too. However, if countries share a border, the implied cost of trade is lower.

**Productivity parameters:** The steps I follow to obtain each country's technology parameter i.e. $\lambda_n^m$s, are as follows. First, I calculate the empirical counterparts of bilateral trade shares $D_{ij}^m$. Next, I numerically solve for the equilibrium level of factor prices taking the calculated $D_{ij}^m$s, estimated trade barriers $\gamma_{ij}^m$s as given and using the expression:

$$\lambda_i^m = \frac{\exp(\hat{S}_i^m)}{({\tau_i}^{s_e^m} {r_i}^{s_k^m} {w_i}^{s_l^m})^{-1/\theta}} \tag{2.4.5}$$

where $\hat{S}_i^m$ shows the estimated coefficients from the gravity equation. As a result of this procedure, productivity parameters are obtained as a function of bilateral trade shares.

**Other common parameters:** Three parameters that are assumed to be the same across countries remain to be determined. One of them is the parameter

[9] This differs from the approaches taken by both Eaton and Kortum (2002) and Waugh (2007) since in their models there is a single aggregate intermediate good that is being traded whereas in this model, there are two tradeable good industries with different technologies.

governing the variability of national idiosyncratic component to productivity, $\theta$ and I choose it to be equal to 0.15 following Waugh (2007). The other two are $\alpha$ and $\beta$ that determine the elasticities of substitution between goods from the same industry and between goods from different industries, respectively. I choose $\alpha = 0.75$ and $\beta = 0.5$ to obtain corresponding elasticities such that $\epsilon = 4 > \phi = 2$. This specific parameter choice reasonably implies that the elasticity of substitution between goods from the same industry is higher than the elasticity between goods from different industries.

In the next section, I outline the main results from the baseline calibration that is carried out using these parameters.

### 2.4.2 Results from the baseline calibration

As one assessment of the model, I consider the model's ability to replicate the data on the link between factor abundance levels of countries and export-import ratios in the clean and pollution-intensive industries. Figure 2.2 plots the capital-labor ratios against the export-import ratios in the dirty industry for each of the OECD countries and compares the model's predictions with the data for year 2000. The model is successful in replicating the fact that countries with higher capital abundance levels have relatively greater export-import ratios in the pollution-intensive industry as the positive slope of both actual and predicted trend lines imply. Similarly, figure 2.3 presents a comparison based on emission-abundance levels and shows a similar pattern. Here, the mechanism that drives these results are largely due to the fact that on average, countries that are more capital abundant are also relatively more emission abundant. Moreover, as explained in the section on calibration, pollution-intensive industry has higher capital and emission requirements than the clean industry. Hence, the coexistence of these two properties in the model leads us to this first property of the model. At this point, it is important to note that the productivity differentials between clean and dirty industries are negligible on average (namely, 0.96%) and hence do not have a significant impact in determination of export-import ratios allowing factor abundance channel to be a dominant determinant.

I repeat the same analysis for the clean industry and summarize the results in figures 2.4 and 2.5. Once again, the model yields consistent results with the data in that for the clean industries, the impact of both capital and emission abundance is weaker.

As a second assessment of the model, I compare actual versus predicted *values* of export-import ratios. Figure 2.6 presents the results for a set of pooled observations from both dirty and clean industries. A regression of the log of predicted values on the log of actual values yields an estimated coefficient equal to 0.614 implying a reasonable fit to data. On a sectoral level, for the pollution-intensive industry, a similar estimation yields a slope coefficient of 0.704 and for the clean industry, 0.506. Hence, the model is capable of producing consistent predictions with the data not only qualitatively but also quantitatively.

Next, I plot the predicted home trade shares of goods from the two industries to compare with the data. As seen in figures 2.7-2.9, in both clean and dirty industries, the values are clustered near the 45-degree line implying a good fit. More specifically, the correlation coefficients between the model's predictions and the data are 0.847 and 0.702 for the clean and dirty industries, respectively. We mainly owe this property of the model to high trade barriers estimated which comprises a number of policy and non-policy costs of trade, namely, geography, border and exporter-specific effects.

Finally, I check the relationship between environmental regulations produced by the model and income levels. The correlation coefficient between income levels and implied environmental taxes is found to be 0.77 supporting the empirical evidence that shows a positive relationship between stringency of environmental policy and income.

## 2.5 Counterfactual Experiments

In this section, using the calibrated version of the model, I analyze the trade and pollution impacts of two different changes in the OECD countries: Total elimination of trade barriers and international harmonization of environmental standards.

I specifically consider two different environmental policies under which those impact analyses will be studied. One is the "cap-and-trade" system that has been described in more detail in section 2.3. In this case, government in each country sets the aggregate pollution level and issues emission permits to be traded between local firms. Pollution permit prices are thus determined in the market. Second is the "environmental taxation" where governments only set the unit tax on pollution emissions and the overall level of pollution is determined endogenously in the economy. Below, for each experiment, I discuss how my model's predictions differ under the two environmental policy regimes.

### 2.5.1 Full Trade Liberalization

First counterfactual exercise that is carried out aims to understand the impact of a hypothetical full trade liberalization on trade specialization patterns and pollution levels. I eliminate all barriers to trade by assuming $\gamma_{in}^{m} = 1$, for every country pair and in every sector. I report the predicted impact on trade in table 2.3. Table 2.3 groups the countries into two according to their capital abundance indices. Countries with indices less than 80 are the less developed countries in the OECD, namely, Czech Republic, Turkey, Slovakia, Poland, Mexico and Hungary. All the other countries are gathered in the second group.

The model predicts that in case of a trade liberalization under cap-and-trade system, on average, more capital abundant countries will move away from clean goods towards pollution-intensive goods. The average impact is predicted to be a 3% increase in export-import ratio in the polluting sector and a 1.2% decline in the clean sector. For the less capital abundant countries, the model predicts a relatively higher decline in the export-import ratios of clean goods than in the pollution-intensive goods. Qualitatively, a similar pattern is predicted under environmental taxation, as well. Hence, within the framework of this model, free trade is not likely to lead to pollution haven effects for the case of OECD countries.

An interesting prediction of the model is that trade liberalizations not only create trade distortions but also help to decrease overall pollution levels under environmental taxation system. More precisely, a full trade liberalization by the OECD countries facilitates a 32% average decline, on average. In relatively more capital abundant countries the decline is predicted to be higher on average with 24% while in relatively less capital abundant countries, 11%. The decline in emission levels as

| | Under Cap-and-Trade | |
|---|---|---|
| Countries with: | Clean Industry | Pollution-Intensive Industry |
| Capital abundance index $\geq 80$ | -1.2% | 3.0% |
| Capital abundance index $< 80$ | -28.8% | -1.7% |
| | **Under Environmental Taxation** | |
| Countries with: | Clean Industry | Pollution-Intensive Industry |
| Capital abundance index $\geq 80$ | -0.9% | 4.4% |
| Capital abundance index $< 80$ | -24.5% | -15.0% |

Table 2.3: Average percentage change in export-import ratios after full trade liberalization

a result of trade liberalization is explained by the relocation of pollution-intensive goods to capital abundant and high productivity countries where environmental policies are stricter.

At this point, it is important to mention the role of productivity differences in obtaining a reduction in emission levels. To isolate the impact of productivity differences, I eliminate productivity differences between countries by choosing $\theta$ close to zero (specifically, 0.05) and repeat the exercise of full trade liberalization. In this case, free trade only leads to an average emissions decline of 17% which is about one-half of the reduction observed in the initial case. In other words, about half of the decline in emission levels is due to international productivity differences. When countries differ in productivities and open up to trade, part of the production in pollution-intensive goods shifts to high productivity countries where regulation levels are higher and this channel substantially contributes to the decline in emissions.

Besides its implications on trade patterns and on pollution, removal of trade barriers also results in a decline in the explanatory power of the model, as expected. Under no trade barriers, a regression of the log of predicted values of export-import ratios on the log of actual values yields an estimated coefficient of 0.182 depicting a decline from 0.614 under the baseline calibration. This is an illustration of the importance of trade barriers in explaining specialization patterns within the OECD.

| | Under Cap-and-Trade | |
|---|---|---|
| Countries with: | Clean Industry | Pollution-Intensive Industry |
| Capital abundance index $\geq 80$ | 0.6% | 0.2% |
| Capital abundance index $< 80$ | -1.8% | 2.8% |
| | Under Environmental Taxation | |
| Countries with: | Clean Industry | Pollution-Intensive Industry |
| Capital abundance index $\geq 80$ | 2.1% | -0.9% |
| Capital abundance index $< 80$ | 12.0% | -13.5% |

Table 2.4: Average percentage change in export-import ratios after international harmonization of environmental policies

### 2.5.2 Harmonization of Environmental Regulations

In this section, I look at the implied impacts of two alternative policies of international harmonization of environmental regulations. Under cap-and-trade system, international harmonization will mean an equalization of national pollution per capita levels. In this case, all the OECD countries decrease their aggregate pollution levels so as to reach the lowest level of emissions per capita prevailing within the OECD countries in the sample. The country that has the lowest level of emissions per labor is Switzerland with a ratio of 0.0182 while the sample average is 0.0794. In this case, harmonization of pollution levels requires an average decrease of 65% in emissions per labor. Under the environmental taxation system, harmonization will require all countries to increase their taxes to the highest prevailing level within the OECD (i.e. the level in Switzerland). The model predicts that these two types of harmonization policies substantially differ in both their trade impacts and effectiveness in reducing pollution.

Table 2.4 demonstrates that under cap-and-trade, as a result of harmonization, less capital abundant countries move away from clean goods towards pollution-intensive goods. However, under environmental taxation, model's prediction is just the opposite for the same group of countries. Once again, although export-import ratios will be affected, net-exporters and net-importers of the goods are not likely to change.

In terms of their implications in reducing pollution, an harmonization of environmental tax levels is more effective than an equalization of aggregate pollution

| Country | Capital-Labor Ratio (OECD Average=100) | Harmonization Under Taxation | Harmonization Under Cap-and-Trade |
|---|---|---|---|
| Czech Republic | 17 | -95% | -77% |
| Turkey | 17 | -96% | -17% |
| Slovakia | 21 | -95% | -65% |
| Poland | 29 | -96% | -57% |
| Mexico | 36 | -95% | -60% |
| Hungary | 45 | -95% | -74% |
| | Average | -95% | -59% |
| Portugal | 65 | -95% | -74% |
| Greece | 81 | -97% | -62% |
| UK | 88 | -85% | -72% |
| New Zealand | 94 | -96% | -79% |
| Spain | 100 | -88% | -74% |
| Iceland | 105 | -85% | -67% |
| Sweden | 110 | -46% | -55% |
| Canada | 113 | -98% | -96% |
| Denmark | 113 | -62% | -20% |
| Australia | 116 | -99% | -91% |
| Germany | 122 | -75% | -70% |
| USA | 123 | -85% | -79% |
| Italy | 128 | -74% | -63% |
| Netherlands | 132 | -78% | -70% |
| Finland | 132 | -57% | -73% |
| France | 135 | -83% | -78% |
| Austria | 143 | -87% | -81% |
| Belgium-Luxembourg | 143 | -87% | -88% |
| Japan | 149 | -1% | -45% |
| Norway | 161 | -76% | -69% |
| Switzerland | 184 | 0% | 0% |
| | Average | -74% | -67% |
| | Overall Average | -83% | -65% |

Table 2.5: Percentage changes in the aggregate pollution levels under two types of harmonization policies

levels, within the context of the model. Under the environmental taxation system, pollution levels will be decreased by 83% on average through harmonization while under the cap-and-trade system, it will be reduced by 65%, as reported in detail in table 2.5.

Overall, the results of these experiments imply that based on the choice of an environmental harmonization policy, impact on trade patterns and the achieved reductions in pollution emissions will differ. Harmonization through equalized taxes is predicted to have higher trade distortions than harmonization through equal environmental pollution levels. However, the use of harmonized taxes results in higher reductions in pollution levels, on average.

## 2.6 Concluding Remarks

In this chapter, I study a general equilibrium model of trade under which the impact of national environmental regulation levels on specialization patterns relative to other factors can be quantitatively analyzed. In the model, the incentive to trade comes from factor abundance, productivity and trade barrier differentials. I calibrate the model parameters for the OECD countries to match the bilateral trade shares of manufacturing goods in year 2000. I find that the model not only captures the qualitative relationship between factor abundance levels and export-import ratios but also quantitatively produces export-import ratios and home trade shares that are in agreement with the data. Counterfactual exercises demonstrate that complete removal of all trade barriers not only has significant impacts on trade but also helps to reduce environmental pollution. The model delivers that the type of the environmental harmonization policy chosen matters as far as its effectiveness and trade impacts are concerned. For the case of OECD countries, uniform pollution quotas are predicted to be less effective in reaching the aim of lower emission levels than harmonized pollution taxes.

An important contribution of this essay is that it provides an analysis of the role of productivity differences in determining environmental quality, which is a factor that had been neglected in the trade and environment literature before this study. In an environment where Ricardian incentives to trade are ignored, reductions in pollution levels facilitated by trade liberalizations would be underestimated.

Overall, this study introduces an alternative methodological approach to a long-debated question on the environmental regulations-trade relation. The approach puts an emphasis on the coexistence and interaction of various sources of comparative advantage in shaping bilateral trade patterns. The general equilibrium model described in the essay can be taken to data successfully with its conveniently calibrated parameters making impact analyses of international environmental policies possible. With all these properties, it provides a useful quantitative tool that could be utilized for policy analyses on environment-trade issues involving large data sets.

## 2.7 Appendix A: Derivation of $P_i^m$

From equation 2.3.6, we have:

$$p_i^m(j) = B \min_n [j_n^\theta {\tau_n}^{s_e^m} {r_n}^{s_k^m} {w_n}^{s_l^m} / \gamma_{in}^m].$$

Then we have:

$$p_i^m(j)^{1/\theta} = B^{1/\theta} \min_n [j_n {\tau_n}^{\frac{s_e^m}{\theta}} {r_n}^{\frac{s_k^m}{\theta}} {w_n}^{\frac{s_l^m}{\theta}} / (\gamma_{in}^m)^{\frac{1}{\theta}}] \qquad (2.7.1)$$

Exponential distribution has two convenient properties:

1. If $j_n \sim \exp(\lambda_n^m)$ and $c > 0 \Rightarrow cj_n \sim \exp(\lambda_n^m / c)$
2. If $j_n, y$ are independent with $j_n \sim \exp(\lambda_n^m), y \sim \exp(\eta)$ and $z = \min(j_n, y)$ $\Rightarrow z \sim \exp(\lambda_n^m + \eta)$

Applying the first property to equation 2.7.1, we obtain:

$$j_n {\tau_n}^{\frac{s_e^m}{\theta}} {r_n}^{\frac{s_k^m}{\theta}} {w_n}^{\frac{s_l^m}{\theta}} / (\gamma_{in}^m)^{\frac{1}{\theta}} \sim \exp\left[({\tau_n}^{s_e^m} {r_n}^{s_k^m} {w_n}^{s_l^m} / \gamma_{in}^m)^{-1/\theta} \lambda_n^m\right]$$

Applying property 2 to equation 2.7.1, we obtain:

$$\min_n [j_n {\tau_n}^{\frac{s_e^m}{\theta}} {r_n}^{\frac{s_k^m}{\theta}} {w_n}^{\frac{s_l^m}{\theta}} / (\gamma_{in}^m)] \sim \exp\left(\sum_{n=1}^{N} \left[({\tau_n}^{s_e^m} {r_n}^{s_k^m} {w_n}^{s_l^m} / \gamma_{in}^m)^{-1/\theta} \lambda_n^m\right]\right)$$

Using property 1 once again,

$$p_i^m(j)^{1/\theta} \sim \exp\left[B^{-1/\theta}\sum_{n=1}^{N}\left[(\tau_n{}^{s_e^m} r_n{}^{s_k^m} w_n{}^{s_l^m}/\gamma_{in}^m)^{-1/\theta}\lambda_n^m\right]\right] = \exp(\mu),$$

where $\mu = B^{-1/\theta}\sum_{n=1}^{N}\left(\frac{\tau_n{}^{s_e^m} r_n{}^{s_k^m} w_n{}^{s_l^m}}{\gamma_{in}^m}\right)^{-1/\theta}\lambda_n^m$.
From 2.3.7, we have:

$$(P_i^m)^{1-\epsilon} = \left[\int p_i^m(j)^{1-\epsilon}\psi(j)dj\right].$$

Letting $p_i^m(j)^{1/\theta} = v$, this could be equivalently written as:

$$(P_i^m)^{1-\epsilon} = \left[\int v^{\theta(1-\epsilon)}\mu\exp(-\mu v)dv\right].$$

Using a change of variables by letting $z = \mu v$, the expression is computed to be:

$$P_i^m = A\mu^{-\theta} = AB\left[\sum_{n=1}^{N}\left(\frac{\tau_n{}^{s_e^m} r_n{}^{s_k^m} w_n{}^{s_l^m}}{\gamma_{in}^m}\right)^{-1/\theta}\lambda_n^m\right]^{-\theta} .Q.E.D.$$

## 2.8 Appendix B: Derivation of $Q_i^m$

With CES utility function, consumer's optimization problem yields equation 2.3.9:

$$Q_i^m = \left[\int_0^\infty Q_i^m(j)^{\frac{\epsilon-1}{\epsilon}}\psi(j)dj\right]^{\frac{\epsilon}{\epsilon-1}},$$

where

$$Q_i^m(j) = \frac{Y_n(P_i^m)^{\epsilon-\phi}}{\sum_{m=1}^{M}(P_i^m)^{1-\phi}}p_i^m(j)^{-\epsilon},$$

from equation 2.3.8. Denoting $Y_n(P_i^m)^{\epsilon-\phi}/[\sum_{m=1}^{M}(P_i^m)^{1-\phi}]$ as $T$, we can rewrite the expression as follows.

$$Q_i^m(j)^{-\frac{1}{\epsilon\theta}} = T^{-\frac{1}{\epsilon\theta}}p_i^m(j)^{1/\theta}$$

By the property of the exponential distribution, $Q_i^m(j)^{-\frac{1}{\epsilon\theta}}$ is distributed as $\exp[\mu_i T^{\frac{1}{\epsilon\theta}}]$. Let $u = Q_i^m(j)^{-\frac{1}{\epsilon\theta}}$. Then,

$$(Q_i^m)^{\frac{\epsilon-1}{\epsilon}} = \int_0^\infty Q_i^m(j)^{\frac{\epsilon-1}{\epsilon}}\psi(j)dj = \int_0^\infty u^{-\theta(\epsilon-1)}\mu T^{\frac{1}{\epsilon\theta}}\exp[-\mu T^{\frac{1}{\epsilon\theta}}u]du.$$

Applying the change of variables $\mu T^{\frac{1}{\epsilon\theta}}u = z$:

$$\begin{aligned}(Q_i^m)^{\frac{\epsilon-1}{\epsilon}} &= \int_0^\infty z^{\theta(1-\epsilon)}\mu^{-\theta(1-\epsilon)}T^{\frac{\epsilon-1}{\epsilon}}\exp[-z]dz \\ &= \mu^{-\theta(1-\epsilon)}T^{\frac{\epsilon-1}{\epsilon}}\int_0^\infty z^{\theta(1-\epsilon)}\exp[-z]dz \\ &= \mu^{-\theta(1-\epsilon)}T^{\frac{\epsilon-1}{\epsilon}}A^{1-\epsilon}.\end{aligned}$$

Hence, we obtain:

$$Q_i^m = A^{-\epsilon}T\mu^{\epsilon\theta},$$

where $\mu = B^{-1/\theta}\sum_{n=1}^N\left(\frac{\tau_n{s_e^m}\, r_n{s_k^m}\, w_n{s_l^m}}{\gamma_{in}^m}\right)^{-1/\theta}\lambda_n^m$.Q.E.D.

## 2.9 Appendix C

**List of Countries Included in the Sample and Country Codes:**
Australia (AUS), Austria (AUT), Belgium-Luxembourg (BLX), Canada (CAN), Czech Republic (CZE), Denmark (DNK), Finland (FIN), France (FRA), Germany (GER), Greece (GRC), Hungary (HUN), Iceland (ISL), Italy (ITA), Japan (JPN), Korea Republic (KOR), Mexico (MEX), Netherlands (NLD), New Zealand (NZL), Norway (NOR), Poland (POL), Portugal (PRT), Slovakia (SVK), Spain (ESP), Sweden (SWE), Switzerland (CHE), Turkey (TUR), United Kingdom (UK), United States (USA)

| Country | Export-Import Ratio in Dirty Industries | % Share of GDP in Total GDP of OECD | Capital-Labor Ratio (OECD Average=100) |
|---|---|---|---|
| Australia | 0.87 | 1.56 | 117.63 |
| Austria | 0.95 | 0.75 | 146.27 |
| Belgium-Luxembourg | 0.92 | 0.98 | 146.24 |
| Canada | 1.30 | 2.82 | 113.96 |
| Czech Republic | 0.85 | 0.22 | 30.66 |
| Denmark | 1.07 | 0.62 | 117.25 |
| Finland | 1.77 | 0.47 | 122.67 |
| France | 0.90 | 5.17 | 131.86 |
| Germany | 1.23 | 7.40 | 126.42 |
| Greece | 0.50 | 0.56 | 75.47 |
| Hungary | 0.64 | 0.19 | 47.84 |
| Iceland | 0.47 | 0.03 | 103.74 |
| Italy | 1.22 | 4.27 | 123.6 |
| Japan | 0.98 | 18.18 | 149.66 |
| Korea Republic | 1.26 | 1.99 | 86.14 |
| Mexico | 0.57 | 2.26 | 33.69 |
| Netherlands | 1.40 | 1.50 | 130.33 |
| New Zealand | 0.72 | 0.21 | 91.20 |
| Norway | 1.43 | 0.66 | 156.69 |
| Poland | 0.74 | 0.67 | 30.50 |
| Portugal | 0.79 | 0.44 | 72.28 |
| Slovakia | 1.08 | 0.08 | 27.44 |
| Spain | 0.81 | 2.26 | 101.48 |
| Sweden | 1.21 | 0.94 | 105.40 |
| Switzerland | 1.24 | 0.96 | 175.80 |
| Turkey | 0.79 | 0.78 | 18.14 |
| United Kingdom | 0.91 | 5.62 | 90.92 |
| United States | 0.55 | 38.03 | 131.79 |

Table 2.6: Data for the OECD countries, year 2000. Sources: For column 1, NBER-UN World Trade Data 1962-2000; for column 2, WDI; for column 3, PWT 6.2.

| Breakdown of the Clean Industry | | | | |
|---|---|---|---|---|
| ISIC Code | Definition | $s_e^1$ | $s_l^1$ | $s_k^1$ |
| 311+313 | Food Products and Beverages | 0.24 | 53.00 | 46.76 |
| 314 | Tobacco | 0.39 | 16.31 | 83.30 |
| 321 | Textiles | 0.47 | 74.07 | 25.46 |
| 322 | Wearing Apparel, Except Footwear | 0.00 | 72.63 | 27.37 |
| 323+324 | Leather Products and Footwear, Except Rubber or Plastic | 0.09 | 69.89 | 30.02 |
| 331 | Wood Products, Except Furniture | 0.23 | 66.05 | 33.72 |
| 342 | Printing and Publishing | 0.10 | 64.77 | 35.14 |
| 355+356 | Rubber Products and Plastic Products | 0.07 | 62.74 | 37.19 |
| 381 | Fabricated Metal Products | 0.08 | 69.19 | 30.73 |
| 382 | Machinery, Except Electrical | 0.15 | 74.94 | 24.91 |
| 383 | Machinery, Electric | 0.04 | 62.85 | 37.11 |
| 385 | Professional and Scientific Equipment | 0.01 | 87.53 | 12.46 |
| 384 | Transport Equipment | 0.20 | 79.56 | 20.24 |
| | Average factor shares in the clean industry | 0.16 | 65.66 | 34.18 |

| Breakdown of the Pollution-Intensive Industry | | | | |
|---|---|---|---|---|
| ISIC Code | Definition | $s_e^2$ | $s_l^2$ | $s_k^2$ |
| 341 | Paper and Products | 0.99 | 60.40 | 38.62 |
| 353+354 | Petroleum Refineries and Misc. Petroleum and Coal Products | 1.29 | 39.64 | 59.07 |
| 351+352 | Industrial Chemicals and Other Chemicals | 0.30 | 43.61 | 56.09 |
| 361+362+369 | Pottery, China, Earthenware and Glass and Products and Other Non-Metallic Mineral Products | 0.33 | 62.93 | 36.74 |
| 371 | Iron and Steel | 2.87 | 76.69 | 20.44 |
| 372 | Non-Ferrous Metals | 5.88 | 70.22 | 23.90 |
| | Average factor shares in the dirty industry | 0.16 | 65.66 | 34.18 |

Table 2.7: Shares of pollution, labor and capital by sector (1994)

| Variable | | Est. | S.E. | % Effect on Costs |
|---|---|---|---|---|
| Distance [0, 600) (in km.) | $-\theta d_1$ | -3.03 | 0.10 | 57.62 |
| Distance [600, 1200) | $-\theta d_2$ | -3.97 | 0.11 | 81.36 |
| Distance [1200, 2400) | $-\theta d_3$ | -4.24 | 0.07 | 88.80 |
| Distance [2400, 4800) | $-\theta d_4$ | -4.68 | 0.05 | 101.85 |
| Distance [4800, 9600) | $-\theta d_5$ | -6.57 | 0.09 | 167.99 |
| Distance [9600, max.] | $-\theta d_6$ | -6.88 | 0.07 | 180.51 |
| Shared Border | $-\theta b$ | 0.63 | 0.09 | -8.98 |

| | | In Clean Industry | | | | In Dirty Industry | | |
|---|---|---|---|---|---|---|---|---|
| Source Country | | Est. | S.E. | % Effect on Costs | | Est. | S.E. | % Effect on Costs |
| New Zealand | $S_1^1$ | -0.53 | 0.17 | 8.24 | $S_1^2$ | -2.12 | 0.18 | 37.39 |
| Australia | $S_2^1$ | 0.21 | 0.17 | -3.14 | $S_2^2$ | 0.59 | 0.17 | -8.53 |
| Slovakia | $S_3^1$ | -2.55 | 0.15 | 46.51 | $S_3^2$ | -2.29 | 0.16 | 40.98 |
| Poland | $S_4^1$ | -1.05 | 0.15 | 17.07 | $S_4^2$ | -1.16 | 0.15 | 18.98 |
| Hungary | $S_5^1$ | -1.10 | 0.15 | 17.90 | $S_5^2$ | -1.67 | 0.15 | 28.38 |
| Czech Republic | $S_6^1$ | -1.29 | 0.15 | 21.31 | $S_6^2$ | -1.70 | 0.15 | 29.00 |
| Switzerland | $S_7^1$ | -0.05 | 0.15 | 0.74 | $S_7^2$ | 0.48 | 0.15 | -6.93 |
| Sweden | $S_8^1$ | 0.57 | 0.15 | -8.17 | $S_8^2$ | 0.83 | 0.15 | -11.65 |
| Norway | $S_9^1$ | -1.61 | 0.15 | 27.26 | $S_9^2$ | -0.35 | 0.15 | 5.46 |
| Iceland | $S_{10}^1$ | -5.00 | 0.16 | 111.79 | $S_{10}^2$ | -4.22 | 0.18 | 88.20 |
| Finland | $S_{11}^1$ | -0.26 | 0.15 | 3.96 | $S_{11}^2$ | 0.54 | 0.15 | -7.80 |
| Austria | $S_{12}^1$ | -0.29 | 0.15 | 4.39 | $S_{12}^2$ | -0.27 | 0.15 | 4.13 |
| United Kingdom | $S_{13}^1$ | 1.57 | 0.15 | -20.94 | $S_{13}^2$ | 1.62 | 0.15 | -21.59 |
| Spain | $S_{14}^1$ | 0.60 | 0.15 | -8.62 | $S_{14}^2$ | 0.63 | 0.15 | -8.99 |
| Portugal | $S_{15}^1$ | -0.83 | 0.15 | 13.31 | $S_{15}^2$ | -1.34 | 0.16 | 22.32 |
| Netherlands | $S_{16}^1$ | 0.70 | 0.15 | -9.94 | $S_{16}^2$ | 1.06 | 0.15 | -14.72 |
| Italy | $S_{17}^1$ | 1.57 | 0.15 | -20.96 | $S_{17}^2$ | 1.38 | 0.15 | -18.64 |
| Greece | $S_{18}^1$ | -2.32 | 0.15 | 41.73 | $S_{18}^2$ | -1.77 | 0.15 | 30.36 |
| Germany | $S_{19}^1$ | 2.22 | 0.15 | -28.32 | $S_{19}^2$ | 2.14 | 0.15 | -27.44 |
| France | $S_{20}^1$ | 1.33 | 0.15 | -18.07 | $S_{20}^2$ | 1.51 | 0.15 | -20.22 |
| Denmark | $S_{21}^1$ | -0.40 | 0.15 | 6.20 | $S_{21}^2$ | -0.46 | 0.15 | 7.17 |
| Belgium-Luxembourg | $S_{22}^1$ | 0.37 | 0.15 | -5.35 | $S_{22}^2$ | 1.06 | 0.15 | -14.67 |
| Turkey | $S_{23}^1$ | -0.92 | 0.15 | 14.74 | $S_{23}^2$ | -1.34 | 0.15 | 22.27 |
| Japan | $S_{24}^1$ | 3.65 | 0.16 | -42.19 | $S_{24}^2$ | 2.32 | 0.16 | -29.39 |
| Mexico | $S_{25}^1$ | 0.30 | 0.16 | -4.36 | $S_{25}^2$ | -0.33 | 0.17 | 5.11 |
| United States | $S_{26}^1$ | 3.96 | 0.18 | -44.83 | $S_{26}^2$ | 3.56 | 0.18 | -41.41 |
| Canada | $S_{27}^1$ | 1.15 | 0.16 | -15.80 | $S_{27}^2$ | 1.30 | 0.16 | -17.72 |

| | |
|---|---|
| Number of Observations | 1375 |
| Sum of Squared Residuals | 770 |
| Total Sum of Squares | 6843 |

Table 2.8: Estimates from the Bilateral Trade Equation, $\theta = 0.15$

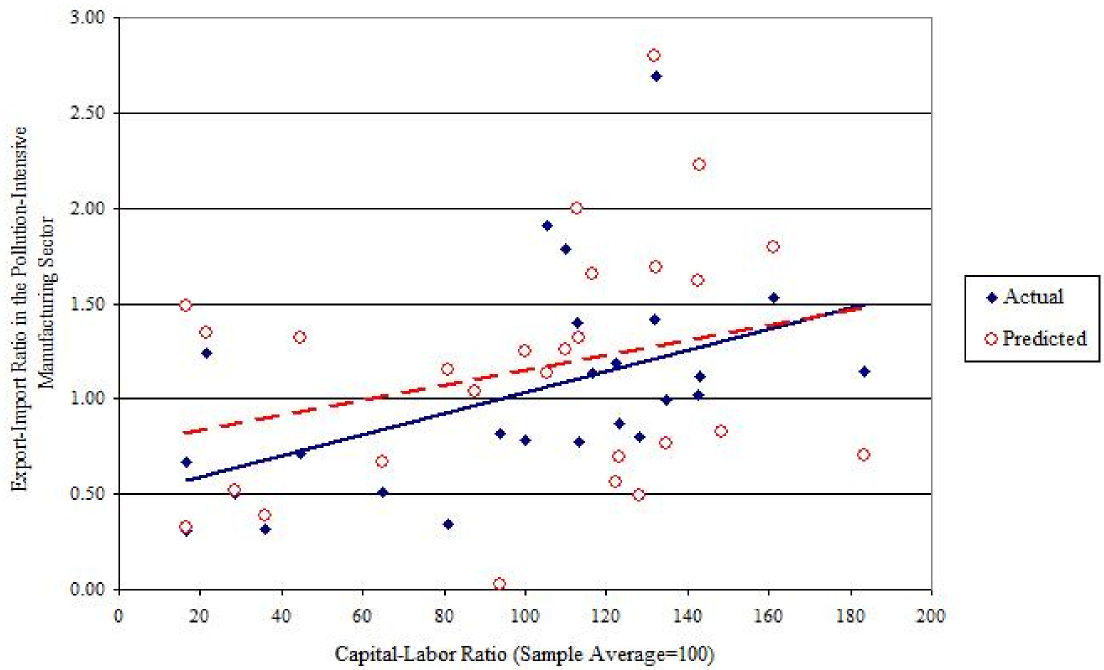


Figure 2.2: Relationship between capital-abundance indices and export-import ratios in the pollution-intensive industry

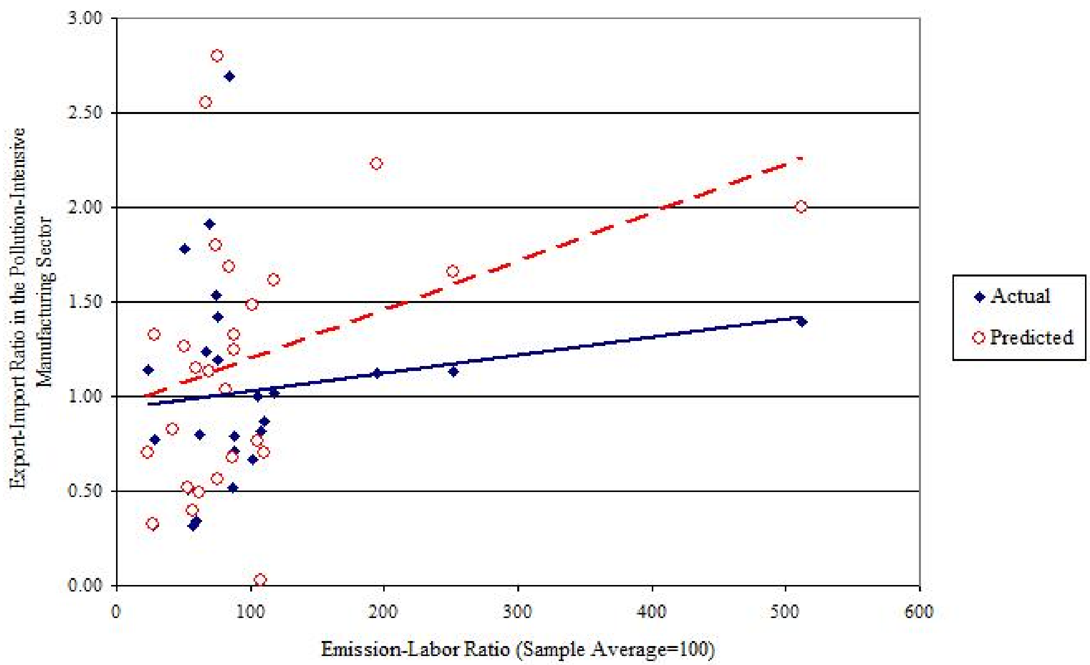


Figure 2.3: Relationship between emission-abundance indices and export-import ratios in the pollution-intensive industry

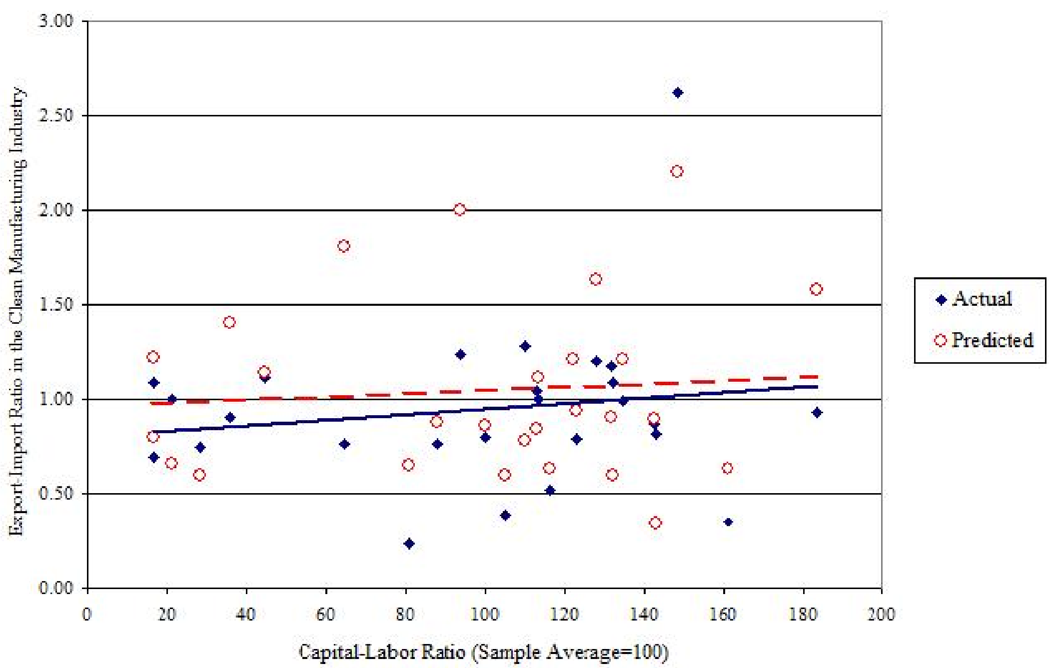


Figure 2.4: Relationship between capital-abundance indices and export-import ratios in the clean industry

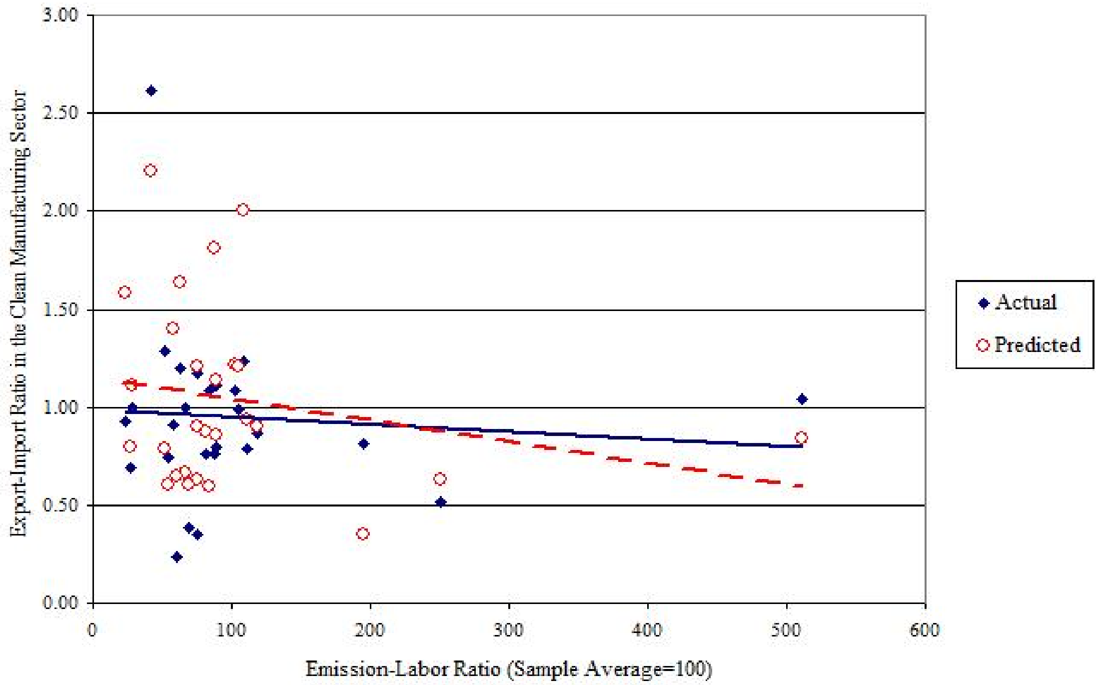


Figure 2.5: Relationship between emission-abundance indices and export-import ratios in the clean industry

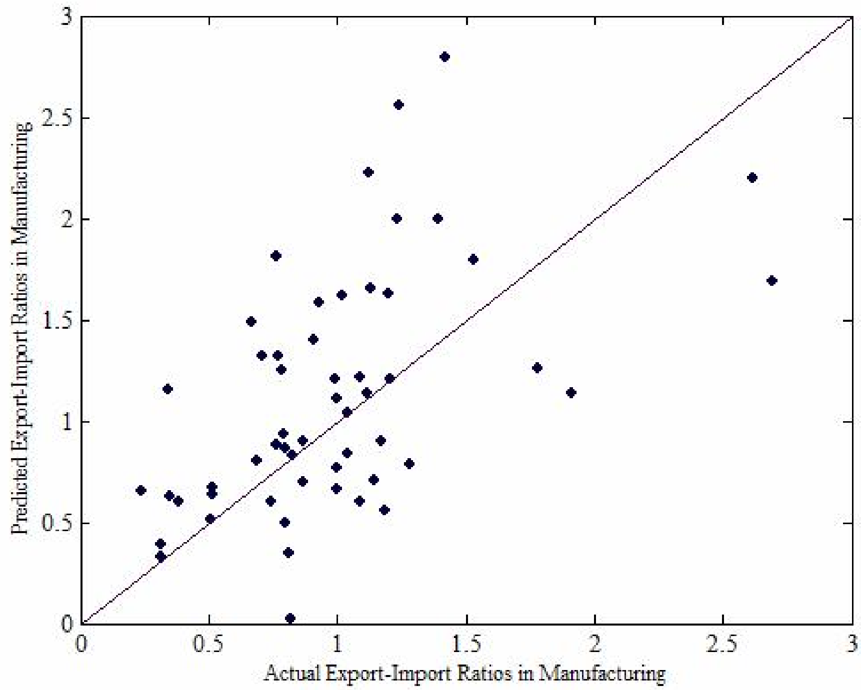


Figure 2.6: Comparison of the actual and predicted values of export-import ratios in the manufacturing sector with respect to the reference line; data year: 2000

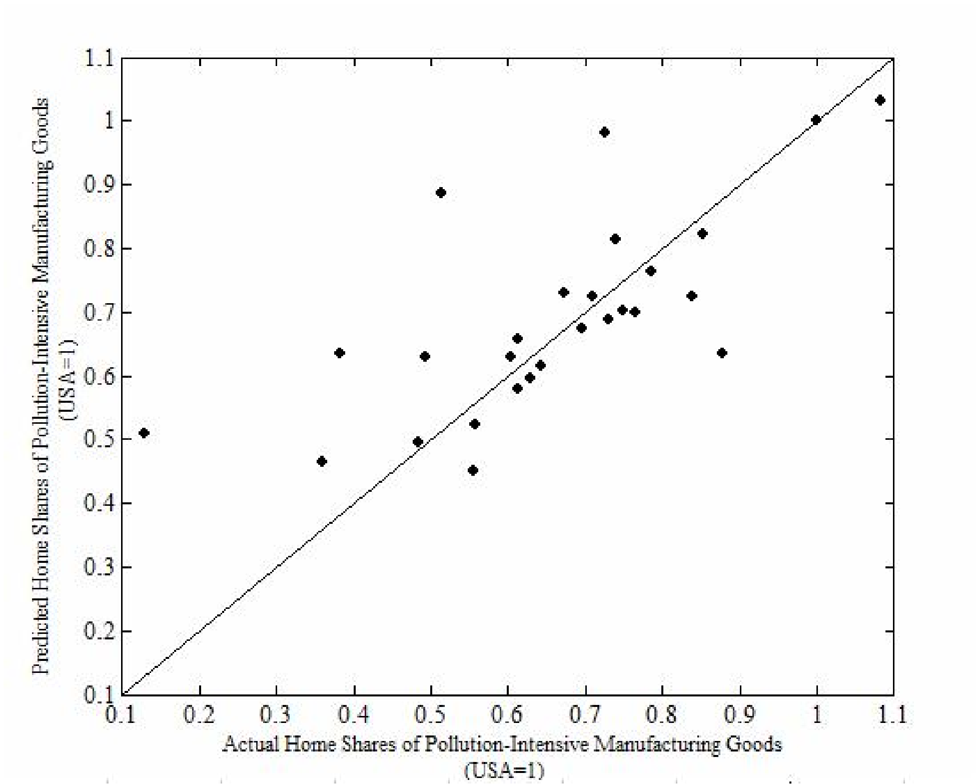


Figure 2.7: Comparison of the actual and predicted values of home trade shares of pollution-intensive manufacturing goods with respect to the reference line; data year: 2000

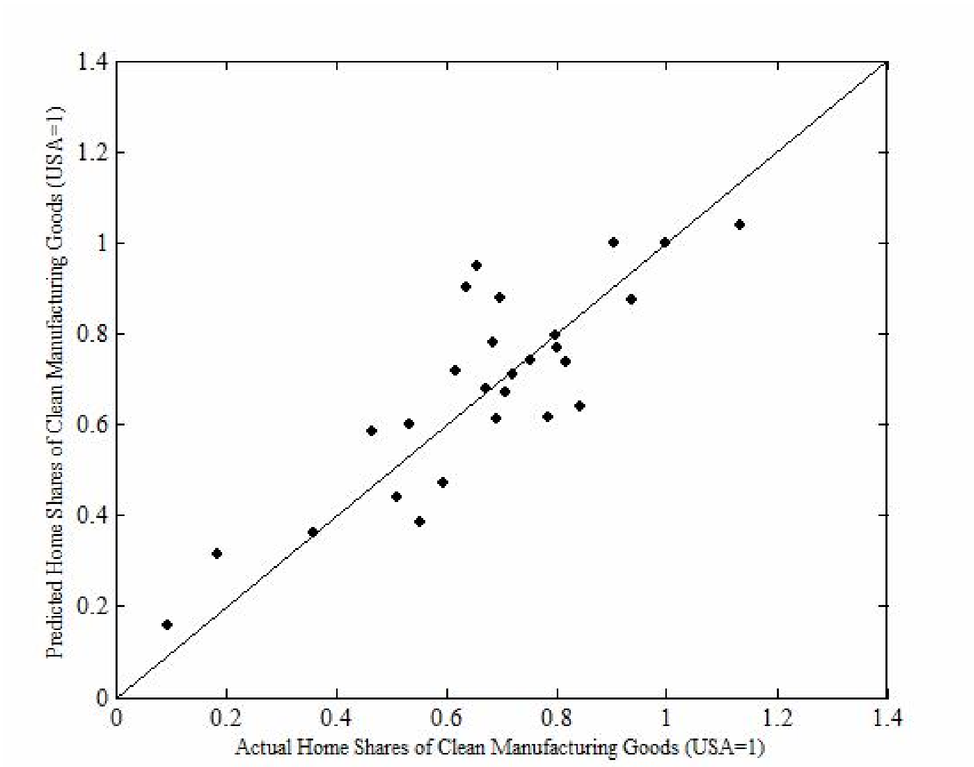


Figure 2.8: Comparison of the actual and predicted values of home trade shares of clean manufacturing goods with respect to the reference line; data year: 2000

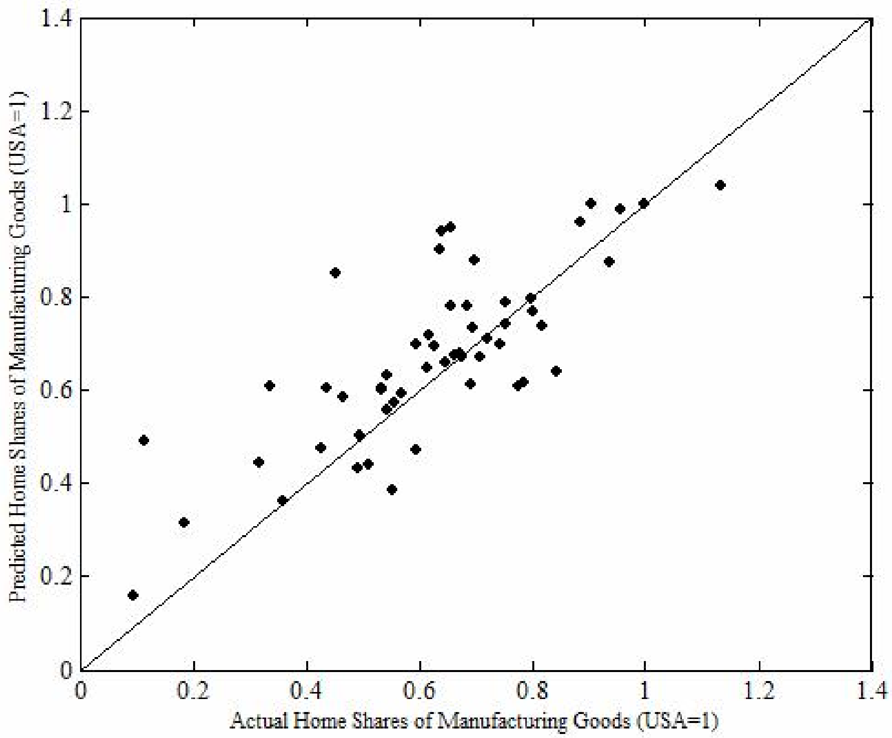


Figure 2.9: Comparison of the actual and predicted values of home trade shares of the manufacturing goods with respect to the reference line; data year: 2000

# Chapter 3

# Global Pollution, Endogenous Pollution Emissions and Trade

## 3.1 Introduction

International externalities associated with environmental pollution are among dominant issues in current public policy debates. The liberalization of trade further complicates the global pollution problem since trade not only affects the level of pollution due to scale and composition effects[1] but also can fundamentally alter the strategic interactions between countries over the emission level. In the presence of trade, most of the existing results about the global environmental pollution in a closed economy must be reconsidered or approached cautiously.

The effects of free trade on *local* environmental pollution have been theoretically analyzed in several papers. Copeland and Taylor (1994) present a model with two countries (high income North and low income South) and a continuum of goods with different pollution intensities where pollution is assumed to have a local nature. Countries aim to control pollution using pollution taxes. The authors find that after trade liberalization, South specializes in the production of the pollution-intensive goods and North in the relatively "cleaner" goods and the technique effect does not neutralize both the scale effect and this composition effect for South. They conclude

[1] For more information on scale, composition and technique effects of international trade, see Grossman and Krueger (1991).

that trade liberalization will alleviate the local environmental problems in North and aggravate them in South turning it into a "pollution haven". A related paper by Chichilnisky (1994) takes the observation that property rights over natural resources are often ill-defined in the South in comparison with the North. They use a simple model to show that the tragedy of the commons is exacerbated by trade between the North and the South. As a result, South specializes in resource-intensive goods to a greater extent than it would have done had the property rights been well-defined.

The focus of this chapter is the link between free trade and *global* types of pollution. Here, global pollution is meant to imply kinds of emissions that can travel away from the origin country and affect other countries. The existence of international externalities creates a market failure where environmental policy choices of local governments will no longer be optimal. A seminal study, Copeland and Taylor (1995), analyzes the consequences of free trade in such a framework. In that paper, pollution is assumed to have a "global" nature and emissions are controlled via national quotas implemented by nationally tradeable emission permits. The authors find that after trade liberalization, the usual composition effect still holds with clean industries expanding in North and polluting industries in South.

The results from Copeland and Taylor (1995), as well as the ones from Copeland and Taylor (1994), are based on the critical assumption that the comparative advantages in the world are determined by differences in environmental standards since the authors choose to concentrate on the role of income effect in shaping trade patterns. However, there exist numerous studies suggesting that other factors determining comparative advantage could easily dominate the policy induced differences. Among them are the empirical studies by Grossman and Krueger (1993) and Jaffe et al. (1995) which find that patterns of trade are mainly determined by factor endowments rather than differences in pollution abatement costs. Antweiler et al. (2001), Copeland and Taylor (2003), (2004) also highlight the importance of capital abundance differences as a trade motive and there are many empirical studies that incorporate the role of factor endowments when analyzing the impact of trade on pollution. However, to the best of my knowledge, the theoretical literature on the general equilibrium models of *global* pollution has been restricted to "pollution haven models" where environmental policy differences are the only source of trade. Debates over the effects of trade on global environmental problems, however, are unlikely to reach a resolution since this task would require more general models where several motives for trade are captured.

A related weakness of the pollution haven models is that these models fail to match the existing evidence on the patterns of specialization in production of the pollution-intensive goods. World Bank (1998) ranks the sectors by emission intensities (i.e. amounts of pollutants emitted in the production process) and thus identifies the six most polluting sectors[2] which are named as the "pollution-intensive" goods. Next, export-import ratios for selected countries are calculated for 1986 and 1995. The data on net exports of pollution-intensive goods presented in Table 3.1 show that developing countries, in general, do not specialize in highly polluting industries since their export-import ratios tend to be lower than one. It is rather the developed countries which are strengthening their position in polluting industries and Figure 3.7 demonstrates this pattern more clearly via grouping the countries according to their income levels. In other words, the pollution haven hypothesis that suggests that low income countries will specialize in production of dirtier goods is clearly in contradiction with the available evidence.

Finally, policy conclusions that might be achieved under the assumption of comparative advantages shaped by differential environmental standards need to be reconsidered. Under the assumptions of the pollution haven hypothesis, trade liberalization between North and South will almost always magnify the pollution problems in the world however, if the classical pattern of comparative advantage based on factor endowment differentials dominates, free trade may reduce world pollution since polluting production can then take place in North with stricter environmental regulations. Moreover, although in a pollution haven model, it is almost guaranteed that free international permit trade helps reduce global pollution (due to permit price and environmental standards equalizing effects of the free trade), a factor endowment model may arrive at a different conclusion. All of these points call for a richer framework for the analysis of the relation between trade and global environment.

With these points in mind, in this essay, I employ a factor endowment model of international trade and global pollution where the incentive to trade does not solely

[2]World Development Indicators (1998) lists the six most polluting sectors as: iron and steel, nonferrous metals, industrial chemicals, petroleum refineries, nonmetallic mineral products and pulp and paper products.

depend on environmental standard differentials. The general equilibrium model I use essentially builds on Copeland and Taylor (1995) with the added capital abundance motive to trade. Furthermore, I assume that the governments in the North and the South use their power to choose national emission levels to affect their terms of trade, strategically. In that framework, I theoretically investigate the effects of trade liberalization on both the overall level and the distribution of pollution in the world and also on the patterns of specialization. Overall, the model is successful in replicating the above-mentioned fact on patterns of trade such that the high income countries are the net exporters of the pollution-intensive goods. It also shows that, in many cases, the share of developed countries in environmental degradation is relatively higher than that of developing countries.

An interesting result from the model is that free trade is not always bad for the world pollution. In an equilibrium with no factor price equalization, it is shown that trade liberalization actually improves the global environmental condition when compared to the closed economy case. This result also leads to fundamentally different implications regarding the possible effects of international permit trade and capital mobility on global environmental quality.

The chapter is organized as follows: In section 3.2, I introduce the model and present the main results regarding the changes in the level and distribution of global pollution with free trade. In section 3.3, I discuss the possible impact of international permit trade and capital mobility on the level of global pollution. In section 3.4, I present the conclusions.

## 3.2 The Model

The global pollution model I use is a variation of Copeland and Taylor (1995) in that it is a North-South Heckscher-Ohlin model with a continuum of goods where pollution emissions are modelled as a factor of production. However, it departs from Copeland and Taylor (1995) in that international trade is motivated by differences in factor endowments rather than differential environmental standards. Furthermore, I concentrate on a case where governments exploit their power to manipulate prices by their choices of national pollution levels.

### 3.2.1 Environment

I consider a world economy consisting of two countries (North-South) where countries differ in their relative factor endowments. North has $K_N$ units of capital and $L_N$ units of labor while South has $K_S$ units of capital and $L_S$ units of labor. I assume $(K_N/L_N) > (K_S/L_S)$ that is, North is capital abundant and South is labor abundant.

There is a continuum of goods in each country, indexed by $z \in [0,1]$. Goods differ in their pollution emission and capital intensities such that the production function has the following functional form $\forall i \in \{N, S\}$:

$$y_i = f(k_i, l_i, e_i; z) = e_i(z)^{\alpha_e(z)}[g(k_i(z), l_i(z))]^{1-\alpha_e(z)}, \text{where}$$

$$g(k_i(z), l_i(z)) = k_i(z)^{\alpha_e(z)} l_i(z)^{1-\alpha_e(z)}$$

Here, $k_i(z)$, $l_i(z)$ and $e_i(z)$ denote, respectively, the quantities of capital, labor and pollution emissions that enter into the production process of a certain good $z$. Then, the production function can be rewritten as:

$$y_i = f(k_i, l_i, e_i; z) = e_i(z)^{\alpha_e(z)} k_i(z)^{\alpha_k(z)} l_i(z)^{\alpha_l(z)}$$

I assume that $0 < \alpha_j(z) < 1$, $\forall j \in \{e, k, l\}$ and $\alpha_e(z) + \alpha_k(z) + \alpha_l(z) = 1$, $\forall z$, that is, the production function exhibits constant returns to scale in $e_i(z)$, $k_i(z)$ and $l_i(z)$. I further assume that $\alpha'_e, \alpha'_k > 0$ and $\alpha'_l < 0$ hold which means as $z$ increases, both pollution intensity and the capital intensity of the goods increase. In other words, a good with a smaller index is assumed to be less pollution-intensive and relatively more labor-intensive than a good with a higher index. The main idea behind this assumption is that inherently most polluting industries are observed to be among the most capital-intensive sectors of all[3]. The functional form that is used for the production function reflects this assumption.

Consumers in North and South have identical utility functions where aggregate world pollution $(E_N+E_S)$ is treated as a pure public bad and the Northern $(E_N)$ and

[3]Mani and Wheeler (1998) show evidence on this assumption by analyzing the five most polluting sectors. Besides, the calculations reported in Table 2.2 (Chapter 2) of this dissertation, provide additional support on this issue.

Southern ($E_S$) pollution emissions are perfect substitutes. In other words, consumers in any country become worse-off not only by the national pollution emissions but by the emissions from the other country. Hence, the utility function of a representative consumer in country $i$ has the following functional form:

$$U_i = \int_0^1 ln[c_i(z)]dz - \gamma \frac{(E_i + E_{h \neq i})^{\mu}}{\mu}$$

where $c_i(z)$ denotes the amount consumed from good $z$ and $\mu,\ \gamma > 0$ are constant parameters that are assumed to be identical in both countries.

Within a period, the timing of events is as follows: First, governments set national pollution quotas, $E_N$ and $E_S$, by issuing pollution permits while on the international basis a noncooperative Nash equilibrium is considered. Each unit of permits allows a domestic firm to emit one unit of pollution. Next, permits are auctioned to producers and their market prices ($\tau_N$ and $\tau_S$) are thus determined. All revenue from permit sales is lump-sum rebated to consumers. Finally, consumers and producers maximize utility and profits treating $E_N$, $E_S$ and prices as given.

### 3.2.2 Autarky Equilibrium

I will first concentrate on an equilibrium when there is no trade and use this case as a benchmark to which free trade equilibria will be compared. Doing so, I will be able to show the effects of free trade on specialization in production and on the overall level and composition of global pollution.

Throughout the analysis, countries will be indexed by $i \in \{N, S\}$ and in country $i$, a representative consumer's problem of constrained utility maximization can be stated as follows,

$$\max_{c_i(z) \geq 0} \int_0^1 ln[c_i(z)]dz - \gamma \frac{(E_i + E_{h \neq i})^{\mu}}{\mu}$$

$$\text{s.t.} \quad \int_0^1 p_i(z)c_i(z)dz \leq w_i L_i + r_i K_i + \tau_i \int_0^1 e_i(z)dz,$$

where $p_i(z)$ is the domestic price of a particular good $z$, $w_i$ is the real wage rate and $r_i$ is the real interest rate.

Now, in this environment where trade is not possible, an equilibrium will be defined and characterized.

**Definition:** *An autarky equilibrium is a set of price functions* $p_N(z)$, $p_S(z)$, *wage rates* $w_N$, $w_S$, *rental rates* $r_N$, $r_S$, *permit prices* $\tau_N$, $\tau_S$, *consumption functions* $c_N(z)$, $c_S(z)$, *production plans* $l_N(z)$, $k_N(z)$, $e_N(z)$, $y_N(z)$, $l_S(z)$, $k_S(z)$, $e_S(z)$, $y_S(z)$ *and pollution levels* $E_N$, $E_S$ *such that:*

1. *Given* $p_i(z)$, $w_i$, $r_i$, $\tau_i$, *the representative consumer in country* $i$, $i \in \{N, S\}$, *chooses* $c_i(z)$ *to solve his problem;*

2. *Given* $c_i(z)$ *and* $E_{h \neq i}$, $h, i \in \{N, S\}$ , *the government in country* $i$, $i \in \{N, S\}$, *chooses* $E_i$ *to maximize consumer utility;*

3. *Firms' profit maximization conditions hold* $\forall i \in \{N, S\}, \forall z$*:*

$$\begin{aligned} p_i(z)\alpha_k(z)e_i(z)^{\alpha_e(z)}k_i(z)^{\alpha_k(z)-1}l_i(z)^{\alpha_l(z)} - r_i &\leq 0 \\ p_i(z)\alpha_l(z)e_i(z)^{\alpha_e(z)}k_i(z)^{\alpha_k(z)}l_i(z)^{\alpha_l(z)-1} - w_i &\leq 0 \\ p_i(z)\alpha_e(z)e_i(z)^{\alpha_e(z)-1}k_i(z)^{\alpha_k(z)}l_i(z)^{\alpha_l(z)} - \tau_i &\leq 0; \end{aligned}$$

4. *Markets clear:*

$$\begin{aligned} c_i(z) &= y_i(z), \quad \forall z, i \\ \int_0^1 l_i(z)dz &= L_i, \quad \forall i \\ \int_0^1 k_i(z)dz &= K_i, \quad \forall i \\ \int_0^1 e_i(z)dz &= E_i, \quad \forall i. \end{aligned}$$

Given the definition of equilibrium and the timing of events within a period, we start from the consumer's problem and obtain the consumption demand for a good $z$ as:

$$c_i(z) = (w_i L_i + r_i K_i + \tau_i E_i)/p_i(z), \ \forall z, i.$$

Producers have the standard problem of profit maximization and hence, the unit cost function is obtained as:

$$\begin{aligned} f_i(w_i, r_i, \tau_i, z) &= \tau_i^{\alpha_e(z)} r_i^{\alpha_k(z)} w_i^{\alpha_l(z)} \alpha_e(z)^{-\alpha_e(z)} \alpha_k(z)^{-\alpha_k(z)} \alpha_l(z)^{-\alpha_l(z)} \\ &= \tau_i^{\alpha_e(z)} r_i^{\alpha_k(z)} w_i^{\alpha_l(z)} \psi(z), \end{aligned}$$

by letting $\psi(z) = \alpha_e(z)^{-\alpha_e(z)} \alpha_k(z)^{-\alpha_k(z)} \alpha_l(z)^{-\alpha_l(z)}$.

The demand for pollution can easily be derived from the firm's first order conditions as follows:

$$\tau_i = p_i(z)\alpha_e(z)e_i(z)^{\alpha_e(z)-1}k_i(z)^{\alpha_k(z)}l_i(z)^{\alpha_l(z)} = p_i(z)\alpha_e(z)y_i(z)/e_i(z)$$

Under autarky, $p_i(z)y_i(z) = p_i(z)c_i(z) = w_iL_i + r_iK_i + \tau_iE_i$ will hold. Using this in the demand for pollution and after integrating over all goods, the aggregate demand for pollution is derived as:

$$\tau_i = \frac{(w_iL_i + r_iK_i)s^e}{(1-s^e)E_i} \tag{3.2.1}$$

where $s^e = \int_0^1 \alpha_e(z)dz$. So, as permit price increases, firms will be less willing to produce pollution-intensive goods since associated costs are now higher and therefore aggregate demand for pollution decreases. However as income earned from productive factors $(w_iL_i + r_iK_i)$ increases, demand for pollution increases, too.

Next, the benevolent government chooses the national pollution emission level $(E_i)$ taking the emission by the other country $(E_{h\neq i})$, $i, h \in \{N, S\}$, and the choices of the other agents as given. More specifically, the government's problem in country $i$ is:

$$\max_{E_i} V_i = \max_{E_i} \left\{ \int_0^1 ln \left[ \frac{(w_iL_i + r_iK_i + \tau_iE_i)}{p_i(z)} \right] dz - \gamma \frac{(E_i + E_{h\neq i})^\mu}{\mu} \right\}$$

which can be rewritten as:

$$\max_{E_i} \left\{ \int_0^1 ln[w_iL_i + r_iK_i + \tau_iE_i]dz - \int_0^1 ln[p_i(z)]dz - \gamma \frac{(E_i + E_{h\neq i})^\mu}{\mu} \right\}.$$

Governments in each country simultaneously solve the above problem taking the pollution level in the other country as given. This implies that it is possible to define a noncooperative simultaneous game and show the existence of a Nash equilibrium. Proposition 1 provides a sketch of the proof of existence for the two-player game $\Gamma = [I, \{S_i\}, \{V_i(.)\}]$ where the players are the governments of North and South with strategy sets $S_i$ and indirect utility functions $V_i(.)$.

**Proposition 1:** *A Nash equilibrium exists in game* $\Gamma = [I, \{S_i\}, \{V_i(.)\}]$.

**Sketch of the proof of proposition 1:**

From the production function,

$$y_i(z) = \begin{cases} e_i(z)^{\alpha_e(z)} k_i(z)^{\alpha_k(z)} l_i(z)^{\alpha_l(z)} & , \text{ if } e_i(z) \leq a k_i(z)^{\alpha_e(z)} l_i(z)^{1-\alpha_e(z)} \\ 0 & , \text{ if } e_i(z) > a k_i(z)^{\alpha_e(z)} l_i(z)^{1-\alpha_e(z)} \end{cases} \tag{3.2.2}$$

it is easy to see that $y_i(z) \leq a^{\alpha_e(z)} k_i(z)^{\alpha_e(z)} l_i(z)^{1-\alpha_e(z)}, \forall z$, i.e. output is bounded. It is also assumed that $e_i(z) \leq a k_i(z)^{\alpha_e(z)} l_i(z)^{1-\alpha_e(z)} \leq \bar{e}_i(z), \forall z$. Integrating this inequality over $z$ yields:

$$E_i = \int_0^1 e_i(z) dz \leq \int_0^1 \bar{e}_i(z) dz = \bar{E}_i.$$

Hence, the strategy sets $S_i = \{E_i : 0 \leq E_i \leq \bar{E}_i\}, \forall i \in \{N, S\}$ are nonempty, compact and convex. It is straightforward to see that the indirect utility functions, $V_i$, are continuous and quasiconcave. Using Proposition 8.D.3 from Mas-Colell et al. (1995), we conclude that a Nash equilibrium exists. Q.E.D.

**Proposition 2:** *Under autarky, North and South emit equal amounts of pollution and the world pollution level,* $E_W^A$, *is* $[2s^e/\gamma]^{1/\mu}$.

**Proof of proposition 2:**

Focusing on country $i$, from the firms' first order conditions we have

$$K_i = [(w_i L_i + r_i K_i + \tau_i E_i) s^k]/r_i \text{ and } L_i = [(w_i L_i + r_i K_i + \tau_i E_i) s^l]/w_i$$

where $s^j = \int_0^1 \alpha_j(z)dz,$ for $j \in \{k, l\}$ which together yield:

$$u_i = w_i/r_i = (s^l/s^k)(K_i/L_i) = G(K_i/L_i).$$

Using the aggregate demand for pollution, we get:

$$v_i = \tau_i/r_i = [(s^l/s^k) + 1][s^e/(1-s^e)](K_i/E_i) = F(K_i/E_i).$$

Now, the government's problem can be written as:

$$\begin{aligned} & \max_{E_i} \left\{ ln[(u_iL_i + K_i + v_iE_i)] - ln(v_i)\int_0^1 \alpha_e(z)dz - \gamma\frac{(E_i + E_{h\neq i})^\mu}{\mu} + D_i \right\} \\ = & \max_{E_i} \left\{ ln[(u_iL_i + K_i + v_iE_i)] - s^e ln(v_i) - \gamma\frac{(E_i + E_{h\neq i})^\mu}{\mu} + D_i \right\} \end{aligned}$$

where $D_i$ is a constant term. The first order condition yields:

$$\frac{s^e}{E_i} = \gamma(E_i + E_{h\neq i})^{\mu-1}, \forall i \in \{N, S\}$$

This immediately implies the equality of $E_N$ and $E_S$. Then, it is easy to show that $E_W^A = [2s^e/\gamma]^{1/\mu}$ holds. Q.E.D.

In autarky equilibrium, the levels of pollution emitted by countries do not depend on the relative abundance of capital which is the only factor that characterizes "North" and "South". Therefore, when the factor abundance channel is thus closed, the two countries make identical choices of pollution. The intuition for this result is that under autarky the capital abundant North demands relatively more pollution emissions than the other country while at the same time, less pollution will be supplied by the government in the capital abundant country due to higher income. Simultaneously, a similar mechanism is present in the labor abundant South where aggregate demand is lower while the aggregate supply is higher due to lower income. This result is identical to the one in Copeland and Taylor (1995) where the result was explained by the argument that the scale and technique effects offset each other.

Another observation is that as the "perceived harm" caused by the global pollution increases, which is represented by a rise in $\gamma$, level of the global pollution will be lower when there is no trade. Moreover, as the share of national income from permit sales ($s^e$) increases, world pollution level will be higher, as expected.

### 3.2.3 Free Trade Equilibrium

Before proceeding to analyzing the impact of free trade on trade and global pollution patterns, we start with the definition of a free trade equilibrium in this framework.

**Definition:** *A free trade equilibrium is a price function $p(z)$, wage rates $w_N$, $w_S$, rental rates $r_N$, $r_S$, permit prices $\tau_N$, $\tau_S$, consumption functions $c_N(z)$, $c_S(z)$, production plans $l_N(z)$, $k_N(z)$, $e_N(z)$, $y_N(z)$, $l_S(z)$, $k_S(z)$, $e_S(z)$, $y_S(z)$ and pollution levels $E_N$, $E_S$ such that:*

1. *Given $p(z)$, $w_i$, $r_i$, $\tau_i$, the representative consumer in country $i$, $i \in \{N, S\}$, chooses $c_i(z)$ to solve consumer's problem;*

2. *Given $c_i(z)$ and $E_{h \neq i}$, $h, i \in \{N, S\}$, the government in country $i$, $i \in \{N, S\}$ chooses $E_i$ to maximize consumer utility;*

3. *Firms' profit maximization conditions hold $\forall i \in \{N, S\}, \forall z$:*

$$\begin{aligned} p(z)\alpha_k(z)e_i(z)^{\alpha_e(z)}k^i(z)^{\alpha_k(z)-1}l_i(z)^{\alpha_l(z)} - r_i &\leq 0 \\ p(z)\alpha_l(z)e_i(z)^{\alpha_e(z)}k_i(z)^{\alpha_k(z)}l_i(z)^{\alpha_l(z)-1} - w_i &\leq 0 \\ p(z)\alpha_e(z)e_i(z)^{\alpha_e(z)-1}k_i(z)^{\alpha_k(z)}l_i(z)^{\alpha_l(z)} - \tau_i &\leq 0; \end{aligned}$$

4. *Markets clear:*

$$\begin{aligned} \sum_i c_i(z) &= \sum_i y_i(z), \quad \forall z \\ \int_0^1 l_i(z)dz &= L_i, \quad \forall i \\ \int_0^1 k_i(z)dz &= K_i, \quad \forall i \\ \int_0^1 e_i(z)dz &= E_i, \quad \forall i. \end{aligned}$$

Under free trade, I analyze two possible equilibria, namely, factor price equalization and no factor price equalization. Under factor price equalization, the exact trade pattern in equilibrium cannot be determined since both countries have identical unit cost functions. In this case, equilibrium conditions for the world economy are equivalent to the equilibrium conditions in the world autarky where the endowments are $K_N + K_S$ and $L_N + L_S$ and the equilibrium level of world pollution can be obtained by equating world demand and world supply.

In the case where there is no factor price equalization, it can be shown that a cutoff good, $\bar{z}$, can be found such that goods in the interval $[0, \bar{z})$ are produced by the South and goods in the interval $(\bar{z}, 1]$ are produced by the North [4]. That means, in this case, North specializes in the relatively pollution-intensive goods while South specializes in the relatively cleaner goods.

Below, I summarize the other findings regarding the effects of free trade on the aggregate level of world pollution and on the distribution of pollution across countries. In a two-country environment, each country is large enough to have an incentive and is able to manipulate prices through its choice of the national pollution quota. In the analysis, I therefore assume that the domestic governments exploit their power to affect the terms of trade by their choices of pollution. Within this framework, first, I state the results that follow under the factor price equalization case.

**Proposition 3:** *Under factor price equalization, free trade does not change the world pollution level.*

**Proof of proposition 3:**

Under factor price equalization, we have $\tau_N = \tau_S = \tau$, $w_N = w_S = w$, $r_N = r_S = r$ and hence, the unit cost functions are identical in the North and the South. Therefore, we will focus on the equilibrium in a "world autarky" where the equilibrium conditions are equivalent to equilibrium conditions in autarky where endowments are equal to $K_N + K_S$ and $L_N + L_S$. From the firms' optimality conditions we have:

[4] Following Dornbusch et al. (1980), I show how one can solve for the cutoff good in Appendix B at the end of this chapter.

$$K_N + K_S = s^k[w(L_N + L_S) + r(K_N + K_S) + \tau(E_N + E_S)]/r \text{ and}$$
$$L_N + L_S = s^l[w(L_N + L_S) + r(K_N + K_S) + \tau(E_N + E_S)]/w$$

which together imply:

$$u = w/r = (s^l/s^k)[(K_N + K_S)/(L_N + L_S)] = G[(K_N + K_S)/(L_N + L_S)].$$

Using the aggregate demand for pollution:

$$v = \tau/r = [(s^l/s^k)+1][s^e/(1-s^e)][(K_N+K_S)/(E_N+E_S)] = F[(K_N+K_S)/(E_N+E_S)].$$

Now, the government's problem in the North can be written as:

$$\begin{aligned} & \max_{E_N} \left\{ ln[(uL_N + K_N + vE_N)] - ln(v)\int_0^1 \alpha_e(z)dz - \gamma\frac{(E_N + E_S)^\mu}{\mu} + D \right\} \\ = & \max_{E_N} \left\{ ln[(uL_N + K_N + vE_N)] - s^e ln(v) - \gamma\frac{(E_N + E_S)^\mu}{\mu} + D \right\} \end{aligned}$$

where $D$ is a constant term. Hence, the first order condition yields:

$$\frac{v_{E_N}E_N + v}{uL_N + K_N + vE_N} - s^e\frac{v_{E_N}}{v} - \gamma(E_N + E_S)^{\mu-1} = 0$$

Using $v_{E_N} = -v/(E_N + E_S)$ and $E_W = E_N + E_S$ in the first order condition, we get:

$$\frac{vE_S}{(uL_N + K_N + vE_N)E_W} - \frac{s^e}{E_W} - \gamma(E_W)^{\mu-1} = 0 \qquad (3.2.3)$$

Similarly for the South, we obtain:

$$\frac{vE}{(uL_S + K_S + vE_S)E_W} - \frac{s^e}{E_W} - \gamma(E_W)^{\mu-1} = 0 \qquad (3.2.4)$$

Summing equations (3.2.3) and (3.2.4) side by side and after tedious algebra to solve for $E_W$, we obtain: $E_W^{FPE} = [2s^e/\gamma]^{1/\mu} = E_W^A$, that is, under factor price equalization, free trade does not change the level of global pollution. Q.E.D.

When compared to the autarky, we observe that free trade does not affect the total amount of the global pollution under factor price equalization. Intuitively, the result should be closely related to the offsetting scale and technique effects as before since factor price equalization takes us to an equilibrium, this time, in the "world autarky". Therefore, the world level of pollution remains unaffected as a result of trade.

Although free trade tends to leave the level of global pollution unaffected, whether or not the share of the North in world pollution will be higher is not obvious. I find that as long as the total income earned by the productive factors (that is, labor and capital) is relatively smaller in the North, North's share in the global pollution will be higher. This result is stated and proved in proposition 4.

**Proposition 4:** *Under factor price equalization, if $(w/r)(L_S - L_N) > K_N - K_S$, then in equilibrium, North emits more pollution than South and vice versa, if otherwise.*

**Proof of proposition 4:**

From equations (3.2.3) and (3.2.4), we have:

$$\frac{E_S}{uL_N + K_N + vE_N} = \frac{E_N}{uL_S + K_S + vE_S} \tag{3.2.5}$$

Using $v = \tau/r = [(s^l/s^k) + 1][s^e/(1 - s^e)][(K_N + K_S)/(E_N + E_S)] = F[(K_N + K_S)/(E_N + E_S)]$ in (3.2.5) and solving (3.2.5) and $E_W = E_N + E_S$ for $E_N$ and $E_S$, we get:

$$E_N = \frac{uL_S + K_S + F(K_N + K_S)}{(2F + 1)(K_N + K_S) + u(L_N + L_S)} E_W \tag{3.2.6}$$

$$E_S = \frac{uL_N + K_N + F(K_N + K_S)}{(2F + 1)(K_N + K_S) + u(L_N + L_S)} E_W \tag{3.2.7}$$

Thus,

$$E_N - E_S = \frac{E_W[u(L_S - L_N) + K_S - K_N]}{(2F + 1)(K_N + K_S) + u(L_N + L_S)}$$

So if $u(L_S - L_N) > K_N - K_S$, then $E_N > E_S$ will follow. Q.E.D.

It is worth mentioning that the condition stated in proposition 4 is not in contradiction with the assumption that North is the capital abundant country, instead, it is just a stricter condition. Intuitively, the proposition implies that when a country gets a smaller return from its productive factors than the other, it has an incentive to raise its domestic pollution emission level so as to compensate for that.

If factor prices are not equalized by trade, the government's problem in the North becomes:

$$\max_{E_N} ln[(u_N L_N + K_N + v_N E_N)] - \int_0^{\bar{z}} ln[\tau_S^{\alpha_e(z)} r_S^{\alpha_k(z)} w_S^{\alpha_l(z)} \psi_S(z)]dz$$
$$- \int_{\bar{z}}^1 ln[\tau_N^{\alpha_e(z)} r_N^{\alpha_k(z)} w_N^{\alpha_l(z)} \psi_N(z)]dz - \gamma \frac{(E_N + E_S)^\mu}{\mu}$$

However, the second term in the problem above does not depend on $E_N$, so the problem can be rewritten as [5]:

$$\max_{E_N} \left\{ ln[(u_N L_N + K_N + v_N E_N)] - ln(v_N) \int_{\bar{z}}^1 \alpha_e(z)dz - \gamma \frac{(E_N + E_S)^\mu}{\mu} \right\}$$

**Proposition 5:** *Under no factor price equalization, free trade decreases the level of the world pollution.*

**Proof of proposition 5:**

Let us define $s_N^e(\bar{z}) = \int_{\bar{z}}^1 \alpha_e(z)dz$ and $s_S^e(\bar{z}) = \int_0^{\bar{z}} \alpha_e(z)dz$. The first order condition from the government's problem in the North yields:

$$\frac{v_{NE} E_N + v_N}{u_N L_N + K_N + v_N E_N} - s_N^e(\bar{z}) \frac{v_{NE}}{v_N} - \gamma (E_W)^{\mu-1} = 0 \tag{3.2.8}$$

Using $v_{NE} = -v_N / E_N$ in this, we get:

$$s_N^e(\bar{z}) \frac{1}{E_N} - \gamma (E_W)^{\mu-1} = 0 \tag{3.2.9}$$

[5]See Appendix A at the end of this chapter for the proof.

Similarly for the South, we will get:

$$s_S^e(\bar{z})\frac{1}{E_S} - \gamma(E_W)^{\mu-1} = 0 \tag{3.2.10}$$

Now, summing these two equations up and solving for $E_W$, one can verify that $E_W^{NFPE} = (s^e/\gamma)^{1/\mu} < (2s^e/\gamma)^{1/\mu} = E_W^A$. Q.E.D.

**Proposition 6:** *Under no factor price equalization, for $s_N^e(\bar{z}) > s_S^e(\bar{z})$, $E_N > E_S$ i.e. North supplies more pollution than South and vice versa, otherwise.*

**Proof of proposition 6:**

From (3.2.9) and (3.2.10) we have:

$$E_N/E_S = s_N^e(\bar{z})/s_S^e(\bar{z})$$

Then, it is straightforward to show the result in the theorem. Q.E.D.

Proposition 6 presents a condition that depends on $\bar{z}$ while $\bar{z}$ is determined by the factor endowments [6]. In order to be able to present a clearer picture showing the range of values of factor endowments for which $\bar{z}$ satisfies $s_N^e(\bar{z}) > s_S^e(\bar{z})$, I employ an analytically convenient functional form for $\alpha_e(z)$ and present the results in the next section.

### 3.2.4 A Numerical Exercise

In this section, I assume $\alpha_e(z) = z$ and restrict $z$ to be in the interval [0, 0.5]. Then the production function can be rewritten as:

$$y = f(k, l, e; z) = e(z)^z k(z)^{z-z^2} l(z)^{1-2z+z^2},$$

and as $z$ increases within the specified interval, both pollution intensity and the capital intensity of the goods increase, as before.

Then by proposition 6, for $\bar{z} \in [0, 0.3536)$, North supplies more pollution than

[6] See Appendix B for the proof.

South and vice versa for $\bar{z} \in (0.3536, 0.5]$ since in a free trade equilibrium:

$$E_N/E_S = s_N^e(\bar{z})/s_S^e(\bar{z}) = (0.25 - \bar{z}^2)/\bar{z}^2$$

will hold.

In this section, I present a set of figures that show the values computed for the cutoff good, $\bar{z}$, as factor endowment ratios vary on the specified intervals. It is observed that in figures 3.1 to 3.6, a substantial fraction of the computed values for $\bar{z}$ fall into the interval [0, 0.3536) which implies that for a large range of the parameters, North's share in global pollution is found to be higher than that of South.

One set of experiments is carried out for the case where North and South have identical labor force sizes and the results are plotted in figures 3.1, 3.2 and 3.3. Figures 3.4, 3.5 and 3.6, on the other hand, show the experiment outcomes for the case where South has a larger labor force than North. Panel A in the figures depicts how $\bar{z}$ values vary with the factor endowment ratios in the two countries. Part B of the figures shows the contour of the three dimensional illustration on the left. More clearly, each curve connects all pairs of factor endowments that yield a unique level of $\bar{z}$. A quick inspection of any of the figures from 3.1 to 3.6 yields that everything else held constant, as the capital abundance of North is increased, $\bar{z}$ declines expanding the range of goods the North will specialize in. Similarly, as the capital abundance of South is increased, $\bar{z}$ tends to rise leading South to specialize in a larger range of goods.

For the case with identical labor forces, Figure 3.1 yields that, for $0 < K_S/L_S < K_N/L_N < 1$, $\bar{z}$ changes in the interval [0, 0.3536) implying that North pollutes more than South. The same observation is also valid for the other intervals in which capital abundance ratios could change as it is seen in Figures 3.2 and 3.3. In part B of each figure, we see that one unit of increase in $\bar{z}$ requires increasingly higher raises in capital levels. This tendency can also be seen in the increasing slope of the contour curves.

The second set of numerical experiments simulates the specialization patterns for the case where the size of the labor force in South is five times the labor force in North. In these experiments, $\bar{z}$ values are found to be higher than in the case

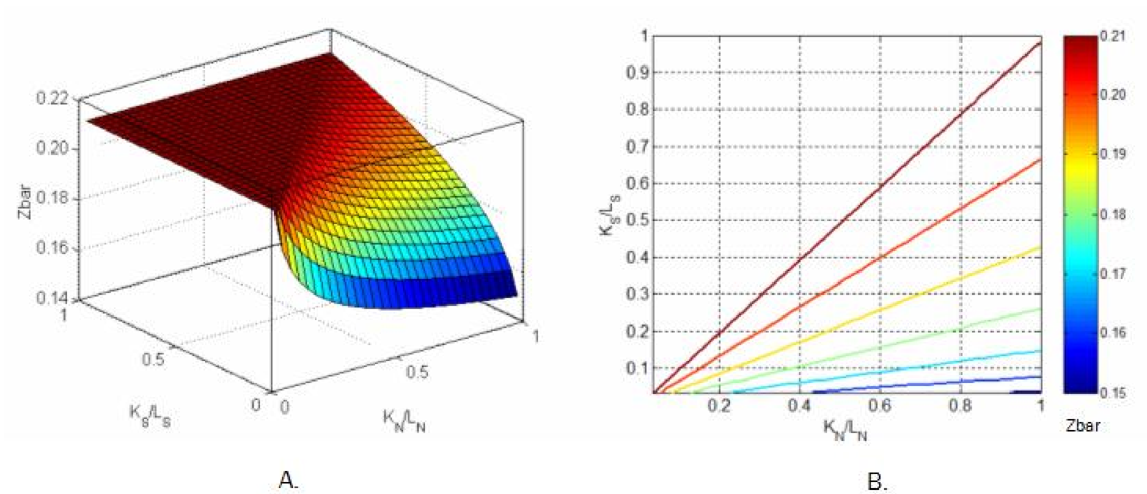


Figure 3.1: $L_N = L_S = 30$ and $0 < (K_S/L_S) < (K_N/L_N) < 1$

with equal labor force sizes, as figures 3.4, 3.5 and 3.6 reveal. In other words, the range of goods that South specializes in is larger than in the case where countries had equal labor force sizes. This situation is seen to lead to cases where South could emit more pollution than North or equivalently, to cases where $\bar{z}$ falls in [0.3536, 0.5]. Figures 3.4, 3.5 and 3.6 present examples of such instances. This particular exercise provides us with insights on the potential patterns of trade and pollution under the case where the poorer country has a significantly labor force than the other. If South is significantly larger than North and the gap in capital abundance levels between North and South is sufficiently small, then it is possible that South pollutes more than North, reversing the general pattern.

## 3.3 International Permit Trade and Capital Mobility

Since global environmental pollution is a pure public bad, the efficient determination of the pollution requires that the permit prices be equalized across North and South and set equal to the global sum of marginal damages. International permit trade has been one of the frequently suggested means to achieve global efficiency in open economies. The argument by the proponents is, most of the time, similar to

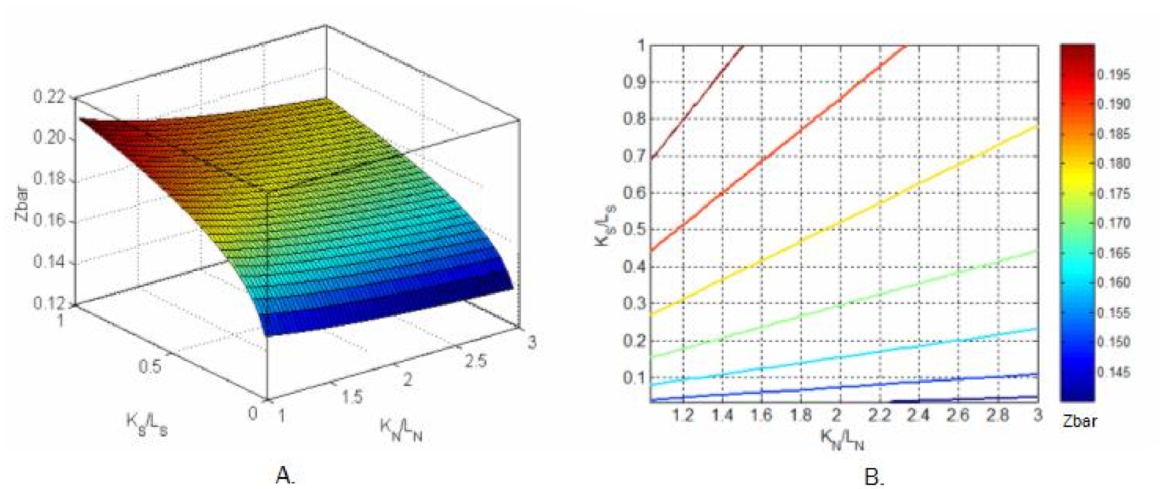


Figure 3.2: $L_N = L_S = 30$ and $(K_S/L_S) < 1 < (K_N/L_N)$

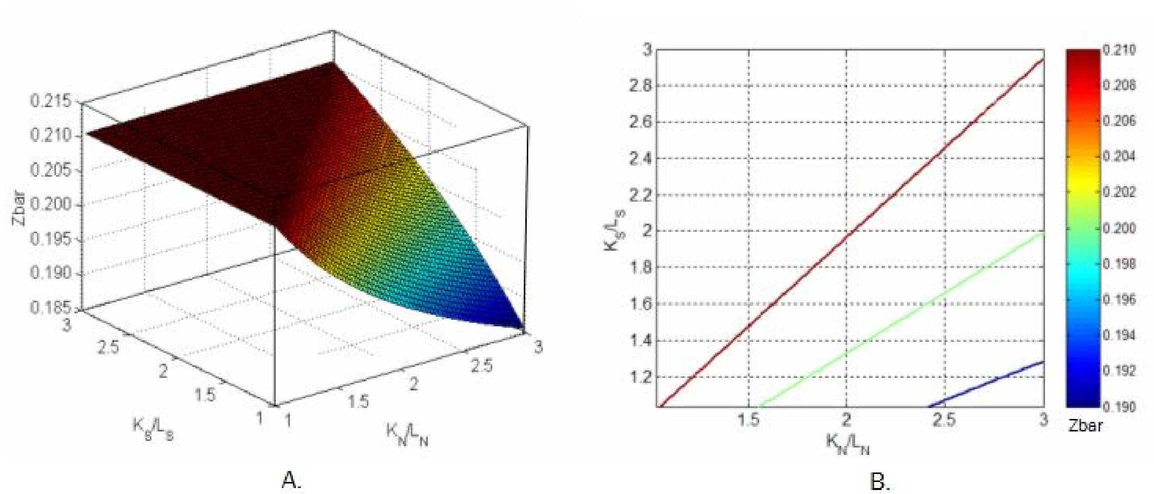


Figure 3.3: $L_N = L_S = 30$ and $1 < (K_S/L_S) < (K_N/L_N)$

the standard economic theory supporting the gains from free trade. However, the question of whether or not liberalization of domestic permit markets helps alleviate global pollution problems does not seem to have an unconditional answer.

In international trade models that are based on the pollution haven hypothesis, countries are distinguished by differential environmental standards. Lower permit prices (or lax environmental standards) prevailing in South provides an incentive

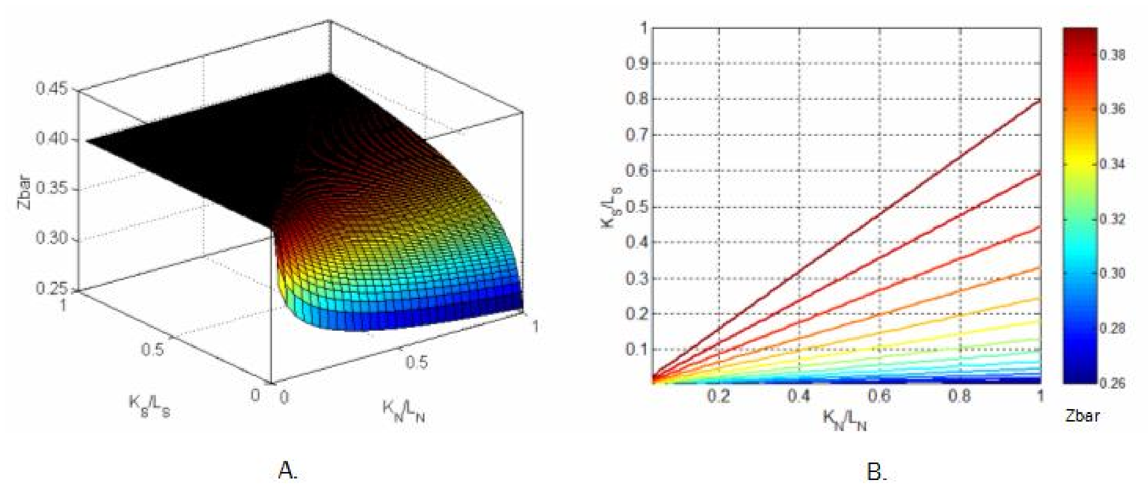


Figure 3.4: $L_N = 30$, $L_S = 150$ and $0 < (K_S/L_S) < (K_N/L_N) < 1$

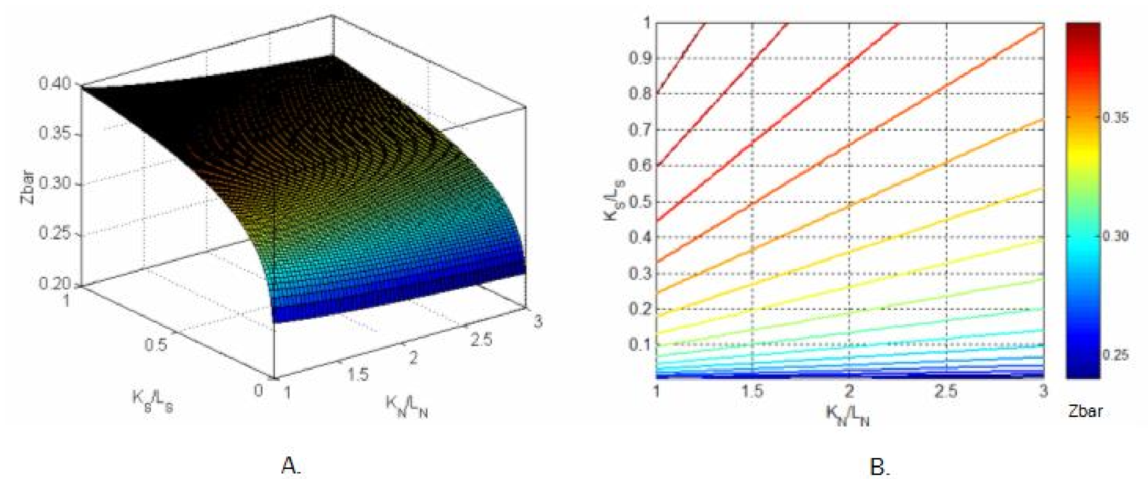


Figure 3.5: $L_N = 30$, $L_S = 150$ and $(K_S/L_S) < 1 < (K_N/L_N)$

for the most-polluting industries to shift to these countries causing them to be pollution havens. In that case, free goods trade tends to increase global pollution and liberalization of permit markets eliminates the pollution haven effect equalizing the permit prices and therefore the environmental standards, in North and South. Hence, in those models, it is almost a natural conclusion that allowing free trade in permits, in cases where free trade in goods does not equalize permit prices, tends

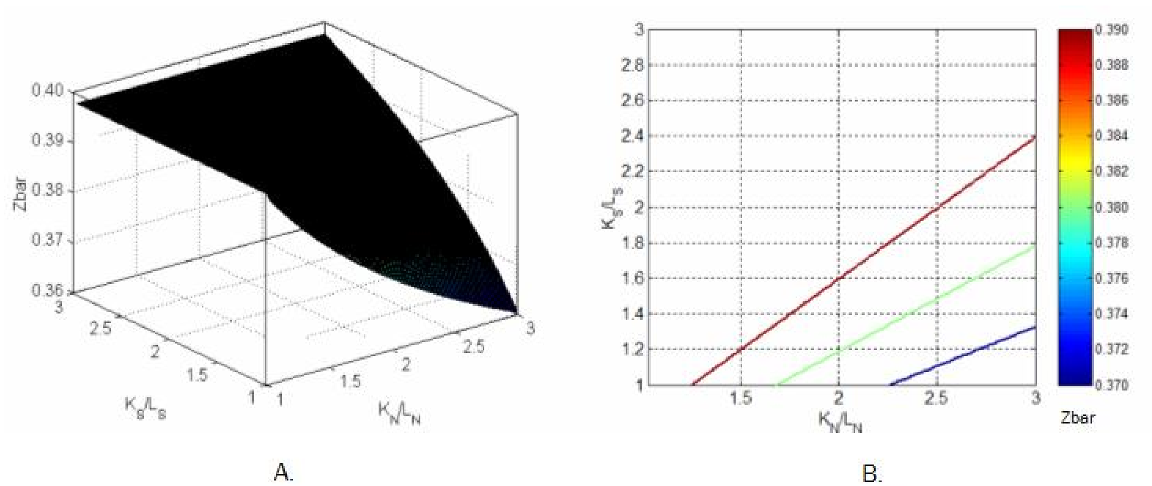


Figure 3.6: $L_N = 30$, $L_S = 150$ and $1 < (K_S/L_S) < (K_N/L_N)$

to reduce global pollution [7].

In this essay, in a trade equilibrium with factor price equalization, allowing permit trade is expected to have no effect on pollution. Since pollution is assumed to be global in nature and permit prices are already equalized, allowing domestic permits to be traded in international markets should not change the incentives of domestic governments to change their choices of pollution quotas. However, when countries are in a free goods trade equilibrium with no factor price equalization, liberalization of permit markets in North and South can actually aggravate global pollution problems.

Consider the case in which North and South are initially in an equilibrium under free goods trade where factor prices (including the permit prices) are not equalized. When domestic permit markets are opened to free international trade, we expect that the permit prices in North and South will eventually be equalized. From firms' optimality conditions we will also have the equality of other factor prices which means that a free trade equilibrium with factor price equalization will thus be attained. Then by proposition 5, international permit trade between North and South results in a higher level of global pollution. Hence, in an environment in

[7]The work by Copeland and Taylor (1995) can be shown as an example from the literature supporting this result.

which comparative advantages depend on factor endowments rather than differences in environmental standards, it is possible to obtain an opposite policy implication concerning the trade in pollution permits.

Since the early 1990s, another important policy related issue has been the possible impact of international capital mobility from developed to less developed countries on global pollution levels. According to the predictions of this model, under the presence of absolute free trade, full liberalization of capital flows will lead to an increase in global emissions. This conclusion can also be traced back to proposition 5 by the same argument we developed to analyze free permit trade. In this case, under free trade, limiting the international capital mobility will be helpful in increasing global environmental quality. Overall, all these discussions indicate that policy implications of pollution haven models, on the control of global pollution, should be approached cautiously. Even the most frequently cited "remedies" to the global pollution problems need to be reconsidered carefully since their successes are highly contingent on the economic model in which they are analyzed.

## 3.4 Concluding Remarks

In this chapter, I specifically concentrate on "global pollution" problems and theoretically examine the effects of free goods trade and endogenous (and strategic) emissions policy on the world pollution level and the patterns of trade in an environment where the incentive to trade comes from both the differences in factor endowments and pollution policies. First, I find that trade liberalization is likely to lead to an improvement in global environmental quality if trade does not cause an equalization in factor prices[8]. Next, I show that under no factor price equalization, high income country specializes in the production of pollution-intensive goods and low income country in the relatively cleaner goods so as to match the pattern observed in the data. Moreover, with the help of a numerical example, I demonstrate that there exists a possibility of having North as the party that produces more environmental pollution. The model also predicts that in the case where the low income country has a significantly larger labor force with a relatively high cap-

[8]However, it is worth mentioning that both autarky and free trade levels of global pollution can be shown to be above the efficient level.

ital abundance level, pollution problems in South might aggravate. Finally, in an open economy context, I consider the possible effects of free international permit trade and capital mobility on the global pollution and state that, in contrast to the outcome one would obtain under a pollution haven model, both permit trade and capital mobility between high income North and low income South are not beneficial for the global environmental quality.

Transboundary pollution problems which were the main emphasis of this study exhibit different characteristics than local pollution types and therefore they must be given special consideration. One such property is the international externalities that the global pollution types create. By the nature of transboundary pollutants, environmental policies in the affected countries will be interdependent. That interdependence accompanied with the possibility of strategic use of environmental policy to affect terms of trade makes it difficult to predict the impacts of international trade and other policy-related issues like permit trade and capital mobility. This study, therefore, aims to contribute to the existing literature by providing insights on those issues of international policy making within the context of a generalized trade model. For this purpose, although there is always room and need for more elaborate models to study different aspects of the global pollution phenomenon, in this essay, a factor endowment model is utilized which seem to fill an important gap between the findings of empirical studies and the claims based on the pollution haven hypothesis.

Overall, this essay also reemphasizes that the general equilibrium linkages between international goods trade and global environmental issues are important in understanding the level and the incidence of global pollution. Global pollution is considered to be a special kind of economic concept known as "global public bad". What makes a global public bad different from other issues is that the existing economic and political mechanisms are in general weak for resolving these problems efficiently. Moreover, local pollution policy can be used as a tool to modify the terms of trade that a country faces in an open economy environment. This strategic incentive adds to the difficulty of implementation of the efficient provision of the environmental quality. Therefore, the design of an efficient mechanism that can reduce global pollution within the context of a trading world economy remains as a challenging question that needs to be explored.

## 3.5 Appendix A

Market clearing conditions in the North and South under free trade are:

$$y_N(z) = \frac{(w_N L_N + r_N K_N + \tau_N E_N) + (w_S L_S + r_S K_S + \tau_S E_S)}{c_N(w_N, r_N, \tau_N, z)}, \quad \text{for} \quad z \in (\bar{z}, 1]$$

$$y_S(z) = \frac{(w_N L_N + r_N K_N + \tau_N E_N) + (w_S L_S + r_S K_S + \tau_S E_S)}{c_S(w_S, r_S, \tau_S, z)}, \quad \text{for} \quad z \in [0, \bar{z})$$

National incomes can be written as follows:

$$M_N = w_N L_N + r_N K_N + \tau_N E_N = \int_{\bar{z}}^{1} (M_N + M_S) dz = (1 - \bar{z})(M_N + M_S)$$

$$M_S = w_S L_S + r_S K_S + \tau_S E_S = \int_{0}^{\bar{z}} (M_N + M_S) dz = \bar{z}(M_N + M_S)$$

From the firms' optimality conditions in the North, we obtain:

$$\alpha_e(z) p(z) y_N(z) = \tau_N e_N(z)$$

Using the market clearing conditions, we get:

$$\alpha_e(z)(M_N + M_S) = \tau_N e_N(z), \quad \text{for} \quad z \in (\bar{z}, 1], \text{ which implies}$$

$$\alpha_e(z) \frac{M_N}{1 - \bar{z}} = \tau_N e_N(z), \quad \text{for} \quad z \in (\bar{z}, 1].$$

Integrating both sides over $z \in (\bar{z}, 1]$ we get:

$$\tau_N E_N = \frac{M_N s_N^e(\bar{z})}{1 - \bar{z}} \tag{3.5.1}$$

and using $M_N = w_N L_N + r_N K_N + \tau_N E_N$ in that expression yields:

$$\tau_N = \frac{(w_N L_N + r_N K_N) s_N^e(\bar{z})}{E_N[1 - \bar{z} - s_N^e(\bar{z})]}$$

Similarly in the South,

$$\tau_S E_S = \frac{M_S s_S^e(\bar{z})}{\bar{z}} \tag{3.5.2}$$

$$\text{and } \ \tau_S = \frac{(w_S L_S + r_S K_S) s_S^e(\bar{z})}{E_S[\bar{z} - s_S^e(\bar{z})]}.$$

Going over the same procedure using the optimality conditions for the choice of capital, in the North, we have:

$$\alpha_k(z)p(z)y_N(z) = r_N k_N(z),$$

and we obtain:

$$r_N K_N = \frac{M_N s_N^k(\bar{z})}{1 - \bar{z}}. \tag{3.5.3}$$

Similarly in the South,

$$r_S K_S = \frac{M_S s_S^k(\bar{z})}{\bar{z}} \tag{3.5.4}$$

Finally, using the optimality conditions for the choice of labor, we have:

$$w_N L_N = \frac{M_N s_N^l(\bar{z})}{1 - \bar{z}}$$

These yield:

$$u_N = \frac{w_N}{r_N} = \frac{s_N^l(\bar{z})}{s_N^k(\bar{z})}\frac{K_N}{L_N}, \ \text{ and}$$

$$v_N = \frac{\tau_N}{r_N} = \frac{s_N^e(\bar{z})}{s_N^k(\bar{z})}\frac{K_N}{E_N}.$$

Similarly, it is straightforward to verify that for the South,

$$u_S = w_S/r_S = f(\bar{z}, K_S, L_S) \text{ and } v_S = \tau_S/r_S = g(\bar{z}, K_S, E_S) \text{ hold.}$$

Thus, we have shown that the second term in the following expression does not depend on $E$,

$$\max_{E_N} ln[(u_N L_N + K_N + \upsilon_N E_N) - \int_0^{\bar{z}} ln[\tau_S{}^{\alpha_e(z)} r_S{}^{\alpha_k(z)} w_S{}^{\alpha_l(z)} \psi_S(z)]dz$$
$$- \int_{\bar{z}}^1 ln[\tau_N^{\alpha_e(z)} r_N^{\alpha_k(z)} w_N^{\alpha_l(z)} \psi_N(z)]dz - \gamma \frac{(E_N + E_S)^\mu}{\mu}$$

and it can be rewritten as follows when the above expressions for the relative price of permits are inserted:

$$\max_{E_N} \left\{ ln[(u_N L_N + K_N + \upsilon_N E_N) - ln(\upsilon_N) \int_{\bar{z}}^1 \alpha_e(z)dz - \gamma \frac{(E_N + E_S)^\mu}{\mu} + \mathrm{D} \right\}$$

## 3.6 Appendix B

If factor prices are not equalized by trade, then the marginal good is produced at equal unit cost in both North and South. That means:

$$c_N(w_N, r_N, \tau_N, \bar{z}) = c_S(w_S, r_S, \tau_S, \bar{z}), \quad \text{which in turn implies:}$$

$$\tau_N^{\alpha_e(\bar{z})} r_N^{\alpha_k(\bar{z})} w_N^{\alpha_l(\bar{z})} = \tau_S{}^{\alpha_e(\bar{z})} r_S{}^{\alpha_k(\bar{z})} w_S{}^{\alpha_l(\bar{z})}.$$

Then, we can solve for the real wage ratio:

$$\frac{w_N}{w_S} = \left[ \left( \frac{\tau_S}{\tau_N} \right)^{\alpha_e(\bar{z})} \left( \frac{r_S}{r_N} \right)^{\alpha_k(\bar{z})} \right]^{1/\alpha_l(\bar{z})} \tag{3.6.1}$$

Using (3.5.1), (3.5.2), (3.5.3) and (3.5.4) in (3.6.1), we get:

$$\frac{w_N}{w_S} = \left[ \frac{K_N}{K_S} \frac{s_S^k(\bar{z})}{s_N^k(\bar{z})} \right]^{\alpha_k(\bar{z})/\alpha_l(\bar{z})} \tag{3.6.2}$$

Inserting (3.5.1) and (3.5.3) in $M_N = w_N L_N + r_N K_N + \tau_N E_N$ and solving for $w_N$:

$$w_N = \frac{M_N}{L_N} \left[ 1 - \frac{s_N^k(\bar{z}) + s_N^e(\bar{z})}{1 - \bar{z}} \right] \tag{3.6.3}$$

Similarly, for the South we obtain:

$$w_S = \frac{M_S}{L_S}\left[1 - \frac{s_S^k(\bar{z}) + s_S^e(\bar{z})}{\bar{z}}\right] \tag{3.6.4}$$

Dividing (3.6.3) by (3.6.4):

$$\frac{w_N}{w_S} = \frac{L_S}{L_N}\left[\frac{1 - \bar{z} - s_N^k(\bar{z}) - s_N^e(\bar{z})}{\bar{z} - s_S^k(\bar{z}) - s_S^e(\bar{z})}\right] \tag{3.6.5}$$

Finally, one can solve for $\bar{z}$ from (3.6.2) and (3.6.5).

| | **1986** | **1995** | | **1986** | **1995** |
|---|---|---|---|---|---|
| Algeria | 1.01 | 0.95 | Malaysia | 0.39 | 0.36 |
| Argentina | 0.60 | 0.58 | Mexico | 0.82 | 0.71 |
| Australia | 1.00 | 1.11 | Morocco | 0.82 | 0.66 |
| Austria | 1.29 | 1.21 | Netherlands | 1.91 | 1.33 |
| Belgium | 2.62 | 2.04 | New Zealand | 0.46 | 0.80 |
| Bolivia | 1.24 | 0.51 | Norway | 1.26 | 1.19 |
| Brazil | 1.57 | 1.02 | Oman | 0.11 | 0.27 |
| Canada | 1.91 | 2.05 | Pakistan | 0.06 | 0.02 |
| Chile | 2.75 | 2.52 | Panama | 0.04 | 0.07 |
| Colombia | 0.35 | 0.34 | Peru | 0.92 | 1.01 |
| Egypt | 0.20 | 0.35 | Philippines | 0.44 | 0.20 |
| El Salvador | 0.19 | 0.20 | Poland | 0.95 | 0.98 |
| Finland | 2.42 | 2.81 | Portugal | 0.69 | 0.60 |
| Germany | 1.14 | 1.18 | Senegal | 0.92 | 1.16 |
| Greece | 0.55 | 0.48 | Singapore | 1.63 | 0.65 |
| Guatemala | 0.09 | 0.15 | Spain | 1.00 | 0.77 |
| Honduras | 0.03 | 0.03 | Sweden | 1.60 | 1.65 |
| India | 0.13 | 0.37 | Switzerland | 0.82 | 1.01 |
| Indonesia | 0.48 | 0.43 | Thailand | 0.16 | 0.17 |
| Ireland | 0.69 | 1.08 | Tunisia | 0.80 | 0.67 |
| Israel | 0.69 | 0.57 | Turkey | 0.55 | 0.41 |
| Italy | 0.77 | 0.71 | United Kingdom | 0.89 | 0.85 |
| Jamaica | 0.66 | 1.05 | Uruguay | 0.22 | 0.24 |
| Japan | 1.26 | 1.19 | United States | 0.51 | 0.89 |
| Jordan | 0.32 | 0.41 | Venezuela | 2.61 | 0.95 |
| Korea, Rep. | 0.65 | 0.68 | Zimbabwe | 0.89 | 0.56 |
| Madagascar | 0.06 | 0.05 | | | |

Table 3.1: Export-import ratios for selected countries, 1986 and 1995 (Source: World Bank, World Development Indicators (1998))

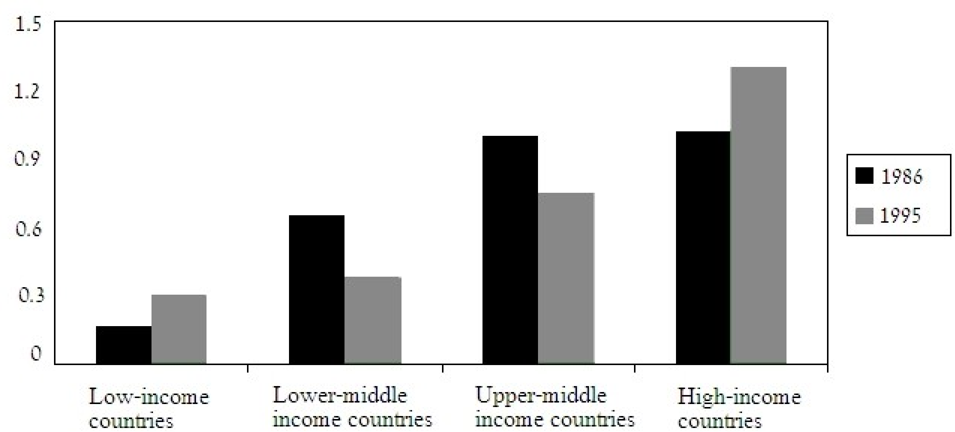


Figure 3.7: Export-import ratios in pollution-intensive goods, 1986 and 1995 (Source: World Trade Organization (1999))

# Chapter 4

# Foreign Direct Investment and Environmental Regulations: A Survey

## 4.1 Introduction

This chapter provides a review of a broad literature dealing with the relationship between foreign direct investment (FDI) and the environment. According to UNCTAD (2008), FDI inflows into developing countries rose by 21% in 2007 to reach a record level of $500 billion. The rise in the scale of FDI flowing to developing countries which originally gained pace in the early 1990s, has initiated a large debate about FDI's relevance to environmental regulations.

The ideas that surround the debate on the link between FDI flows and environmental standards can be classified into three groups. One of them concerns whether or not multinationals would flock to developing countries to take advantage of lax environmental standards. If FDI is sensitive to lower standards, then developing countries are more likely to experience environmental degradation as a consequence. This topic constitutes a large part of the literature and almost all of the research attempts on this issue are empirical. The second group of studies explores the reasons of the lack of consistent evidence on the responsiveness of FDI to environmental standards. This relatively new strand of the literature offers both some empirical and theoretical explanations to the question in hand. The third group investigates the reverse relationship, that is, the possible effects of FDI on environmental regulations, which is a less explored issue in the literature. If feedback from FDI to regulations exists, then any empirical study that fails to take into account this channel will produce spurious results.

This chapter is organized as follows. First, it reviews the empirical studies that analyze the impact of environmental costs on FDI locations. Next, it focuses on the main papers that try to explain the lack of evidence for the pollution haven hypothesis with a special emphasis on Eskeland and Harrison (2003). Then, it reviews the literature on the impact of FDI on local environmental regulations by focusing on two recent political economy models, Cole et al. (2006) and Cole and Fredriksson (2009). Finally, it concludes by summarizing the main findings of the literature and discussing some future research directions.

## 4.2 Impact of Environmental Costs on FDI Locations

In the literature that explores the relationship between FDI and environmental regulations, a large number of studies concentrate on searching for evidence of "pollution havens". In the context of FDI, pollution haven hypothesis emphasizes the possibility that investors will seek other countries to locate their industries where it will be cheaper in light of lower regulatory requirements. A closer look at the literature shows that the most of the authors who focus on the pollution haven hypothesis have taken an empirical approach. This trend can be attributed to the fact that the theory of multinational enterprises is far from explaining FDI flows in a satisfactory manner.

In this section, I outline some of the empirical studies from the pollution haven literature and discuss their results. Dean (1992) is a detailed literature survey on trade and the environment which also focuses on the subject of international relocation of industries to pollution havens. According to this survey, in most of the empirical studies until 1992 there is little evidence for pollution havens. Levinson (1996b) surveys the empirical literature on the sensitivity of investment to environmental regulations, both internationally and within the US. Levinson states that differences in pollution regulation across states do not affect plant location decisions and concludes, "more than twenty years of empirical research has been unable to show convincingly that stringent environmental standards deter investment or that weak regulations attract investment". These findings may also be attributed to the fact that the most significant increases in volume of FDI flows were experienced later in 1990s. In this survey, I focus on studies carried out after 1992 with a specific emphasis on the most recent ones.

One path that the researchers have taken to analyze the pollution haven hypothesis has been to explore the link between industry abatement costs and FDI outflows. If empirical analysis yields that the flight of direct investment from developed to developing countries are significantly concentrated on industries where pollution abatement costs are higher, then this is regarded as an evidence supporting pollution haven hypothesis. Grossman and Krueger (1993) is among the early examples of such studies and focuses on maquiladora activity in Mexico. The authors show that neither pollution abatement costs nor other possible factors adequately help to explain the pattern of maquiladora activity in Mexico. The paper also searches for determinants of the pattern of US FDI abroad and emphasizes the difficulty of developing a satisfactory explanation to this phenomenon.

Repetto (1995) finds that the ratio of outward FDI in 1992 from the US to developing countries and transition economies is 45% of total outward US FDI. However, the ratio of that investment channelled to pollution-intensive sectors (where abatement costs are higher) such as petroleum, gas, chemicals and metals is found to be only 5% in developing countries while the fraction channelled to the same sectors in developed countries is 24%. In other words, developed countries seem to be sending a larger fraction of pollution-intensive industries to other developed countries. Olewiler (1994) supports this trend via an assessment of trade and investment data on the pollution-intensive industries in the US. The study concludes that there was no pattern of investment in less developed country pollution havens. On average, FDI was found to be much higher in developed countries than in developing countries even for the most polluting sectors like the mineral processing sector. Additionally, the study finds no correlation with the stringency of environmental policy.

Among the many other papers that cannot find a significant evidence that investors seek developing countries as pollution havens are Zarsky (1999), Fabry and Zenghi (2000), Wheeler (2000) and Eskeland and Harrison (2003). Zarsky (1999) highlights that no consistent statistical evidence has been found that differences in standards affect foreign investors' location decisions, presumably because, in most industries, environmental control costs are a small component of total costs. Wheeler (2000) argues that the data does not support the pollution haven hypothesis and Fabry and Zenghi (2000) states a similar result analyzing FDI flows to China. A detailed discussion of Eskeland and Harrison (2003) is provided at the end of this section.

Despite this tendency in the literature, there are a number of case studies which have found that in certain pollution-intensive industries, such as leather tanning, more stringent standards in OECD countries propelled companies to shift production to countries with lower standards causing environmental degradation (Mabey and McNally 1999). Keller and Levinson (2002) also support this finding by showing that differences in abatement costs between US states have a moderate deterrent effect on FDI.

According to OECD (1997), although there is some evidence that in industries with higher than average pollution control costs, production may indeed seem to migrate overseas to areas with lower (and therefore cheaper) environmental requirements, not all types of firms are likely to do so. Among the three types of firms engaged in FDI (namely, market-seeking, production-platform-seeking and resource-seeking), resource-seeking FDI firms are most likely to take advantage of lower standards.

Dean et al. (2003) analyzes the strength of pollution haven effect by studying the location choices of equity joint venture (EJV) projects in China and reaches a striking conclusion: Contrary to the pollution haven argument, developed countries are attracted by high standards rather than low. The authors utilize a location choice model to estimate conditional logit and nested multinomial logit models using new data sets on EJV projects, environmental taxes on water pollution and Chinese emissions and abatement costs for 3-digit ISIC industries. The location choice analysis of 2886 EJV projects in manufacturing undertaken between 1993-1996 yields interesting results. Regardless of the origin country, investments are drawn into provinces with already "high concentrations of foreign investment, relatively abundant stocks of skilled workers, concentrations of foreign firms, and special incentives". In contrast to the pollution haven hypothesis, while lax environmental standards constitute a pull-factor for partners from developing countries such as Hong Kong, Macao, Taiwan, investors from industrial countries such as US, UK and Japan are actually attracted by stringent environmental standards. This conclusion is robust to the level of pollution intensity of the industry in question.

List and Co (2000) estimates the effects of environmental regulation on foreign multinationals' new plant location decisions from 1986 to 1993 using a conditional logit model and finds evidence that, heterogeneous environmental policies across countries do matter. Their results are robust to the four different choices of environmental stringency measures.

Xing and Kolstad (2002) report strong evidence on the impact of lax environmental regulations in attracting foreign investment. The authors model FDI flows from US firms to twenty-two destination countries as a function of "environmental laxity" and some other characteristics in six different sectors. "Environmental laxity" is estimated as a function of sulfur dioxide ($SO_2$) emissions, real GDP, an electricity structure index, and the share of industry output in GDP. Using this estimate in the equation for FDI, they estimate the reduced form for six manufacturing industries, namely, chemicals and primary metals, electrical machinery and non-electrical machinery, food products, and transportation equipment. As an evidence supporting the pollution havens effect, the regression results yield a significant positive effect of $SO_2$ emissions for the chemicals and primary metals sectors.

Wagner and Timmins (2004) test the pollution haven hypothesis using panel data on the outward FDI flows of six manufacturing industries in Germany. In doing so, they take into account some important econometric issues that are ignored in previous studies. One of these issues is the externality problem related to FDI agglomeration. Hence, the authors not only include FDI stock in their analysis to account for these positive spillovers but also control for its endogeneity. Finally, a number of controls are included to account for the possible correlation between unobservable characteristics of FDI recipients and their environmental stringency. After all these issues are considered, the authors report that they find strong support for the pollution havens hypothesis in the most pollution-intensive industries.

He (2006) is a recent paper that studies two sides of the FDI-emission relation in China. He develops a simultaneous model that incorporates both the FDI entry decision in a dynamic recursive framework and the linkage from FDI to emission levels. Then, the model is estimated using the panel data on industrial $SO_2$ emissions in China's 29 provinces. The paper finds that as a result of a 1% increase in FDI stock, industrial $SO_2$ emissions will increase by 0.098% or in other words, the impact of FDI on industrial $SO_2$ emissions is very small. Next, it is assumed that the FDI entry decision depends on economic growth and environmental regulation stringency in the previous period. In that recursive environment, the paper highlights that an increase in the stringency of environmental regulations has "modest deterrent effect on FDI capital inflow" providing support for the pollution haven hypothesis.

## 4.3 Attempts to Explain the Weak Evidence of Pollution Haven Effect

Empirical research in the 1990s was unable to show convincingly that weak environmental regulation attracts foreign direct investment and as a consequence, a new strand of literature started to develop in the 2000s, attempting to explain the reasons of this lack of evidence.

Most analyses of investment location decision-making processes point to the many factors involved in these decisions: political stability, size and growth potential of market, access to other markets, labour costs, ease of repatriation of profits, transparency and predictability of administrative and legal framework, cultural affinity, infrastructure, quality of life, etc. The level of environment regulations is usually portrayed as having a very small role in these decisions. (OECD 1997) A World Bank study, Wheeler and Mody (1992), examines data on manufacturing investments by US multinationals in the 1980s. The authors claim that "agglomeration economies" (infrastructure quality, degree of industrialization, and level of existing FDI) constitutes the dominant influence on investor decisions, with labor costs and market size as the next most important factors. Overall, a number of studies embrace the idea that very few companies investing overseas seek to reduce environmental compliance costs as their primary goal. Although establishing a low-cost base of operations may be an important reason for setting up operations abroad, multinational enterprises generally seek consistent environmental enforcement, rather than lax enforcement. (OECD 1997)

One well-known recent study that attempts to explain the weak empirical evidence of pollution havens is Smarzynska and Wei (2001) which lists some potential challenges awaiting the researchers in uncovering the so-called "dirty secret". According to the authors, one potential difficulty might be the correlation of stringency of environmental standards with some characteristics of FDI-receiving countries, such as corruption. These characteristics may prevent FDI from flowing into that country despite the laxity of environmental standards and hence, may hide the effect. They also mention the importance of using firm-level data rather than country or industry-level since aggregated data sets could potentially conceal the firm-level effects. Finally, the researchers should overcome some crucial measurement problems with environmental standards and pollution intensity of the multinational firms for a clear analysis of the issue. With these points in mind, the authors utilize a firm level data set on investment projects in 24 transition economies and include the level of corruption in the FDI-receiving country in their statistical analysis. Consequently, although their study provides some support for the pollution haven hypothesis, a strong evidence is still not observed.

Another approach is to consider the effect of capital intensity when analyzing the impact of environmental regulations on FDI. In the case where there is a complementarity between capital and pollution abatement, the link between the stringency of environmental regulations and investment is blurred. To the best of my knowledge, Eskeland and Harrison (2003) is the first study that provides a theoretical model to formalize this idea. Therefore, I will proceed to presenting this model along with its main results at the end of this section.

The idea in Eskeland and Harrison (2003) forms the basis of an influential recent study that both highlights the role of capital and partially explains why pollution havens are not more widespread: Cole and Elliott (2005). In this paper, factor endowment differentials are emphasized as an ignored reason for the insufficiency of pollution haven evidence. As a first step, the authors show the link between the capital intensity and the pollution intensity of US industries employing data from the US Bureau of the Census that reports the pollution abatement costs and physical capital intensity per worker for the two-digit SIC industries up to 1994. As a result, it is shown that there is a positive correlation between pollution intensity and capital intensity across sectors. Then they state that a profit-maximizing firm producing a pollution-intensive product will consider investing in a country with a relatively high capital-labor ratio and a relatively low level of environmental regulations in order to take advantage of lower production costs. Along these lines, Brazil and Mexico are identified as possible host countries for pollution-intensive foreign investment with their reasonably high capital-labor ratios and with reasonably low levels of environmental regulations. Finally, they study the determinants of US multi-sector FDI to Brazil and Mexico. They find the capital requirements of a sector to be a key determinant of FDI and the level of pollution abatement costs in a US industry to be a statistically significant determinant of FDI in that industry. Overall, the study provides important insights into why pollution haven evidence has previously been so limited.

### 4.3.1 Eskeland and Harrison (2003)

This paper examines the impact of capital intensity and environmental regulations on outbound FDI, both theoretically and empirically. The authors demonstrate that the effect of an increase in environmental regulations on outward FDI may be ambiguous due to a possible complementarity between capital and pollution abatement. Assuming such a complementarity exists, depending on the parameter values, a firm in a given sector may choose to operate at home keeping the old technology and paying the abatements costs or to move to a country keeping the old technology and paying lower abatement costs or to stay at home investing in cleaner technology and thus paying lower abatement costs. Below, I explain the model setup and the main analytical and empirical results, briefly.

**Model Setup**

The authors consider the perfectly competitive market for a homogenous good in which two types of firms operate: A type that produces in home country, $H$, and another type that produces abroad, $A$. Environmental regulation is assumed to take place in one country, namely in $H$. The model is aimed to examine the factors that determine the effect of the environmental regulation in $H$ on investment and output in both countries.

A representative firm located in country $H$ has the following profit, $\pi^H$:

$$\pi^H = px^H - c^H(x^H, k^H, a^H) - rk^H$$

where p is the price of the good, $x^H$ denotes the quantity, $c^H$ is the firm's operating costs, $k^H$ denotes the firm's capital stock, $a^H$ shows the amount of the resources needed for pollution abatement and $r$ is the cost of capital. $c^H$ is assumed to be continuous, twice differentiable and convex. The operating costs have the following properties: Short-term marginal costs are positive (i.e., $\partial c^H/\partial x^H \geq 0$), capital reduces operating costs ($\partial c^H/\partial k^H \leq 0$) while abatement increases operating costs ($\partial c^H/\partial a^H \geq 0$).

**Analytical Results**

The authors derive the first-order conditions from the firm's profit maximization with respect to $k^H$ and $x^H$, differentiate these with respect to the regulatory parameter $a^H$ and report the results for the intermediate run:

$$\frac{dx^H}{da^H} = \frac{\left[\left(\frac{dp}{da^H} - \frac{\partial^2 c^H}{\partial x^H \partial a^H}\right)\frac{\partial^2 c^H}{\partial k^{H^2}} + \frac{\partial^2 c^H}{\partial k^H \partial a^H}\frac{\partial^2 c^H}{\partial x^H \partial k^H}\right]}{\left(\frac{\partial^2 c^H}{\partial x^{H^2}}\frac{\partial^2 c^H}{\partial k^{H^2}} - \frac{\partial^2 c^H}{\partial x^H \partial k^H}\right)}$$

$$\frac{dk^H}{da^H} = -\frac{\left[\left(\frac{dp}{da^H} - \frac{\partial^2 c^H}{\partial x^H \partial a^H}\right)\frac{\partial^2 c^H}{\partial k^H \partial a^H} + \frac{\partial^2 c^H}{\partial k^H \partial a^H}\frac{\partial^2 c^H}{\partial x^{H^2}}\right]}{\left(\frac{\partial^2 c^H}{\partial x^{H^2}}\frac{\partial^2 c^H}{\partial k^{H^2}} - \frac{\partial^2 c^H}{\partial x^H \partial k^H}\right)}$$

Analyzing the sign of each term in the above equations, the authors reach a number of conclusions. First, the pollution haven result (i.e. $dx^H/da^H < 0$) is achieved under the following restrictive set of assumptions that the price does not change ($dp/da^H = 0$), that there is no interaction between capital and abatement ($\partial^2 c^H/(\partial k^H \partial a^H)$=0), and that abatement increases marginal operating costs ($\partial^2 c^H/(\partial x^H \partial a^H) > 0$). Otherwise, the effect of increasing abatement costs on firm's output is ambiguous. In the case where capital-intensive technologies are less polluting and capital reduces marginal costs, it is possible to obtain an increase in output in response to an increase in abatement costs. Similarly, the effect of higher abatement costs on capital investment also depends on the complementarity between capital and abatement and is, therefore, ambiguous.

**Empirical Results**

The authors proceed to analyzing the patterns of FDI in four developing countries: Mexico, Morocco, Côte d'Ivoire and Venezuela. FDI regression equation for a four-digit sector $i$ and time $t$ is specified as follows.

$$\begin{aligned} FDI_{i,t} &= \alpha_1 ABCOST_{i,t} + \alpha_2 IMPENET_{i,t-1} + \alpha_3 HERF_{i,t-1} \\ &+ \alpha_4 (IMPENET \times HERF)_{i,t-1} + \alpha_5 LAB/CAP_{i,t-1} + \alpha_6 REGUL_{i,t} \\ &+ \alpha_7 MARKETSIZE_{i,t-1} + \alpha_8 WAGE_{i,t} + \alpha_9 YEAR_t + f_i + \epsilon_{i,t} \end{aligned}$$

The independent variables included in the equation are: *ABCOST* pollution abatement cost; *IMPENET* import penetration as a proxy for openness; *HERF* the Herfindahl index as a measure of scale and concentration; *IMPENET* × *HERF* the interaction of market concentration and import penetration; *LAB/CAP* the sectoral labor-capital ratio; *REGUL* a measure of regulatory barriers against FDI that changes from 0 (no restrictions) to 2 (foreign investment prohibited); *MARKET-SIZE* a measure of market size, which is defined as the lagged share of domestic sales in the sector $j$ as a percentage of total manufacturing output; and *WAGE* wages in the sector $j$ in the source country. Additionally, *YEAR* denotes time effects and $f$ industry fixed effects.

Regression results show that, across all specifications, there is no significant relationship between pollution abatement costs and the pattern of FDI. On the hand hand, import penetration and Herfindahl index are found to be negatively related to FDI, implying that foreign investors are likely to operate in industries with little competition from imports and less likely to operate in concentrated sectors.

Furthermore, the authors verify that their results are robust to the choice of different measures of pollution emissions, such as total particulates, biological oxygen demand and total toxic releases. In other words, there is no systematic relationship between pollution abatement costs and the pattern of foreign investment. If pollution emissions instead of actual abatement costs are used, the results seem to depend on the type of the pollution. In the case of air pollution emissions, the authors find that there is some evidence that high-emission industries attract FDI in several countries. However, in the cases of water pollution or toxic releases, the pattern is reversed: FDI is less likely in high-emission sectors.

**Summary**

This paper begins with a simplistic theoretical model which shows that the impact of environmental regulation in developed countries on FDI flows to developing countries depends on the complementarities between capital and abatement and is, therefore, ambiguous. In that sense, the paper provides an explanation to the lack of strong evidence of pollution havens by pointing to the other factors affecting the relationship between environmental regulations and foreign investment. Empirical analyses show that FDI in the chosen developing countries is not related to abatement costs in industrialized countries.

## 4.4 Impact of FDI on Local Environmental Standards

Among the arguments against globalization, one is related to the impact of foreign investment on local environmental standards. Also known more generally as "race to the bottom" or "regulatory chill effect", this argument centers around the idea that the presence of multinational companies may lead local environmental standards to be reduced below or freezed at suboptimal levels.

The pressures to lower environmental standards may be quite strong, and may come from either the investor or the investee, depending on market conditions. In China, for example, provinces compete intensely for foreign capital, and provincial leaders may be tempted to promise preferential treatment to potential foreign investors (Esty and Mendelsohn, 1995). This preferential treatment may include a tacit (or express) commitment to more lax enforcement of environmental standards (Esty and Gentry, 1997). In resource-seeking industries, where products are relatively undifferentiated and small cost differences can translate into large market share gains and losses (i.e. where demand is relatively elastic), foreign investors can sometimes exert considerable pressure on recipient countries. However, competitive pressures can also operate in the opposite direction. In some markets, overseas investors push for higher environmental standards. Foreign investors in Costa Rican banana production have been observed to insist upon environmental care, perceiving that their European customers want an environmentally-sound product (Gentry et al., 1996). A number of Asian lumber products are similarly geared to the European market, where consumer sensitivity often demands a product that meets certain minimum environmental conditions.

Although a large body of literature that analyzes the pollution haven hypothesis exists, studies that examine the responsiveness of environmental standards to FDI are not many. Prior to the development of this branch of the literature, several papers analyzed the effect of different aspects of globalization on environmental regulations. One of them is Damania et al. (2003) where the authors examine the impact of free trade on environmental standards. They find that greater trade openness leads to stricter (weaker) environmental policies where government corruptibility is relatively high (low). Fredriksson et al. (2003) is another empirical study of the effect of environmental regulations on FDI flowing into the US considering possible endogeneity of environmental policy. The authors show that stricter state environmental policies negatively affect the inflow of FDI in several industry sectors.

Within this relatively sparse strand of literature, I believe that Cole et al. (2006) and Cole and Fredriksson (2009) require special attention in that both papers present theoretical models aimed at explaining the channels through which FDI may affect local environmental standards. Below, I briefly present these models and discuss their results.

### 4.4.1 Cole et al. (2006)

The authors develop a political economy model with imperfect competition that emphasizes the role of lobbying and corruption in affecting the environmental policy. The model yields that FDI's impact on local environmental regulations depends on the bureaucratic corruption level prevailing in the host country. Furthermore, the empirical tests for 33 countries are shown to support their arguments. The study contributes to the existing literature both by emphasizing the importance of possible endogeneity of environmental regulations which were treated as exogenous in most of the preceding empirical studies and by suggesting a new mechanism through which FDI could affect environmental policy formation.

**Model Setup**

In a small economy with no trade, identical domestic and foreign firms supply a homogenous good in an imperfectly competitive market. Along the line of Grossman and Helpman (1996), there is a continuum of $N^D$ domestic and $N^F$ foreign firms, with $N^D + N^F = N$, operating in the market. Firms compete in quantities and output of a firm $i$ is given by $q_i$. Production causes local pollution whose amount is denoted by $s$. Government imposes a pollution tax $t \in T \subset R_+$ per unit of pollution and distributes the tax revenue equally across consumers. Then the gross profit of firm $i$ can be written as follows.

$$\pi_i = p(Q)q_i - e(q_i, w_i) - s_i t - F$$

where $p(Q)$ is the inverse demand function, $Q = \sum_i q_i = Nq_i$ is the aggregate quantity produced, $e_i(q_i, w_i)$ is the cost function, $s_i t$ is the pollution tax expenditures and $F_i$ is the fixed cost.

It is assumed that $e_i(q_i, w_i) = cq_i + gw_i$ holds where $w_i$ is abatement expenses, $g$ is the marginal abatement cost and $c > 0$ is a constant. Finally, the pollution damage function is given by $s_i = \nu q_i + \beta w_i^{-\gamma}$, which is increasing and linear in output ($q$) and decreasing and concave in abatement expenses ($w$) with $s_i \geq 0$ and $\nu$, $\beta$, $\gamma$ as positive parameters.

The number of consumers in the economy is normalized to 1. The utility of the representative consumer equals $U = u(Q) - s$, where $Q$ is consumption of the polluting good with price $p = a - Q$, where $a > 0$ denotes the market size. $u(Q)$ is a concave and twice differentiable function.

The expression for the consumers' aggregate welfare is given by:

$$W^{CO}(t) = \int_0^Q p(x)dx - P(Q)Q + N(t-1)s(q, w).$$

Hence, the aggregate welfare is calculated as the sum of the total consumer surplus and pollution tax revenues net of the pollution damage.

The timing is as follows in the three-stage game. In stage one, all domestic and foreign firms operating in the economy join the lobby and the lobby offers a bribe $C(t)$ to the government that is contingent on the government's choice of pollution taxes, $t$. In the second stage, the government chooses the tax level, $t$, and collects the corresponding bribes from the lobbies. In the final stage, the firms set output and abatement expenditure levels.

The lobby's objective is to maximize the sum of the profits and the objective function is given by $V(t) = (N^D + N^F)\pi$. The government maximizes a weighted sum of bribes and aggregate social welfare, given by $G(t) = C(t) + \alpha W^A(t)$, where $\alpha > 0$ is a measure of the degree of government corruptibility and $W^A(t) = W^{CO}(t) + N^D\pi$.

**Analytical Results**

Applying the implicit function theorem to the first order conditions from the profit function yields $dq_i/dt < 0$ and $dw_i/dt > 0$. In the Nash equilibrium, firm $i$'s output and abatement levels, given the pollution tax, are $q_i = (a - c - \nu t)/(1 + N)$ and $w_i = (\beta\gamma t/g)^{1/1+\gamma}$.

The authors follow Bernheim and Whinston (1986), Grossman and Helpman (1994) and Fredriksson (1997) and state that the subgame-perfect Nash equilibrium pollution tax, $t^*$, could be shown to satisfy the following condition:

$$\partial V(t^*)/\partial t + \alpha(\partial W^A(t^*)/\partial t) = 0.$$

This condition produces the main result of the paper: In the political equilibrium, the pollution tax increases (decreases) with the number of foreign firms if the level of corruptibility of local policymakers is sufficiently low (high). In such an environment, there are two opposing forces on the local environmental regulation levels. One is the downward pressure on pollution tax levels with the rise in the number of foreign firms, due to an increasing political pressure by these firms. The other is the upward pressure on the environmental stringency due to an improvement in the product market competition. In this case, government does not have to keep pollution taxes low in order to increase aggregate welfare since welfare levels are higher due to increased competition. Overall, depending on the corruptibility of the local government, the aggregate impact on the local environmental standards will differ.

**Empirical Results**

The authors analyze the relationship between environmental policy, FDI and corruptibility to find out whether their theory is supported by the data for 20 developing and 13 OECD countries. They estimate the coefficients of the following equation using both fixed and random effects specifications:

$$REGS_{it} = \alpha_i + \gamma_t + \beta' X + \epsilon_{it}.$$

Dependent variable is the environmental regulation stringency in country $i$ in year $t$, denoted by *REGS*; $\alpha_i$ and $\gamma_t$ are the country and time fixed effects, respectively and $X$ is the vector of independent variables.

$X$ includes a number of explanatory variables: A continuous measure of inward *FDI*; a measure of the degree of corruptibility, *CORRUPT*; an interaction term, *FDI* $\times$ *CORRUPT*; per capita income, *GDP*; urban population share, *URBANPOPsh*; share of manufacturing, *MANUFsh* and three quadratic terms, $(GDP)^2$, $(URBANPOPsh)^2$, $(MANUFsh)^2$. While *GDP* controls for the increasing demand for environmental quality in higher income countries, *URBANPOPsh* controls for the greater exposure to pollution and higher demand for environmental stringency in urbanized countries. Finally, *MANUFsh* is aimed to capture the pressure from the workers for lower regulations. All independent variables are lagged by one year to capture the possible time lag in affecting environmental regulations.

The results of the regressions show that *FDI* has a positive impact on *REGS* in all four models chosen, with statistical significance at 1% level in three of them. As the theory suggests, the effect of FDI on environmental regulations is conditional on the corruptibility since the coefficient of *FDI* $\times$ *CORRUPT* is negative in all models and significant in three of them. In other words, the model's predictions are shown to be consistent with the empirical analysis.

**Summary**

Cole et al. (2006) is one of the few examples in the literature that examine the link between FDI and environmental standards using a political economy model of environmental policymaking. In a market with imperfect competition, domestic and foreign firms compete through quantities and lobby for lower pollution taxes offering bribes to the domestic government. The model implies that the effect of environmental policy on foreign direct investment is conditional on the degree of government corruptibility in the host country. Foreign direct investment is found to lead to a less (more) stringent environmental policy when the level of government corruptibility is high (low). Empirical findings are also shown to support the results from the model.

This study also has important implications for the pollution haven analysis since most of the literature in this area has ignored the fact that environmental regulations are determined endogenously. Therefore, the application of the ideas presented in this paper, including the environmental policy effects of foreign direct investment, could potentially alter the results from the empirical studies on pollution havens.

### 4.4.2 Cole and Fredriksson (2009)

This paper examines whether environmental regulations are sensitive to FDI considering the role of political institutions in shaping environmental policy. The authors study a multi-agent multi-principal political economy model which suggests that the impact of FDI on environmental policy depends on the structure of FDI-receiving countries' political institutions such as the number of legislative units (LUs). The model yields that if the number of LUs are many (few), FDI raises (reduces) the stringency of environmental policy. A cross-country empirical analysis produces results that support predictions of the model. While Cole et al. (2006) only considers the interaction between FDI and corruption, this study links FDI to the structure of domestic political institutions.

**Model Setup**

The model is an extension of Cole et al. (2006) which is explained earlier in this section. The difference is that the government consists of $n \geq 1$ independent and identical legislative units (LUs) indexed by $k$. Each LU is assumed to be a branch of government that independently sets its optimal pollution tax. With all these properties, this single-agent multi-agent model is technically a special case of Prat and Rustichini (2003).

The timing in the three-stage game is similar to the one in Cole et al. (2006). In the first stage, all domestic and foreign firms operating in the local economy join the firm lobby and offer a political contribution $C^k(t^k)$ to each LU indexed by $k$. In the next stage, each LU chooses its optimal pollution tax, $t^{k^*}$, and collects the corresponding bribes. Finally, in the third stage, the firms choose output and abatement expenditure levels. The authors follow Prat and Rustichini (2003) and state that the prospective bribe $C^k(t^k)$ is contingent only on $t^k$. Focusing on a symmetric equilibrium, equilibrium pollution tax levels will satisfy: $t^{k^*} = t^*$.

Each LU indexed by $k$ maximizes $L^k(t^k) = C^k(t^k) + \alpha W^k(t^k)$ where the first term denotes the amount of the bribe and the second term, aggregate social welfare, is given by $W^k(t^k) = W^{CO}(t^k) + N^D\pi(t^k)$. The authors interpret the exogenous weight on the aggregate social welfare, $\alpha > 0$, "as a measure of LU honesty, i.e. the inverse of corruptibility".

**Analytical Results**

The authors concentrate on a pure strategy subgame perfect equilibrium of the three-stage game. Following Prat and Rustichini (2003), they characterize this equilibrium and reach some important results.

The first result is that "in the political equilibrium, the pollution tax increases (decreases) with the number of foreign firms if the number of legislative units or aggregate honesty is sufficiently high (low), ceteris paribus". The two opposing effects of FDI inflows on environmental policy that are present in Cole et al. (2006) are also valid in this context. When there are sufficiently many LUs or aggregate honesty is high, the lobbying becomes more costly for the firms and the government's incentive to raise the taxes dominates the pressures from the firms to decrease it, leading to an improvement in the environmental regulation levels.

The other result is that "in the political equilibrium, the pollution tax increases with the number of LUs or with aggregate honesty". With a higher number of LUs, the cost of lobbying relative to its benefit is also higher. This results in a decline in the political contribution offered to LUs leading to a rise in the stringency of environmental regulations.

It is important to note that these two results suggest that in economies with few LUs and with low aggregate honesty, FDI inflows are more likely to lead to pollution havens due to lower regulations in these economies.

**Empirical Results**

The authors empirically test the relationship between environmental regulations, inward FDI, LUs and aggregate honesty. They estimate the coefficients of the regression of environmental regulations on country-specific and time-specific fixed effects, two alternative measures of inward FDI, the number of legislative units, aggregate honesty along with the terms that show interactions of FDI with the number of LUs and aggregate honesty and finally, a number of control variables. The data set includes 13 OECD and 20 developing countries for 1982-1992.

For the number of legislative units, the two measures used are *CHECKS*, "the number of checks and balances within government" and *POLCON*, "the number of political constraints within the legislature". The two aggregate honesty measures are formed by the multiplication of a measure of government honesty by *CHECKS* and *POLCON*. The dependent variable, environmental policy, is measured such that an increase in its value implies a rise in the stringency of environmental regulations. The estimation results are shown to provide support for the predictions of the theoretical model. The coefficient of *FDI* is found to be negative and statistically significant implying a negative impact on the environmental policy. Moreover, the interaction of *FDI* with *CHECKS* and *POLCON* is positive and statistically significant. In other words, the impact of FDI on the stringency of environmental policy is shown to depend on the number of LUs, as the theory suggests.

**Summary**

In this paper, the authors develop a theoretical model which shows that FDI has an impact on the stringency of host country environmental regulations and test the predictions of this model empirically. However, the effect is conditional on the political institutions in the host country. More clearly, the number of legislative units in the country affects the success of lobbying efforts by the firms and therefore has an important impact on the environmental policy effects of FDI. A concept of 'aggregate honesty' is also defined as a measure that takes into account both the number of legislative units and their corruptibility and its effects are also analyzed. The results show that, both theoretically and empirically, pollution havens are more likely to occur in countries with political institutions composed of few legislative units or low aggregate honesty.

### 4.4.3 FDI and Economic Growth

One of the key issues involved in assessing the environmental effects of FDI has to do with scale effects that FDI creates through economic growth. Although the impact of economic growth is usually assumed to be negative for the environment, the magnitude of this impact has been heavily discussed in the literature. Several studies, including Selden and Song (1994), have suggested that the negative scale effects could be limited by the existence of an inverted-U relationship between pollution and per capita income level in a country. This relationship is currently known as the "environmental Kuznets curve" (EKC). EKC hypothesizes that FDI-induced economic growth might initially lead to aggravated environmental problems, but after a certain point, due to higher levels of income, there would be higher demand for environmental quality which leads to an increase in the stringency of environmental regulations and as a result, pollution would first level off and then eventually decline. Research at the World Bank (Dasgupta et al. (1995)) has indeed found that the amount of environmental regulation increases steadily with the growth in per capita incomes. Other authors (e.g. Lucas et al. (1992), Shafik and Banyopadhyay (1992), Grossman and Krueger (1995), Selden and Song (1994)) have also generally found that many indicators of environmental quality tend to deteriorate with growth up to a certain level of income, but then level off and begin to improve after a certain point.

The EKC hypothesis has been criticized in many different dimensions. One view points out that the "turning point" in many countries may be at quite high levels of income, suggesting that the environmental degradation would have to continue for some time, perhaps to levels that imply significant environmental irreversibilities (Opschoor, 1995). Others suggests that the inverted-U relationship may not hold for all pollutants in all countries at all times, nor at the global level. Moreover, its influence may be limited (both in space and in time) by simultaneous changes in structural conditions (Saint-Paul, 1994). The result may be that environmental problems worsen more slowly over time, but never actually decline in absolute terms, even as per capita income levels rise (Esty and Gentry, 1997).

According to Mabey and McNally (1999), the EKC is, in fact, an oversimplification of the complex relationships between economic growth, democratization and political and public attitudes to the environment. Irreversibility of environmental damage also means that even where market and policy failures are corrected, and natural resources allocated efficiently, sustainability is not necessarily ensured sustainability being defined as preserving the ability to maintain the well-being of future generations given a legacy of past and current environmental degradation. The theoretical literature clearly shows that economic efficiency is not a sufficient condition for sustainability.

Despite the obvious contributions of the EKC literature, skepticism about the existence of a clear relationship between pollution and per capita income still remains. Such concerns are pronounced in many papers, especially in a recent and comprehensive literature review study by Copeland and Taylor (2004). In much of the work in the EKC literature, theory is seen to have a limited role and the factors that could potentially affect pollution are reduced to solely per capita income levels (Copeland and Taylor, 2004). Moreover, there is evidence that shows that the EKC is not robust to the changes in country data sets and time periods. All of this suggests that in order to be able to proceed in this branch of the literature, there is an obvious need for guidance from economic theory.

## 4.5 Concluding Remarks

This survey has reviewed the literature on the possible channels that link FDI and environmental regulations and covered the most recent papers on the topic. The main findings from this vast literature can be summarized as follows.

The empirical studies show that it is very hard to find widespread support for the pollution haven hypothesis that is triggered by FDI flows from developed to developing countries. For many industries and many firm types environmental control costs (ECC) are not found to be a major determinant of FDI. For especially in most polluting industries and natural-resource-seeking firms, anecdotal evidence of industrial relocation from developed to developing countries is available. In that sense, pollution haven effect is present, however, pollution haven hypothesis is not supported empirically. At this point, it is important to note that any empirical investigation of this issue is not without challenges: there is neither a clear measure of ECC nor a consensus over the definition of ECC; there are various problems with the availability and quality of ECC data for the developing countries and the other possible factors that shape FDI are not entirely identified.

The papers that explore the impact of FDI on local environmental regulations are relatively new and the literature on this issue is rather sparse. Evidence on whether host countries modify their environmental regulation systems to attract FDI is not consistent and also limited by the lack of information from host countries. However, the endogenous formation of environmental standards as a response to FDI inflows is capable of altering the results obtained under exogeneity assumption. Political process through which the local standards are set is affected by both country-specific characteristics like corruptibility and lobbying efforts of foreign and domestic enterprises. When this aspect of environmental policymaking is considered, empirical evidence supports the existence of the effect of FDI on environmental policy, however this effect is not unconditional.

Future research efforts should include the formation of reliable data sets on environmental costs especially for large FDI-receiving countries and should proceed hand in hand with the theoretical studies on the determinants of FDI. Most of the empirical work in this literature has little connection with theory and policy debates are inconclusive since results from policy discussions are heavily dependent on the relative importance of theoretical magnitudes. International capital movements are determined as an outcome of many simultaneous factors. Therefore, theoretical models that are able to identify these channels are heavily needed to isolate the relative impact of environmental regulations on FDI.

# Bibliography

[1] Alvarez, F. and R. E. Lucas, Jr. "General Equilibrium Analysis of the Eaton-Kortum Model of International Trade." *Journal of Monetary Economics*, 2007, 54, pp. 1726-1768.

[2] Antweiler, W., B. R. Copeland and M.S. Taylor. "Is Free Trade Good for the Environment?" *American Economic Review*, 2001, 91(4), pp. 877-908.

[3] Baumol, W. J. and W. E. Oates. "The Theory of Environmental Policy." Cambridge University Press, Cambridge, UK, 1988.

[4] Birdsall, N. and D. Wheeler. "Trade Policy and Industrial Pollution in Latin America: Where Are the Pollution Havens?", *Journal of Environment and Development*, 1993, 2(1), pp. 137-149.

[5] Caselli, F. "Accounting for Cross-Country Income Differences" in Handbook of Economic Growth, ed. by P. Aghion, and S. Durlauf, 2005.

[6] Chichilnisky, G. "North-South Trade and the Global Environment." *American Economic Review*, September 1994, pp. 851-74.

[7] Cole, M. A. and R. J. R. Elliott. "FDI and the Capital Intensity of Dirty Sectors: A Missing Piece of the Pollution Haven Puzzle." *Review of Development Economics*, 2005, 9(4), pp. 530-548.

[8] Cole, M. A., R. J. R. Elliott and P. G. Fredriksson. "Endogenous Pollution Havens: Does FDI Influence Environmental Regulations?" *Scandinavian Journal of Economics*, 2006, 108 (1), pp. 157-178.

[9] Cole, M. A. and P. G. Fredriksson. "Institutionalized Pollution Havens." *Ecological Economics*, 2009, 68, pp. 1239-1256.

[10] Copeland, B. R. and M. S. Taylor. "North-South Trade and the Environment." *Quarterly Journal of Economics*, 1994, 109(3), pp. 755-787.

[11] Copeland, B. R. and M. S. Taylor. "Trade and Transboundary Pollution." *The American Economic Review*, September 1995, 85(4), pp. 716-737.

[12] Copeland, B. R. and M. S. Taylor. "Trade and the Environment: Theory and Evidence." Princeton University Press, New Jersey, USA, 2003.

[13] Copeland, B. R. and M. S. Taylor. "Trade, Growth, and the Environment." *Journal of Economic Literature*, March 2004, XLII, pp. 7-71.

[14] Damania, R., P. G. Fredriksson, J.A. List. "Trade Liberalization, Corruption, and Environmental Policy Formation: Theory and Evidence." *Journal of Environmental Economics and Management*, 2003, 46, pp. 490-512.

[15] Dasgupta, S., A. Mody, S. Roy and D. Wheeler. "Environmental Regulation and Development: A Cross-Country Empirical Analysis." *World Bank Policy Research Working Paper*, 1995, No. 1448.

[16] Dean, J. "Trade and Environment: A Survey of the Literature." *World Bank Policy Research Working Paper World Development Report*, 1992, No. 966.

[17] Dean, J. M., M. E. Lovely and H. Wang. "Foreign Direct Investment and Pollution Havens: Evaluating the Evidence from China." *U.S. International Trade Commission Working Paper*, 2003, No. 2004-01-B.

[18] Dornbusch, R., S. Fischer, and P. A. Samuelson. "Heckscher-Ohlin Trade Theory with a Continuum of Goods." *Quarterly Journal of Economics*, September 1980, 95(2), pp. 203-224.

[19] Eaton, J. and S. Kortum. "Technology, Geography and Trade." *Econometrica*, 2002, 70(5), pp. 1741-1779.

[20] Eskeland, G. S. and A. E. Harrison. "Moving to Greener Pastures? Multinationals and the Pollution Haven Hypothesis." *Journal of Development Economics*, 2003, 70, pp. 1-23.

[21] Esty, D. C. and R. Mendelsohn. "Powering China: The Environmental Implications of Chinas Economic Growth." New Haven: Yale Center for Environmental Law and Policy, 1995.

[22] Esty, D. C. and B. S. Gentry. "Foreign Investment, Globalisation and Environment" in *Globalisation and Environment: Preliminary Perspectives*, OECD, Paris, France, 1997.

[23] Fabry, N. and S. Zenghi. "FDI and the Environment: Is China a Polluter Haven?" *Universite de Marne-la-Vallee Working Paper*, 2000, No. 2002-02.

[24] Feenstra, R. C., R. E. Lipsey, H. Deng, A. C. Ma and H. Mo. "World Trade Flows: 1962-2000." *NBER Working Paper*, January 2005, No. 11040.

[25] Fredriksson, P. G., J. A. List, and D. L. Millimet. "Bureaucratic Corruption, Environmental Policy an Inbound US FDI: Theory and Evidence." *Journal of Public Economics*, 2003, 87, pp. 14071430.

[26] Gentry, B. S. et al. (eds.) "Private Capital Flows and the Environment: Lessons from Latin America." Yale Center for Environmental Law and Policy (draft), 1996.

[27] Grossman, G. M. and A. B. Krueger. "Environmental Impacts of a North American Free Trade Agreement." *NBER Working Paper*, November 1991, No. 3914.

[28] Grossman, G. M. and A. B. Krueger. "Environmental Impacts of a North American Free Trade Agreement" in P.M. Garber (ed.). *The Mexico-US Free Trade Agreement*, The MIT Press, Cambridge, Massachusetts, USA, 1993.

[29] Grossman, G. M. and A. B. Krueger. "Economic Growth and the Environment", *Quarterly Journal of Economics*, 1995, 110, pp. 353-77.

[30] He, J. "Pollution Haven Hypothesis and Environmental Impacts of Foreign Direct Investment: The Case of Industrial Emission of Sulfur Dioxide (SO2) in Chinese Provinces." *Ecological Economics*, 2006, 60, pp. 228-245.

[31] Heston, A., R. Summers and B. Aten. "Penn World Table Version 6.2." Center for International Comparisons of Production, Income and Prices at the University of Pennsylvania, September 2006.

[32] Hettige, H., P. Martin, M. Singh, D. Wheeler. "IPPS Pollution Intensity and Abatement Cost Datasets." World Bank, 1987.

[33] Jaffe, A. B., S. R. Peterson, P. R. Portney and R. N. Stavins. "Environmental Regulation and the Competitiveness of US Manufacturing: What Does the Evidence Tell Us?" *Journal of Economic Literature*, 1995, 33(1), pp. 132-163.

[34] Janicke, M., M. Binder and H. Monch. ""Dirty Industries": Patterns of Change in Industrial Countries." *Environmental and Resource Economics*, 1997, 9, pp. 467-91.

[35] Keller W. and A. Levinson. "Pollution Abatement Costs and Foreign Direct Investment Inflows to U.S. States." *Review of Economics and Statistics*, 2002, 84(4), pp. 691-703.

[36] Levinson, A. "Environmental Regulations and Industry Locations: International and Domestic Evidence" in J. Bhagwati and R. Hudec (eds.) *Fair Trade and Harmonization*, The MIT Press, Cambridge, Massachusetts, USA, and London, UK, 1996a.

[37] Levinson, A. "Environmental Regulations and Manufacturers Location Choices: Evidence from the Census of Manufacturing." *Journal of Public Economics*, 1996b, 61, pp. 529.

[38] List, J. A. and C. Y. Co. "The Effects of Environmental Regulations on Foreign Direct Investment." *Journal of Environmental Economics and Management*, 2000, 40, pp. 120.

[39] Low, P. and A. Yeats. "Do 'Dirty' Industries Migrate?" in Low, P. (ed.). *International Trade and the Environment*, 1992, World Bank Discussion Paper No. 159, Washington, DC.

[40] Lucas, R. et al. "Economic Development, Environmental Regulation and International Migration of Toxic Pollution" in Low, P. (ed.). *International Trade and the Environment*, 1992, World Bank Discussion Paper No. 159, Washington, DC.

[41] Mabey, N. and R. McNally. "Foreign Direct Investment and the Environment, From Pollution Havens to Sustainable Development." *WWF-UK Report*, August, 1999.

[42] Mani M. and D. Wheeler. "In Search of Pollution Havens? Dirty Industries in the World Economy, 1960-1995." *Journal of Environment and Development*, 1998, 7(3), pp. 215-247.

[43] OECD. *Foreign Direct Investment and the Environment: An Overview of the Literature*. Paris, France, 1997.

[44] OECD. *STAN (Structural Analysis) Database*, 2008.

[45] OECD. *Environmental Data Compendium*, 2004.

[46] Olewiler, N. "The Impact of Environmental Regulation on Investment." in Benidickson et al., 1994.

[47] Opschoor, J. B. "Ecospace and the Fall and Rise of Throughput Intensity." *Ecological Economics*, 1995, 15, pp. 137-140.

[48] Prat, A. and A. Rustichini. "Games Played Through Agents." *Econometrica*, 2003, 71, pp.9891026.

[49] Repetto, R. "Jobs, Competitiveness, and Environmental Regulation: What Are the Real Issues?" *WRI Research Report*, 1995, Washington, DC.

[50] Saint Paul, G. "Trade Patterns and Pollution." *Fondazione Eni Enrico Mattei Working Paper*, 1994, No. 40.94, Milan.

[51] Selden, T. M. and D. Song. "Environmental Quality and Development: Is There a Kuznets Curve for Air Pollution Emissions?" *Journal of Environmental Economics and Management*, 1994, 27, pp. 147-162.

[52] Shafik, N. and S. Bandyopadhyay. "Economic Growth and Environmental Quality: Time Series and Cross Section Evidence." 1992, World Development Report Background Paper. Washington, D.C., World Bank.

[53] Smarzynska, B. K. and S. J. Wei. "Pollution Havens and Foreign Direct Investment: Dirty Secret or Popular Myth?" *NBER Working Paper*, 2001, No. 8465.

[54] Tobey, J. "The Effects of Domestic Environmental Policies on Patterns of World Trade: An Empirical Test." *Kyklos*, 1990, 43(2), pp. 191-209.

[55] UNCTAD. *World Investment Report*, 2008.

[56] Wagner, U. J. and C. Timmins. "Agglomeration Effects in Foreign Direct Investment and the Pollution Haven Hypothesis." *Yale University Working Paper*, 2004.

[57] Waugh, M. E. "International Trade and Income Differences." Manuscript, University of Iowa, 2007.

[58] Wheeler, D. and A. Mody. "International Investment Location Decisions: The Case of US Firms." *Journal of International Economics*, 1992, 33, pp. 57-76.

[59] Wheeler, D. "Racing to the Bottom? Foreign Investment and Air Quality in Developing Countries." Unpublished working paper, 2000, The World Bank, November.

[60] World Bank. *World Development Indicators*. Washington D.C., U.S.A., 1998.

[61] World Trade Organization. *Special Studies 4, Trade and Environment.* Geneva, Switzerland, 1999.

[62] Xing, Y. and C. D. Kolstad. "Do Lax Environmental Regulations Attract Foreign Direct Investment?" *Environmental and Resource Economics*, 2002, 21, pp. 122.

[63] Zarsky, L. "Havens, Halos and Spaghetti: Untangling the Evidence about Foreign Direct Investment and the Environment" in *Foreign Direct Investment and the Environment*, 1999, OECD, pp. 47-74.