ABSTRACT

YANG, TSUNG-YU. Trade and Environment - Essays on the Pollution Haven Hypothesis. (Under the direction of Ivan Kandilov).

The empirical support for the pollution haven hypothesis is limited and it is primarily based on anecdotes and case studies. In the first chapter of my dissertation, I use a cross-country analysis and a two-way error components regression model to analyze trade flows and industry composition changes of the most polluting industries in the manufacturing sectors in order to provide more robust evidence for the pollution haven hypothesis. Based on the theoretical foundation of the Heckscher-Ohlin model, I consider environmental regulatory stringency as one of the determinants which contribute to comparative advantage. The empirical results suggest that environmental regulatory stringency would decrease a country's net exports and production share of the most polluting industries. This lends support to the pollution haven hypothesis. In the second and third chapters of my dissertation, I examine whether this hypothesis holds for outward foreign direct investment using firm-level data from Taiwan. The empirical results suggest that Taiwanese manufacturing firms, on average, tend to invest in countries with less stringent environmental regulations, but the estimates also indicate that less polluting firms are more likely to seek pollution havens than are more polluting firms. The results are mixed. On the one hand, firms that spend more on environmental protection at home, invest more in countries with less stringent environmental regulations. On the other hand, I also find that less polluting firms have a higher propensity to invest in countries with less stringent environmental regulations.

Trade and Environment - Essays on Pollution Haven Hypothesis

by
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A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Economics

Raleigh, North Carolina

2015

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DEDICATION

To my parents, Mr. Chia-Ching Yang and Mrs. Hsing-Hau Lin, my wife, Chien-Ju Liao, and my lovely sons, Aaron and Edric.

BIOGRAPHY

Tsung Yu Yang was born in Taiwan. He received a bachelor degree in accounting at Chang Jung Christian University and a master degree in economics at Chinese Culture University. He came to the United States and received a master degree in finance at Clark University. He started his Ph.D. program in economics in 2008 at North Carolina State University.

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Introduction

The "Pollution Haven Hypothesis" (PHH) is a hotly debated principle in international economics. The debate started in the early 1990s when the North American Free Trade Agreement (NAFTA) placed firms located in rich and tightly regulated economies (the U.S. and Canada) and firms located in a poor and laxly regulated one (Mexico) in direct competition for the North American market. The hypothesis predicts liberalized trade in goods will lead to the relocation of pollution intensive production from the high income country with more strict environmental regulations to the low income country where environmental regulations are more lax. It was used to support the prediction of environmental disasters in countries with lax environmental regulations (because they would specialize in pollution intensive goods) and job disasters in partner countries (because jobs in pollution intensive industries would be destroyed by imports from countries with lax environmental regulations). It can be used to argue for trade interventions such as green countervailing duties on imported goods, or export bans on tropical timber (Taylor, 2004). Therefore, it has been the motivation for researchers in both international and environmental economics to provide empirical evidence in support of or against the pollution haven hypothesis.

The early theoretical literature models the idea of pollution haven as differences in the comparative advantage of countries in the production of pollution intensive goods (e.g. Copeland and Taylor, 1994; Antweiler et al., 2001). In those models, a country's comparative advantage in pollution intensive industries is weakened by stringent environmental regulations, thereby reducing its net exports in such sectors. Models have also been developed to show that similar results hold for capital flows (e.g. McGuire, 1982; Eskeland and Harrison, 2003). Stringent environmental regulations imposed at home would drive out investment and outward investment may be attracted to countries with lax environmental regulations.

Taylor (2004) points out that the empirical work on the PHH has sometimes confused two quite different concepts – PHH and the pollution haven effect (PHE). The PHE states that the cost of meeting regulations has significant influence on investment decision as well as exports and imports of dirty goods. However, it does not necessarily lead to pollution haven, where a given country specializes in the production of heavy polluting industries due to less stringent environmental regulations. That implies that PHE is a necessary, but not a sufficient condition for PHH (Taylor, 2004). Previous studies typically do not find support for the pollution haven hypothesis (Mulatu et al., 2004; Ederington et al., 2004, 2005). Analyzing cross-country trade flows in the first chapter of my dissertation, I reach some more general conclusions on the issue of production relocation for pollution intensive industries. In Chapter 2 and Chapter 3, I use firm-level data from the Taiwanese manufacturing sector to continue to examine whether PHH holds employing different empirical tests.

In Chapter 1, *Pollution Haven Hypothesis: Evidence from Trade Flows in the Manufacturing Sector*, I estimate a two-way error components regression model to analyze trade flows and changes in output composition in the most polluting manufacturing industries across many countries. The empirical results suggest that environmental regulatory stringency decreases net export and production share of the most polluting industries, which provides evidence for the pollution haven hypothesis. However, when I examine the interaction between environmental regulatory stringency and trade openness, I find that high income countries with high regulatory stringency do not lose their comparative advantage in pollution-intensive sectors as trade openness grows.

With respect to FDI, most of the empirical work so far has focused on flows from developed countries to poorer, non-develop nations. Few studies pay attention to the pollution haven seeking behavior of firms form non-developed countries. My work, in Chapter 2, using Taiwanese manufacturing firm-level data attempts to fills this void in the literature. In that Chapter, a least squares dummy variable (LSDV) model is employed to analyze firm's outward FDI. In the regression model, FDI is determined by the firm's characteristic and the host country's traits and policies, including the firm's environmental protection expenditure in Taiwan and the host country's environmental stringency. The empirical results suggest that firms in less pollution-intensive industries are more likely to be pollution haven seekers. In addition, firms with higher domestic expenditure on environmental protection tend to invest more in countries with stricter environmental regulations.

Finally, in Chapter 3, I use a location choice model (conditional logit regression) developed by McFadden (1974) to examine whether environmental regulatory stringency influences the location choice of FDI. The results are consistent with the conclusions suggested by the LSDV model in Chapter 2. I find that firms in polluting industries are relatively less attracted to the countries with weak environmental regulatory stringency.

This dissertation furthers our understanding of the pollution haven hypothesis by providing empirical evidence using country-level trade flows and industry output as well as firm-level outward FDI flows from the Taiwanese manufacturing sector. While some of the findings supports the pollution haven hypothesis, others conflict with its predictions.

Chapter 1

The Pollution Haven Hypothesis: Evidence from Trade Flows in the Manufacturing Sector

Previous empirical studies of the pollution haven hypothesis (PHH) have not reached a consistent conclusion which justifies why this topic merits further investigation. The existing literature is primarily based on anecdotes and scattered case studies. I analyze trade flows and composition changes in pollution-intensive industries in the manufacturing sector across a large number of countries in an attempt to reach a stronger conclusion. I find that environmental regulatory stringency decreases net exports and the production share of the most polluting industries, which provides evidence for the pollution haven hypothesis. However, when I examine the interaction between environmental regulatory stringency and trade openness, I find that high income countries with high regulatory stringency do not lose their comparative advantage in pollution-intensive industries as trade openness raises. I also find that the ability to innovate, to invent a new environment-related technology (that helps reduce pollution), bestows comparative advantage in the pollution-intensive industries. This finding implies that government policies do not have to constrained based on the tradeoff between pollution control and international competitiveness, since stimulating innovative ability may help achieve both goals – pollution control and international competitiveness.

1.1 Introduction

Issues related to international trade and the environment have been debated since the early 1970s. Some of the issues focused on the impacts of environmental policies on international trade. One study of GATT (the General Agreement on Tariffs and Trade), the predecessor of the WTO (the World Trade Organization), reflected the concern that environmental policies could become a new form of protectionism[1]. Many trade agreements in the 1990s included environmental considerations – for example, the North American Free Trade Agreement (NAFTA), the United Nations Conference on Environment and Development (UNCED), Uruguay Round of the GATT. In 1999, President Clinton's Executive Order 13141, Environmental Review of Trade Agreements, required that the United States "factor environmental considerations into . . . its trade negotiating objectives." The opponents of trade liberalization argue that the concentration of pollution-intensive production in poor, developing countries that have less stringent environmental regulations would cause negative impacts to the environment and developed country consumers will enjoy the pollution-intensive goods at a lower price due to the underestimated pollution costs. The phenomenon of concentration of pollution-intensive production in certain countries or areas to take advantage of the less stringent environmental regulations is usually referred to as the pollution haven hypothesis (PHH).

The empirical studies on PHH are mainly conducted either through the analysis of foreign director investment (FDI hereafter) behavior or through the analysis of trade flows. The studies analyzing FDI relate measures of environmental regulation stringency and FDI location choice. In this chapter I revisit this question by looking instead at trade flows across a large number of countries and ask if uneven stringency of environmental regulations affects trade and allocation of pollution-intensive production. While FDI can shift pollution-intensive production from one country to another, it is more likely that it is trade and production patterns that change in response to environmental regulations. These changes in the volume of trade and local

[1] In 1972, the UN held a Conference on the Human Environment in Stockholm. During the preparations in 1971, the Secretariat of GATT therefore prepared a study under its own responsibility. Entitled "Industrial Pollution Control and International Trade", the study focused on the implications of environmental protection policies on international trade. It reflected the concern of trade officials at the time that such policies could become obstacles to trade as well as constitute a new form of protectionism (i.e. green protectionism").

production often occur via entry (into pollution-intensive industries) and exit of domestic firms, not multinationals. Hence, analyzing FDI flows may underestimate the impact of environmental regulations on the relocation of pollution-intensive production.

Previous studies that relate trade flows and environmental stringency can be classified into two groups. The first group is based on the Heckscher-Ohlin theoretical foundation. In addition to factor endowments, lax environmental regulations are also modeled as a determinant of comparative advantage. In 1990, Toby (1990) was among the first to examine whether the net exports of five pollution-intensive industries across a number of countries were affected by factor endowments and environmental stringency. Example of other studies similar to Toby's (1990) are in Table 1 in Appendix D. One shortcoming of these studies is that neglect of the role of trade openness. Even though there are differential endowments and environmental regulations among countries, comparative advantage is affected by trade openness. To account for the misspecification, another group of studies (see Table 2 in Appendix D) focuses on the interactions between endowments and trade openness.

Antweiler et al. (2001) and Copeland and Taylor (2003) present a unified framework, in which comparative advantage of the standard Heckscher-Ohlin model and PHH are nested. They decompose the change in pollution emissions into scale, composition, and technique effects. The interactions of trade determinants (factor endowment and environmental stringency) and trade openness are used to measure an unobserved composition change, which is defined as a trade-induced composition effect. They underline the joint role of factor endowments and environmental stringency in the determination of trade patterns of pollution-intensive goods, which are presumably capital-intensive, as well (Mulatu et al, 2004). Using their model specification, I set up an estimating equation where trade flows are determined by factors that may bestow comparative advantage to pollution-intensive production and by the interactions of those factors with trade openness.

Previous studies predominantly use trade flow data from developed countries due to lack of environmental regulation data from developing countries. Often, these papers conduct case studies on specific countries. Some find empirical support for the pollution haven effect (PHE)

[2], but they typically do not find the same effects on their trading partners to support PHH (Mulatu et al., 2004; Ederington et al., 2004, 2005). This study conducts a cross-country analysis, which allows me to come to conclusions that are more general.

Another distinguishing characteristic of this study is that it examines the relation between trade flows and innovative ability in environmental-related technology. Previous work on the relationship between induced R&D and productivity, such as Hamamoto (2006) and Yang et al. (2012), find that R&D expenditure induced by stricter environmental regulations contributes significantly to productivity growth. Therefore, I argue that innovative ability may also affect the comparative advantage of pollution-intensive production.

This study contributes to the existing literature in two ways. First, it searches for evidence of the existence of PHH by analyzing trade flows and output in the most pollution intensive industries across a wide range of countries. Second, this study also examines whether innovative ability in environmental-related technology affects comparative advantage of pollution-intensive production. The empirical strategy is presented in next section. The data are described in section 3. I present and discuss the results in section 4. The final section concludes.

1.2 Model

Given a closed economy, the cost of pollution-intensive production is determined by factor endowments (END) and environmental regulations (ENV). Output is determined by productivity and it is also a function of END and ENV.

$$\text{Cost} = \text{Cost}(\text{END}, \text{ENV})$$
$$\text{Production} = \text{Productivity} * f(\text{END}, \text{ENV})$$

[2] Taylor (2004) indicates that even though environmental regulations are related to production costs (i.e. existing PHE), the PHH may not hold with high trade barriers. That is to say, PHE is necessary, but usually not sufficient for PHH to hold.

In an open economy setting, END and ENV are thus considered sources of comparative advantage. Therefore, trade flows, which are dependent on comparative advantage, are a function of END, ENV, Productivity, and trade openness (O).

Trade Flows = f (END, ENV, Productivity, O)

Among the potential determinants, capital abundance and environmental regulations are important factors affecting comparative advantage as suggested by previous studies. Countries with higher income per capita are usually capital abundant and implement stricter environmental regulations, two determinants of comparative advantage that have opposite effects for pollution-intensive goods. Hence, it is important to control for both for these factors when searching for evidence of PHH.

According to the Rybczyinski theorem, an increase in the supply of a given factor will lead to an increase in the output of the good using that factor intensively. I argue that the pollution intensive industries tend to be more capital intensive due to the fact that more fixed capital would consume more energy and resources, and then generate more waste and pollution[3]. On the other hand, stricter environmental regulations also affect firms' production cost. In addition to capital abundance and environmental regulations, I argue that innovative ability in environment-related technology, which is an outcome of environmental policy, technology policy, R&D and human capital, may contribute to industrial productivity (Hamamoto, 2006; Yang et al., 2012) and bestow comparative advantage in pollution-intensive industries.

I estimate the following two-way error components regression model which controls for unobserved country-specific (μ_i) and time-specific fixed effects[4] (λ_t):

$$\ln(\mathrm{NetEXPO}_{it}) = \alpha_0 + \alpha_1 \mathrm{KL}_{it} + \alpha_2 (\mathrm{KL}_{it})^2 + \alpha_3 \mathrm{I}_{it} + \alpha_4 (\mathrm{I}_{it})^2 + \alpha_5 \mathrm{INNOV}_{it} + \alpha_6 (\mathrm{INNOV}_{it})^2 + \alpha_7 \mathrm{KL}_{it}\mathrm{I}_{it} + \alpha_8 \mathrm{KL}_{it}\mathrm{INNOV}_{it} + \alpha_9 \mathrm{I}_{it}\mathrm{INNOV}_{it} + \gamma_0 \mathrm{O}_{it} + \mu_i + \lambda_t + \varepsilon_{it} \text{ ------------------------ } (1)$$

[3] According to the database in Nicita and Olarreaga (2006) and the classification of Hettige et al. for the World Bank (1995), I find that the most polluting industries tend to have higher KL ratios than others do in the manufacturing sector. (See Appendix C)

[4] Country-specific fixed effects control for unobserved effects which are time invariant, but vary across countries, such as natural resource endowments. In contrast, time-specific fixed effects are used to control for time-variant unobserved variables that affect all countries. In our study, capital stock and GDP per capita are measured in current dollars, so, time-specific fixed effect control for inflation, as well.

The dependent variable $NetEXPO_{it}$ is net exports scaled by output (in the most polluting manufacturing industries) for country i at year t. KL_{it} is the capital-labor ratio for the manufacturing sector. Higher income per capita is associated with heightened public awareness of environmental issues and often stricter environmental regulations. However, there may be a time lag between increasing income per capita and implementation of stricter environmental regulations. Hence, I_{it} is one period lagged GDP per capita and it proxies for the stringency of environmental regulations. $INNOV_{it}$ is the accumulated innovative output of country i in year t divided by GDP. The accumulated innovative output is measured by accumulated patent counts of environment-related innovations with a given obsolescence rate of 5 percent. $INNOV_{it} = 0.95* INNOV_{i,\ t-1}$ + patent counts in year t. Because the quantity of innovative output is highly correlated with the country's size, it is scaled by GDP. The variable O_{it} measures trade openness which is defined as total trade (imports plus exports) as a fraction of GDP[5]. The effects of capital abundance, environmental regulations, and innovative ability may be non-linear, so I allow for this in the empirical model.

I expect a positive estimate of α_1 and a negative estimate of α_2. This would indicate higher net exports in pollution-intensive industries for countries that are more capital abundant. I_{it} represents the stringency of environment regulations which raise production costs for polluting industries, such that α_3 is expected to be negative and α_4 is expected to be positive. Innovative ability in environmental-related technology strengthens the productivity of polluting industries, therefore, α_5 is expected to be positive, and α_6 negative.

Further, since the capital abundance and environmental regulations have opposite effects on the net export of pollution-intensive production, an expected negative α_7 would imply that an increase in the stringency of environmental regulations offsets the advantage conferred by capital abundance. In the same manner, we can expect a negative sign on α_9 and a positive sign on α_8. It is worth noting that even though the direct effects (α_1, α_3, α_5) measure the impact on comparative advantage (or disadvantage) from the right-hand side determinants of net exports, robust conclusions should be based on the total effects from these determinants.

[5] This study focuses on trade exposure rather than trade liberalization. I do not study the effect of a reduction of tariffs.

Unlike Ederington et al. (2004), who analyze U.S. manufacturing imports and use an interaction term between tariffs and abatement costs to examine the PHH, my cross-country analysis of the relationship between net exports and environmental regulatory stringency will allow me to provide direct evidence on the pollution haven hypothesis.

To conduct an even more strict test of PHH, I employ the functional form of Antweiler et al. (2001) and Cole et al. (2003), and add "trade-induced effects" into equation (1). Because comparative advantage is a relative concept, the determinants of net exports in the trade-induced effect are expressed as ratios relative to the world averages. $O_{it}\mathrm{RK}L_{it}$ is an interaction term between trade openness and the country's relative capital-labor ratio (relative to the world average capital-labor ratio). $O_{it}\mathrm{R}I_{it}$ is an interaction between trade openness and country i's one period lagged relative income[6] (relative to world average GDP per capita). Similarly, $O_{it}\,\mathrm{R}\,INNOV_{it}$ represents the interaction between trade openness and relative innovative ability.

$$\ln(\mathrm{NetEXPO}_{it}) = \alpha_0 + \alpha_1 \mathrm{KL}_{it} + \alpha_2(\mathrm{KL}_{it})^2 + \alpha_3 \mathrm{I}_{it} + \alpha_4(\mathrm{I}_{it})^2 + \alpha_5 \mathrm{INNOV}_{it} + \alpha_6(\mathrm{INNOV}_{it})^2 + \alpha_7 \mathrm{KL}_{it}\mathrm{I}_{it} + \alpha_8 \mathrm{KL}_{it}\mathrm{INNOV}_{it} + \alpha_9 \mathrm{I}_{it}\mathrm{INNOV}_{it} + \text{Trade Induced Effect} + \mu_i + \lambda_t + \varepsilon_{it} \quad \text{-----(2)}$$

$$\text{Trade Induced Effect} = \gamma_0 \mathrm{O}_{it} + \gamma_1 \mathrm{O}_{it}\mathrm{RKL}_{it} + \gamma_2 \mathrm{O}_{it}(\mathrm{RKL}_{it})^2 + \gamma_3 \mathrm{O}_{it}\mathrm{RI}_{it} + \gamma_4 \mathrm{O}_{it}(\mathrm{RI}_{it})^2 + \gamma_5 \mathrm{O}_{it}\,\mathrm{RINNOV}_{it} + \gamma_6 \mathrm{O}_{it}\,(\mathrm{RINNOV}_{it})^2 + \gamma_7 \mathrm{O}_{it}\,\mathrm{RK\,L}_{it}\;\mathrm{R\,I}_{it} + \gamma_8 \mathrm{O}_{it}\,\mathrm{RK\,L}_{it}\;\mathrm{R\,INNOV}_{it} + \gamma_9 \mathrm{O}_{it}\mathrm{RI}_{it}\,\mathrm{RINNOV}_{it}$$

The direct effect of trade openness (O_{it}) depends on the trading status of the country and so γ_0 may not be significant. If $\gamma_1<0$ and $\gamma_2>0$, then countries with lower capital abundance would have comparative disadvantage in producing pollution-intensive commodities such that an increase in trade openness corresponds to a fall in the net exports of pollution-intensive commodities. In contrast, countries at higher levels of capital abundance would have higher net exports of pollution-intensive commodities. In the same manner, $\gamma_5<0$ and $\gamma_6>0$ would demonstrate that the innovative ability does not bestow comparative advantage to the

[6] It is assumed that there is a time lag between the implementation of stricter environmental regulations and the public's demand for higher environmental quality when per capita income raises. Using the lag term may also help alleviate endogeneity concerns.

pollution-intensive industries. Different from capital abundance and innovative ability in environmental-related technology, environmental stringency is considered a factor that reduces comparative advantage in pollution-intensive goods. Therefore, $\gamma_3 > 0$ would imply that countries with less stringent environmental regulations would have comparative advantage in pollution-intensive goods and an increase in trade openness would correspond to an increase in the net export of such goods. On the other hand, $\gamma_4 < 0$ would mean that an increase in trade openness corresponds to a fall in net exports of pollution-intensive goods at higher levels of environmental stringency. Both positive γ_3 and negative γ_4 provide more robust evidence for PHH.

By taking the derivative of equation (2) with respect to O_{it} and I_{it}, I can identify the effect of environmental stringency (I_{it}) through trade openness (O_{it}):

$$E_{OI} = \frac{\partial^2 \ln(\mathrm{NetEXPO_{it}})}{\partial O_{it} \partial \mathrm{I_{it}}} = \gamma_3 \frac{\partial \mathrm{RI_{it}}}{\partial \mathrm{I_{it}}} + 2\gamma_4 \mathrm{RI_{it}} \frac{\partial \mathrm{RI_{it}}}{\partial \mathrm{I_{it}}} + \gamma_7 \mathrm{RKL_{it}} \frac{\partial \mathrm{RI_{it}}}{\partial \mathrm{I_{it}}} + \gamma_9 \mathrm{RINNOV_{it}} \frac{\partial \mathrm{RI_{it}}}{\partial \mathrm{I_{it}}} \quad \text{------ (3)}$$

Recall that $\mathrm{RI_{it}} = I_{it} / W_t$, where, W_t = the world average of I_{it} in year t. E_{OI} predicts the change in a pollution-intensive goods' net export brought about by environmental regulations (I_{it}) through an increase in trade openness (O_{it}). According to the theoretical predictions, γ_3 should be positive and γ_4 should be negative. Therefore, the effect of environmental regulation through trade openness depends on its relative (to the world average) magnitude and the interactions with RKL_{it} and $RINNOV_{it}$. If RI_{kt} is small, E_{OI} may be positive, which means that trade openness would lead to an increase in net exports of pollution-intensive commodities for low-income countries with less stringent environmental regulations. On the contrary, trade openness would lead to a decrease in net exports of pollution-intensive production for a high-income country, such that E_{OI} would be negative.

The overall pollution haven effect (PHE) is identified as the total effect of environmental regulation

TE_I = direct effect of I_{it} + indirect effect of I_{it}

$$= \frac{\partial \ln(\mathrm{NetEXPO_{it}})}{\partial \mathrm{I_{it}}} = \alpha_3 + 2\alpha_4 \mathrm{I_{it}} + \alpha_7 \mathrm{KL_{it}} + \alpha_9 \mathrm{INNOV_{it}} + O_{it} * E_{OI} < 0 \quad \text{------------------(4)}$$

where, direct effect of I_{it} equals to $\alpha_3 + 2\alpha_4 I_{it}$. Indirect effects include $\alpha_7 KL_{it} + \alpha_9 INNOV_{it}$ and the trade-induced effect, $O_{it} * E_{OI}$. The total effect of trade openness (O_{it}) can then be computed as:

$$TE_O = \gamma_0 + \gamma_1 RKL_{it} + \gamma_2 (RKL_{it})^2 + \gamma_3 RI_{it} + \gamma_4 (RI_{it})^2 + \gamma_5 RINNOV_{it} + \gamma_6 (RINNOV_{it})^2 + \gamma_7 RKL_{it} RI_{it} + \gamma_8 RKL_{it} RINNOV_{it} + \gamma_9 RI_{it} RINNOV_{it} \quad \text{------(5)}$$

1.3 Data

Combining data sets from the World Bank and the database created by Nicita and Olarreaga in 2006, this study uses country-level data from 1978 to 2001, including 35 developed and non-developed countries[7] for a total of 494 observations. Some data related issues are discussed in the following paragraphs.

Trade Flows: To extend the data availability, this study uses “mirrored” import and export values. Different from the formal import (export) value, mirrored import (export) values represent the value of imports (exports) of the reporting country observed as exports (imports) from partner countries. These import and export values for 28 manufacturing industries are collected by Nicita and Olarreaga in 2006 at the 3-digit level International Standard Industrial Classification (ISIC), Revision 2.

Capital-labor ratio (K/L): The KL ratio is total fixed capital stock divided by the total labor force, which is a measure of a country’s capital abundance. However, the gross fixed capital formation provided by the World Bank is total domestic investment, which represents a “flow” measure, not a stock measure. Some analysts assume an average life for fixed capital and accumulate the gross fixed capital formation (over time) using a given depreciation rate[8]. In our unbalanced panel analysis, such a methodology could result in a loss of observations or in a bias due to assuming identical depreciation rates across countries. Hence, I use the industrial level gross fixed capital stock built by Nicita and Olarreaga to construct the capital-labor (KL) ratio for the manufacturing sector in each country.

[7] The criterion is based on the World Bank Classifications standards.

[8] Leamer (1984) and Toby (1990) assume an average life of 15 years and 13.3% depreciation rate.

Measurements of environmental stringency: GDP per capita and CO_2 intensity of the manufacturing sector are used to proxy for environmental stringency. To reduce the endogeneity problem, GDP per capita is one-period-lagged to trade flows. CO_2 intensity of the manufacturing sector is obtained from WDI (World Development Indicators, the primary World Bank collection of development indicators).

The most polluting industries: To classify different industries by pollution intensity (emission per unit of output), I use the three-digit International Standard Industrial Classification (ISIC) system developed in the Industrial Pollution Projection System study carried out by Hettige et al. for the World Bank (1994). For the purpose of analyzing the impacts of trade on pollution levels, they chose to use the pollution intensity levels for all media released by physical volume of output. Table 1.1 lists the classified industries (according to three-digit ISIC). The total toxic pollution abbreviated in the table as ToxTot is the sum of toxic pollution to air (ToxAir), toxic pollution to water (ToxWat), and toxic pollution to land (ToxLand).

Patent counts in environmental-related innovations: To construct countries' stock of innovative output, I use OECD's patents statistics in environmental-related technologies (refer to Appendix B). The patent counts are from applications to the European Patent Office (EPO). They are sorted by inventors' country in order to measure the technological innovations of researchers and laboratories located in a given county. Also, the patent applications are attributed to the priority date, which is the closest to the date of invention. Patents are the source of data most widely used to measure innovative activity. However, some do criticize the usage of patents as indicators of innovative activity[9]. The major criticism is assuming that each patent makes the same contribution to environmental performance. Popp (2005) states: "Most importantly, the quality of individual patents varies widely. Some inventions are extremely valuable, whereas others are of almost no commercial value. This is partly a result of the random nature of the inventive process. ... Accordingly, the results of studies using patent data are best interpreted as the effect of an average patent, rather than any specific invention." In my study, I build an index to measure the combined outcome of other factors, which may

[9] More detailed discussion about the advantages and limitations of patens counts are referred to STI Review and Popp (2005).

affect the productivity of pollution-intensive production, such as R&D expenditure, human capital, technology policy, environmental policy, etc.

Also note that the counts of patents for each country at the EPO, USPTO, or other International Searching Authority (ISA) are not the counts of patents applied for or granted by individual national patent offices, even though nearly all patents are first filed in the inventor's home country. Therefore, the index I build does not represent the level of adoption of those environmental technologies. Inventors who intend to market a product in that area or country would choose to patent in that market. So, the patent applications from individual countries filed to EPO or USPTO likely represent appropriate measures to compare the level of innovative activity of environmental-related technology across countries. Since the process of adopting environmental technologies is not in the realm of this research paper, it is reasonable to assume that countries with higher innovative capability would use cleaner or more advanced technologies when producing pollution-intensive goods.

The OECD patent counts are fractional counts applied for patents with multiple inventors/applicants. When a patent was invented by several inventors from different countries, the respective contributions of each country is taken into account. This is done in order to eliminate double-counting of such patents. For example, a patent co-invented by 1 French, 1 American and 2 German residents will be counted as: 1/4 of a patent for France, 1/4 for the USA and 1/ 2 patent for Germany.

1.4 Empirical Results

Table 1.3 shows the results. In Model (1), I start by assuming a linear relationship between net exports and its determinants. The impact of these determinants on trade flows depend on the trade openness, and thus I control for it in Model (2). Since Model (1) is nested in Model (2), I conduct a Likelihood-ratio test (LR test) to test if the expanded model is more appropriate. The likelihood ratio (2*(448.223 - 447.76547) = .91505514) follows a Chi-squared distribution with one degree of freedom under the null hypothesis, and I cannot reject the null that O_{it} does not improve the model specification. This may be due to the fact that the direct effect of trade openness (O_{it}) has opposite impacts on importers and exports of pollution-intensive goods.

Furthermore, there is not much evidence to believe that the impacts of the determinants would be linear, so I add quadratic terms and additional interaction terms in Model(3). The LR test (LR = 23.539086) verifies that the specification has statistically significantly improved. The coefficient (0.00032) of I^2 is statistically significantly positive and it indicates that the impact of environmental regulations is decreasing as regulations are getting stricter.

By adding trade-induced effects into Model (3), the log-likelihood value in Model (4) has significantly increased, implying that Model (4) is statistically superior to Model (3). I only obtain significantly negative γ_1 and insignificantly positive γ_2, which do not allow me to conclude that trade openness will increase the net export of the most polluting industries in countries with high level of relative capital-labor ratios (RKL). Meanwhile, positive γ_3 suggests that trade openness will increase net exports in the most polluting industries in those countries with low levels of relative environmental stringency (RI). While γ_4 is positive, it is not significant.

Relative capital-labor ratio (RKL) depends on both KL and the world average ($RKL_{it} = KL_{it} \big/ \frac{\sum_i KL_{it}}{N_t}$). If I take the derivative of ln(NetEXPO$_{it}$) with respect to O_{it} and KL_{it} instead of RKL_{it}, I obtain

$$\frac{\partial \ln(\mathrm{NetEXPO_{it}})}{\partial \mathrm{O_{it}} \partial \mathrm{KL_{it}}} = \gamma_1 * \frac{\partial (KL_{it} \big/ \frac{\sum_i KL_{it}}{N_t})}{\partial \mathrm{KL_{it}}} + 2\gamma_2 * \mathrm{RKL_{it}} * \frac{\partial (KL_{it} \big/ \frac{\sum_i KL_{it}}{N_t})^2}{\partial \mathrm{KL_{it}}} + \gamma_7 *(\ .\ ) + \gamma_8 *(\ .\ )$$

I can ignore the second, third, and fourth terms since $\gamma_2, \gamma_7, \gamma_8$ are relatively small and statistically insignificant in Model (4). Then I rewrite the derivative as:

$$\frac{\partial^2 \ln(\mathrm{NetEXPO_{it}})}{\partial O_{it} \partial \mathrm{KL_{it}}} = \gamma_1 N_t \left(\frac{1}{\sum_i KL_{it}} - \frac{KL_{it}}{(\sum_i KL_{it})^2} \right).$$

Whereas the empirical results suggest that γ_1 is statistically significantly negative, the derivative is negative at low levels of KL and positive at high levels, which indicates that trade openness reduces net exports at lower levels of KL and increases net exports at high levels of KL. This result is consistent with our previous finding - countries with lower capital abundance would not have comparative advantage in producing pollution-intensive good such that an increase in trade openness corresponds to a fall in net exports of such goods. Countries with higher capital abundance would have comparative advantage in producing pollution-intensive goods such that an increase in trade openness corresponds to a rise in net exports of such goods. In the same way, by taking the derivative of $\ln(NetEXPO_{it})$ with respect to O_{it} and I_{it}, I can obtain a positive derivative at a lower level of I_{it} and a negative derivative at a higher level of I_{it}, which would support the PHH – when trade barriers decline, countries with less stringent environmental regulations will specialize in pollution-intensive production.

To check for robustness, I re-estimate regression model (4) without using the normalized (relative to the world average) variables in the trade-induced effects. The results of Model (5), shown in Table 1.3-1 consistently support the main conclusions from Model (4) except the interaction effect between trade openness and the quadratic term of environmental stringency (I_{it}). The significantly positive γ_4 denotes trade openness will increase net exports even more at higher levels of environmental stringency. This result runs counter to the prediction of PHH since environmental regulation is considered a factor that weakens comparative advantage in pollution-intensive industries.

Also note that in Model (5) the interaction term between KL and I is statistically significantly positive, which is opposite to what I found previously. This suggests that the marginal impact of environmental regulations is lessened at higher levels of KL. So, I may conclude that in countries with higher levels of KL and environmental stringency, which usually refers to developed countries, the marginal impact of environmental regulations would be quite small as KL and I keep increasing. In contrast, the marginal impact of KL would be higher as KL and I are increasing. A similar conclusion holds for the interaction term between INNOV and I. On the other hand, the interaction term between KL and INNOV is negative. These cross terms with trade openness are oppositely signed and this indicates that the interaction effects are diminishing in importance as trade openness grows.

To check for robustness, I re-estimate the baseline model using exports, imports, and productions in the most polluting industries as dependent variables. The estimates are presented in Table 1.4 and Table 1.4-1. One can see that the effects on net exports are mainly driven by the effects on imports. Also, the estimated effects on output are very similar to the effects on net exports, which would be consistent with PHH.

It is worth noting that even though the direct effects (α_1, α_3, α_5) of KL, I, and INNOV, and their interactions with trade openness carry implications for comparative advantage, conclusions about the effects of KL, I, and INNOV should be based on their total effects (direct and indirect). The elasticities for the total effects of each of these 3 determinants are presented in Appendix G and they confirm the conclusions I have reached so far.

In sum, all of the empirical results are consistent when it comes to the direct effects of capital abundance and innovative ability in environmental-related technology and their indirect effects through international trade. The results also provide direct evidence for the pollution haven hypothesis (PHH). However, in contrast to what the PHH would implies, when I examine the interaction between environmental regulatory stringency and trade openness, I find that high income countries with high regulatory stringency do not lose their comparative disadvantage in pollution-intensive industries as trade openness grows.

1.5 Conclusion

I examine the pollution haven hypothesis (PHH) using data on trade and production from a large number of countries over 23 years. In particular, I analyze net exports in the most polluting industries in the manufacturing sector from 35 countries from 1978 to 2001. I summarize the main results below.

First, capital abundance contributes to comparative advantage and increases net exports in industries that are pollution-intensive. This finding is consistent with Antweiler et. al. (2001) and Cole and Elliot (2003). I extend the previous literature by also showing that endowments (capital intensity) affect composition changes in aggregate output. As capital intensity grows, so does the share of output in pollution-intensive manufacturing industries.

Second, and not surprisingly, regulatory stringency (proxied by GDP per capita) leads to a reduction in comparative advantage in pollution-intensive production. In my cross-country analysis, I directly examine the relationship between trade flows and environmental regulatory stringency. The estimated total effect of environmental regulatory stringency provides direct evidence for the pollution haven hypothesis. However, I do uncover some evidence that does not support the PHH – I find that high income countries with high regulatory stringency do not lose their comparative disadvantage in pollution-intensive production as trade openness grows.

Last, but not least, I document that a country's innovative ability in environmental-related technology confers comparative advantage in pollution-intensive industries. This finding has important policy implications. It suggests that governments may have a better option than environmental regulation for the purpose of pollution control. While regulation may effectively control pollution levels, it also raises the likelihood of losing comparative advantage and competitiveness in pollution-intensive industries vis-à-vis other trading partners. The results indicate that fostering a country's innovative ability in environmental-related technology could not only strengthen competitiveness, but also control pollution.

Table 1.1: Summary of pollution intensity classification by sector

	Category 1 Most Polluting Sector	Category 2 Moderately Polluting Sector	Category 1 Least Polluting Sector
Definition	ToxTot>= 1500 pnds/USD million	500 pnds/ USD million <ToxTot<= 1500 pnds/USD million	ToxTot<= 500 pnds/USD million
Sectors (ISIC)	industrial chemicals (351) non-ferrous metals (372) iron and steel (371) leather products (323) pulp and paper (341) petroleum refineries (353) other chemicals (352) plastic products (356) fabricated metal products (381) furniture, except metal (332)	pottery, china, earthenware (361) electrical machinery (383) rubber products (355) other non-metallic mineral products (369) textiles (321) transport equipment (384) other manufactured products (390) misc. petroleum and coal products (354) non-electrical machinery (382)	professional and scientific equipment(385) footwear, except rubber or plastic(324) printing and publishing (342) wood products, except furniture (331) glass and products (362) tobacco (314) food products (311) beverages (313) wearing apparel, except footwear (322)

Table 1.2: Descriptive statistics (Obs. = 394)

Variable	Definition	Mean	Std. Dev.	Min	Max
NetEXPO	net export scaled by the output value of the most polluting industries among the manufacturing industries	-.0622979	.1977484	-1.099131	.3973114
KL	capital-labor ratio of the whole manufacturing sector (million USD per labor)	.0041702	.0035233	-.0027699	.0216517
I	one period lag GDP per ca. (ten thousand USD per ca)	.6999419	.785585	.01835533	4.196765
INNOV	accumulated patent stock of environment-related technologies with 5% obsolescence rate divided by GDP. (stock per hundred million USD)	.0300418	.0564973	0	.2960061
O	total import and export / GDP	.486109	.2705108	.091023	2.175709
RKL	national capital-labor ratio / world average	1.032563	.6662922	-.6771066	3.428215
RI	one period lag GDP per ca. / world average	1.359905	1.404137	.0416596	5.896218
RINNOV	INNOV / world average	1.625733	2.906248	0	18.87731

Table 1.3: Two-way error component regression model for the net export of most polluting industries

Dependent Variable = (total export value - total import value of most polluting industries) / total output value of the most polluting industries.				
Independent Variables	Model (1)	Model (2)	Model (3)	Model (4)
KL ($\boldsymbol{\alpha_1}$)	4.2066* (1.78)	4.0627* (1.72)	14.3395** (2.53)	37.3995*** (3.73)
KL^2 ($\boldsymbol{\alpha_2}$)			-469.6728 (-1.54)	-970.0227** (-2.28)
I ($\boldsymbol{\alpha_3}$)	-.0524*** (-2.71)	-.0571*** (-2.85)	-.264065*** (-4.83)	-.5911*** (-7.09)
I^2 ($\boldsymbol{\alpha_4}$)			.032* (1.95)	.0742*** (2.94)
INNOV ($\boldsymbol{\alpha_5}$)	.4843** (2.34)	.5068** (2.43)	1.3088** (2.45)	1.895*** (2.73)
INNOV^2 ($\boldsymbol{\alpha_6}$)			-3.3012* (-1.73)	-4.8006** (-2.26)
KL*I ($\boldsymbol{\alpha_7}$)			3.824 (0.69)	4.6517 (0.54)
KL*INNOV ($\boldsymbol{\alpha_8}$)			-17.4227 (-0.22)	-90.6536 (-0.76)
I*INNOV ($\boldsymbol{\alpha_9}$)			.1822 (0.52)	.1831 (0.44)
O ($\boldsymbol{\gamma_0}$)		-.0507 (-0.88)	-.07905 (-1.37)	-.1031 (-1.11)
O*RKL ($\boldsymbol{\gamma_1}$)				-.1879** (-2.04)
O*RKL^2 ($\boldsymbol{\gamma_2}$)				.0072 (0.28)
O*RI ($\boldsymbol{\gamma_3}$)				.3107*** (3.09)
O*RI^2 ($\boldsymbol{\gamma_4}$)				.0045 (0.21)
O* RINNOV ($\boldsymbol{\gamma_5}$)				.0191 (0.58)
O* RINNOV^2 ($\boldsymbol{\gamma_6}$)				-.0009 (-0.70)
O*RKL*RI ($\boldsymbol{\gamma_7}$)				.017 (0.35)
O*RKL* RINNOV ($\boldsymbol{\gamma_8}$)				-.0059 (-0.28)
O*RI* RINNOV ($\boldsymbol{\gamma_9}$)				.0041 (0.33)
Number of countries	35			
Observations	394			
Log-likelihood	447.76547	448.223	459.99254	488.67313
Likelihood Ratio		.91505514	23.539086***	57.361164***
Prob > chi2(df)		.33877669	.00063464	4.309e-09

*, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.
Values in parentheses

Table 1.3-1: Two-way error component regression model for the net export of most polluting industries - Compare the estimations of trade-induced effects by normalized determinants and by non-normalized determinants

Dependent Variable = (total export value - total import value of the most polluting industries) / total output value of the most polluting industries

Independent Variables	Model (4)	Independent Variables	Model (5)
KL ($\boldsymbol{\alpha_1}$)	37.3995*** (3.73)	KL (α_1)	48.3294*** (3.55)
KL^2 ($\boldsymbol{\alpha_2}$)	-970.0227** (-2.28)	KL^2 (α_2)	-4711.069*** (-3.83)
I ($\boldsymbol{\alpha_3}$)	-.5911*** (-7.09)	I (α_3)	-1.133*** (-9.42)
I^2 ($\boldsymbol{\alpha_4}$)	.0742*** (2.94)	I^2 (α_4)	-.1088 (-1.47)
INNOV ($\boldsymbol{\alpha_5}$)	1.895*** (2.73)	INNOV (α_5)	10.9243*** (5.31)
$INNOV^2$ ($\boldsymbol{\alpha_6}$)	-4.8006** (-2.26)	$INNOV^2$ (α_6)	-18.632 (-1.65)
KL*I ($\boldsymbol{\alpha_7}$)	4.6517 (0.54)	KL*I (α_7)	105.6459*** (3.88)
KL*INNOV ($\boldsymbol{\alpha_8}$)	-90.6536 (-0.76)	KL*INNOV (α_8)	-1918.173*** (-3.02)
I*INNOV ($\boldsymbol{\alpha_9}$)	.1831 (0.44)	I*INNOV (α_9)	4.6945** (2.32)
O ($\boldsymbol{\gamma_0}$)	-.1031 (-1.11)	O (γ_0)	-.1745* (-1.81)
O*RKL ($\boldsymbol{\gamma_1}$)	-.1879** (-2.04)	O*KL (γ_1)	-70.9828*** (-3.01)
O*RKL^2 ($\boldsymbol{\gamma_2}$)	.0072 (0.28)	O*KL^2 (γ_2)	7433.111*** (3.40)
O*RI ($\boldsymbol{\gamma_3}$)	.3107*** (3.09)	O*I (γ_3)	1.4246*** (6.16)
O*RI^2 ($\boldsymbol{\gamma_4}$)	.0045 (0.21)	O*I^2 (γ_4)	.3058** (2.30)
O* RINNOV ($\boldsymbol{\gamma_5}$)	.0191 (0.58)	O* INNOV (γ_5)	-14.7761*** (-4.39)
O* $RINNOV^2$ ($\boldsymbol{\gamma_6}$)	-.0009 (-0.70)	O* $INNOV^2$ (γ_6)	27.1617* (1.73)
O*RKL*RI ($\boldsymbol{\gamma_7}$)	.017 (0.35)	O*KL*I (γ_7)	-162.1014*** (-3.71)
O*RKL* RINNOV ($\boldsymbol{\gamma_8}$)	-.0059 (-0.28)	O*KL* INNOV (γ_8)	2828.863*** (3.00)
O*RI* RINNOV ($\boldsymbol{\gamma_9}$)	.0041 (0.33)	O*I* INNOV (γ_9)	-7.7766** (-2.54)
Prob > chi2(df)	4.309e-09		7.701e-17

Table 1.3-1: Continued

Number of countries	35	
Observations	394	
Log-likelihood	488.67313	508.28544
Likelihood Ratio	57.361164***	96.585786***

*, **, *** indicate significance at the 10%, 5%, and 1% level, respectively.
Values in parentheses are t-values.

Table 1.4: Two-way error component regression model for impacts to export, import, and production of the most polluting industries - With estimations of trade-induced effects by normalized determinants

Dependent Variables / Independent Variables	Export	Import	Production 1	Production 2
KL	-5.3565 (-1.23)	-42.7559*** (-4.22)	2.3018 (0.25)	18.15 (1.41)
KL^2	561.3424*** (3.03)	1531.365*** (3.56)	-172.542 (-0.44)	-864.2523 (-1.58)
I	.0733** (2.02)	.6644*** (7.88)	-.4613*** (-6.04)	-.5229*** (-4.87)
I^2	-.0021 (-0.19)	-.0763*** (-2.98)	.0523** (2.26)	.056* (1.84)
INNOV	.5812* (1.92)	-1.3138* (-1.87)	.638 (1.00)	1.2317 (1.38)
$INNOV^2$	-1.0371 (-1.12)	3.7634* (1.75)	-2.9691 (-1.53)	-3.6976 (-1.35)
KL*I	-5.736 (-1.54)	-10.3876 (-1.20)	7.0002 (0.90)	6.4815 (0.59)
KL*INNOV	92.6041* (1.79)	183.2577 (1.53)	-50.2222 (-0.46)	-28.901 (-0.19)
I*INNOV	-.2706 (-1.48)	-.4538 (-1.07)	-.0058 (-0.02)	-.2355 (-0.44)
O	.2181*** (5.40)	.3211*** (3.42)	-.1791** (-2.11)	-.1352 (-1.13)
O*RKL	-.015 (-0.37)	.1729* (1.85)	-.1642* (-1.95)	-.3709*** (-3.13)
$O*RKL^2$	-.0106 (-0.94)	-.0177 (-0.68)	.0369 (1.57)	.0831** (2.51)
O*RI	-.0666 (-1.52)	-.3772*** (-3.70)	.0535 (0.58)	.068 (0.52)
$O*RI^2$	.0069 (0.76)	.0025 (0.12)	.0033 (0.17)	.009 (0.33)
O* RINNOV	.0125 (0.88)	-.0065 (-0.20)	.0006 (0.02)	-.0043 (-0.10)
$O* RINNOV^2$	-.0008 (-1.48)	.0001 (0.06)	-.0008 (-0.73)	-.0003 (-0.18)
O*RKL*RI	.0207 (0.99)	.0037 (0.08)	.0106 (0.24)	.0252 (0.41)
O*RKL* RINNOV	-.0072 (-0.78)	-.0014 (-0.06)	-.0203 (-1.04)	-.0261 (-0.95)
O*RI* RINNOV	.0064 (1.19)	.0023 (0.19)	.023** (2.03)	.0245 (1.54)

Table 1.4: Continued

Number of countries	35			
Observations	349			
R- Squared (within)	0.5864	0.2929	0.4086	0.3923

*, **, *** indicate significant at the 10%, 5%, and 1%.
Export = export value divided by output value of polluting industries.
Import = import value divided by output value of polluting industries.
Production 1 = logarithm of output value of the most polluting industries divided by the output value of the whole manufacturing industry.
Production 2 = logarithm of value added of the most polluting industries divided by the value added of the whole manufacturing industry.

Table 1.4-1: Two-way error component regression model for impacts to export, import, and production of the most polluting industries - With estimations of trade-induced effects by non-normalized determinants

Dependent Variables / Independent Variables	Export	Import	Production 1	Production 2
KL	7.1788 (1.18)	-41.1505*** (-3.01)	1.6327 (0.13)	-13.429 (-0.72)
KL^2	-69.6445 (-0.13)	4641.424*** (3.77)	-3491.074*** (-3.04)	-2467.841 (-1.46)
I	.1071** (1.98)	1.2401*** (10.27)	-.8075*** (-7.18)	-.7207*** (-4.36)
I^2	.0518 (1.56)	.1607** (2.16)	-.1193* (-1.72)	-.1087 (-1.07)
INNOV	.085 (0.09)	-10.8392*** (-5.26)	7.6403*** (3.98)	7.6833*** (2.72)
$INNOV^2$	-.0312 (-0.01)	18.6008 (1.64)	-17.5291* (-1.66)	-21.3089 (-1.37)
KL*I	-23.6392* (-1.93)	-129.2851*** (-4.73)	90.4646*** (3.55)	81.2595* (2.17)
KL*INNOV	634.2819** (2.23)	2552.455*** (4.01)	-1260.109** (-2.12)	-991.2275 (-1.14)
I*INNOV	-2.2094** (-2.44)	-6.9039*** (-3.40)	3.0603 (1.62)	2.1679 (0.78)
O	.3057*** (7.07)	.4803*** (4.97)	-.3207*** (-3.56)	-.4557*** (-3.44)
O*KL	-28.5059*** (-2.69)	42.4769* (1.79)	-25.7364 (-1.17)	4.2128 (0.13)
$O*KL^2$	1127.421 (1.15)	-6305.688*** (-2.87)	6715.104*** (3.28)	4464.977 (1.49)
O*I	-.1247 (-1.20)	-1.5493*** (-6.68)	.6212*** (2.87)	.3774 (1.19)
$O*I^2$	-.0576 (-0.97)	-.3634*** (-2.73)	.3534*** (2.85)	.3302* (1.81)
O* INNOV	1.205 (0.80)	15.9811*** (4.73)	-11.5609*** (-3.67)	-10.8024** (-2.34)
$O*INNOV^2$	-3.4576 (-0.49)	-30.6193* (-1.94)	26.02* (1.77)	29.3334 (1.36)
O*KL*I	30.5747 (1.56)	192.6761*** (4.40)	-141.2947*** (-3.46)	-120.3217** (-2.01)
O*KL* INNOV	-841.4622** (-1.99)	-3670.325*** (-3.88)	1817.174** (2.06)	1377.934 (1.06)
O*I* INNOV	3.2669** (2.38)	11.0435*** (3.60)	-4.5072 (-1.58)	-2.884 (-0.69)

Table 1.4-1: Continued

Number of countries	35			
Observations	349			
R- Squared (within)	0.6034	0.3715	0.4429	0.3756

*, **, *** indicate significant at the 10%, 5%, and 1%.

Export = export value divided by output value of polluting industries.

Import = import value divided by output value of polluting industries.

Production 1 = logarithm of output value of the most polluting industries divided by the output value of the whole manufacturing industry.

Production 2 = logarithm of value added of the most polluting industries divided by the value added of the whole manufacturing industry.

Chapter 2

Do the Manufacturing Industries in Taiwan Transfer Their Pollution-intensive Production via Foreign Direct Investment?

Outward foreign direct investment (FDI) by Taiwanese manufacturing firms has grown significantly in term of number of new deals and total volume since 1987. During the same period, the government began to execute a series of revisions to its various environmental statutes and in the early 1990s, it also upgraded the effectiveness of its environmental supervision. Using firm-level data, this study examines whether the increased stringency of environmental regulations in Taiwan can account for some of the increased outward FDI flows, especially to countries with less strict environmental regulations, which would be consistent with the Pollution Haven Hypothesis (PHH). The results suggest that less polluting firms are more likely to be pollution haven seekers than polluting firms are. In addition, polluting firms undergoing more environmental protection expenditure at home tend to invest more in countries with stricter environmental regulations. The empirical results imply that the impact of stricter environmental regulations may be two-fold. Stricter regulations do not only increase firm's production costs in terms of environmental protection expenditure (consistent with PHH), but they also provide incentives for technology upgrading.

2.1 Introduction

The relationships between economic growth, environmental pollution, and foreign direct investment have a prominent place among the debates on the effects of globalization. Opponents of globalization often worry about the adverse effects of trade on environmental quality, and argue that free trade would cause the movement of polluting industries from one country to another. The debate started in the early 1990s. The critics focus on the issue that pollution-intensive production located in rich and tightly regulated countries, such as US and Canada, would flock to a poor and laxly regulated country (e.g., Mexico) under the North-American Free Trade Agreement (NAFTA). This is the so-called “pollution haven hypothesis” (PHH).

The empirical studies finding evidence for the PHH are usually conducted by analyzing FDI or trade flows (composition changes of imports and exports). The studies analyzing trade flows consider environmental regulation as one of the factors contributing to comparative advantage in pollution-intensive goods. Since stricter environmental regulations would increase production cost, the stringency of environmental regulations is taken as a factor contributing to the comparative advantage of pollution-intensive production. A country with less stringent environmental regulations would specialize in heavy polluting industries, and increase its exports of “dirty” goods and imports of “clean” goods. This basic logic is widely adopted in many PHH studies using trade flows.

Another type of empirical studies looking for evidence of PHH is conducted via the analysis of FDI. Those studies examine whether there exists significant relationship between multinational’s direct investment decision and the stringency of environmental regulations. That is, whether dirty industries would be attracted to the countries with less stringent environmental regulations. The existing literature of PHH analyzing FDI flows can be divided into three subgroups: (1) FDI inflows into a developed country, (2) FDI outflows from a developed country, and (3) FDI inflows into a non-developed country[10]. The first two subgroups take a large portion of literature because data from developed countries is more readily available.

To examine PHH, a proper design is needed to identify the differential stringency of environmental regulations across countries or industries. Javorcik and Wei (2004) use a probit model to test multinationals’ direct investment decision. Their empirical model uses an interaction term between the pollution intensity of multinationals and overall stringency of environmental protection in the host country to test for the PHH. A statistically significant

[10] Due to data availability, the third subgroup also focuses on the direct investment from developed countries, e.g. Javorcik and Wei, 2004; Cole and Elliott, 2005; Eskeland and Harrison, 2003.

negative sign of the coefficient provides evidence of PHH (FDI by pollution-intensive multinationals locates in countries with weaker environmental standards). However, their results do not show such a significant relation. Similar strategy of using an interaction term in an empirical model can be seen in other papers, such as Manderson and Kneller (2012).

Cole and Elliott (2005) use industry-level data on U.S. outbound FDI to Mexico and Brazil to test the PHH. They find that the U.S. sectors facing higher abatement cost would invest more in its counterparts in Mexico and Brazil. This positive relation supports the existence of PHE and provides evidence for PHH, even though they do not exactly use a measure of environmental stringency of the host country (Mexico or Brazil) in their empirical model. The evidence for PHH is weak, at best, because the outbound FDI from U.S. is constrained to the direct investments only in one country with relatively less stringent environmental regulation.

Eskeland and Harrison (2003) conduct a similar study. They strategically analyze inbound FDI into developing countries. Those FDI inflows mainly originate from developed countries (the U.S. and France). They also analyze individually inbound FDI into four developing countries to see whether it is concentrated in pollution-intensive sectors. Their data sets are also constrained to FDI flows between two countries with differential stringency of environmental regulations. They find some evidence that foreign investors locate in sectors with high levels of air pollution.

In addition to environmental regulations, Eskeland and Harrison (2003) categorize three types of framework for the potential determinants of foreign investment. The first one is based on the factor proportions theory, which is similar to using factor endowments to predict trade patterns. FDI would locate in countries with lower factor prices. This theory of FDI is described in detail in Caves (1928), Helpman (1984), and Brainard (1993). The variables used to capture such effects are skill intensity, capital-labor ratios, and wage differentials between countries.

The second type of theoretical framework to explain FDI behavior focuses on the role of ownership itself, which is called intangible asset. The theory was developed by Horstmann and Markusen (1989) among others. It states that intangible assets, such as managerial abilities, technology and business relationships, are essentially related to the control of production; otherwise they will be sold at arm’s length. For example, in countries where patent protection is weak, research-intensive goods might be sold via direct investment rather than via a licensing agreement with a local firm. In Eskeland and Harrison (2003), they use total factor productivity growth to capture such an effect and I use R&D intensity in this paper.

The third type of framework is the proximity-concentration trade-off between multinational sales and trade. Brainard (1997) indicates that there are factors (other than intangible assets and factor prices) which make it desirable to locate near the target market. These factors include tariff barriers and transport costs. However, there is a trade-off between the benefit of concentrating production in one location (e.g. scale economy) and the advantage of accessing the target market.

This paper aims to analyze the outward investment behavior of Taiwanese manufacturing firms during the 1990s when the government was executing a series of revisions to the various environmental statutes and upgrading the effectiveness of its environmental supervision. Thus, I am able to test whether manufacturing firms use outward FDI to transfer pollution-intensive production abroad in response to stricter environmental regulations.

To the best of my knowledge, this is the first paper using Taiwanese firm-level data to analyze pollution haven behavior in the manufacturing sector. The firm-level data allows me to avoid aggregation bias and gives me an opportunity to control for firm characteristics that may affect investment decisions. In addition, I also control for host country characteristics that allows me to track whether the dirtier firms experiencing higher environmental protection expenditure at home would invest more in countries with less stringent environmental regulations.

Our findings are thought-provoking. The empirical results suggest that less polluting firms are more likely to be pollution haven seekers than are polluting firms. The empirical results even suggest that polluting firms undergoing more environmental protection expenditure at home tend to invest more in countries with stricter environmental regulations. The polluting firms' behavior contradicts the prediction of PHH and this implies that environmental regulations may not always be harmful to firm's international competitiveness.

2.2 Background on Taiwan's Environmental Regulations and Outward Investment of Manufacturing Industries

Around the mid-1970s, Taiwan began to develop capital-intensive and energy-consuming industries such as metal, petrochemical, synthetic fiber, and electronics industries. Due to lax environmental regulations, rapid increases in the emission of various pollutants occurred since then, and deteriorated the quality of the environment. Along with people's awareness on environmental quality, debate on the relationship between economic growth and environment emerged in the late 1970s. In response to the public concern for environmental protection, the government initially enacted two major environment statutes, the Water Pollution Control Act and the Waste Disposal Act, in 1974. The Air Pollution Control Act came into effect the following year. By 1983, when the Noise Control Act was legislated, the environmental statutes seemed to be complete in Taiwan (Yang et al, 2012).

Economic growth remained the primary national target for Taiwan in the 1980s. Each of the aforementioned environmental statutes had been revised slightly or perhaps not at all in the 1980s. Furthermore, that the supervision did not sufficiently implement the environmental statutes was also a reason for failing to mitigate the degradation of environmental quality during the 1980s. Until 1992, the RCA pollution event[11] shocked the Taiwanese society and deeply awakened the environmental awareness of both the public and the government. As a result, the government began to execute a series of revisions to the various environmental statutes and upgraded the effectiveness of the environmental supervision since the 1990s.

Taiwan's environmental regulations were basically "command and control" before 1991. That is, plants emitting pollution that exceeds the emission standard will be fined and asked to improve production process. Since 1991, the environmental regulations were combined with other policies which offered market based incentives to achieve the purpose of pollution control. For example, the Statute for Upgrading Industries (SUI), which was put into practice on January 1, 1991, offered a 20-year tax incentive scheme to encourage R&D, technological

[11] RCA is an American electrical appliances company, which established its Taiwan affiliate in 1970. During its operating period, the company persistently released toxic chemicals into the environment. In 1988, when the RCA plant was sold to Thomson Inc. of France, the buyer drilled wells to investigate the quality of water and soil and found high level of toxic chemicals. This plant was forced to shut down in 1992, and then the event was divulged to the public.

upgrading, and development. In Article 6, investment tax credits are provided for R&D, personnel training, and pollution control. The SUI applying to all manufacturing firms aims to technological upgrading and reaches the purpose of pollution control at the same time.

According to statistics on approved outward investment by the Investment Commission in the Ministry of Economic Affairs (MOEA), Taiwan, the outward investment of Taiwanese manufacturing firms has significantly increased since 1987 (see Figure 2.1). Even though I do not observe significant changes in the composition of FDI (e.g. non-polluting vs. polluting industries (e.g. pulp, paper, and paper products, chemical material, chemical products, petroleum and coal product, non-metallic mineral products, and basic metal industries etc.)) during the 1990s, the amounts of the investments in polluting industries still grew as rapidly as the overall outward investment. As both environmental regulations and their enforcement were enhanced in the early-1990s, it would be interesting to examine whether the stricter environmental stringency accounts for any of the variation in outward investment of Taiwanese manufacturing firms. Such investigation could offer a more general understanding of the outward investment behavior of manufacturing firms in Taiwan and its possible relationship to the differential environmental regulation stringency between Taiwan and the host countries.

In Table 2.1, I compare the distributions of the aggregate data from the Investment Commission and the data employed in this study. I find that over half of outward FDI flows into China. The FDI flowing into China counts to 55.51%, in average, of overall FDI during the three referenced years. The FDI from the manufacturing sector flowing into China counts to 79.52%. Both in terms of overall FDI and in terms of FDI from the manufacturing sector, China and USA are the largest host countries of Taiwanese outward investment. Since the U.S. is considered to have stricter environmental regulations than Taiwan, here comes the question: if Taiwanese firms sought for pollution havens to reduce environmental protection cost, why would the U.S. be the second largest host country of Taiwanese outward FDI? Further analyzing the firm-level data, I find that manufacturing firms in Taiwan belonging to the polluting industries have significantly higher domestic environmental expenditures than that its firms belonging to the non-polluting industries. However, the average outward investment flow of those "polluting" firms is slightly lower than that of the firms belonging to non-polluting industries (see Table 2.2). It seems that the PHE does not even exist.

The PHE states that firms facing higher environmental protection cost would invest more oversea in order to look for cost reduction and, additionally, the destination of its FDI would locate at countries with relatively lax environmental regulations for the PHH to hold. Based on the aforementioned statistics, it seems that PHE does not exist and PHH does not hold for Taiwanese manufacturing firms. However, the PHE and PHH tend to be overwhelmed by other factors, such as industrial characteristics, firm's characteristics, host country's characteristics. The outward FDI decision is seen as the integration of strategical considerations. In order to examine the PHE and PHH, those potential factors need to be appropriately controlled.

2.3 Empirical Specification and Variables Description

To analyze whether Taiwanese manufacturing firms transfer domestic pollution through outward investment, the empirical analysis in this paper uses a least squares dummy variable regression model (LSDV) to examine the relationship between environmental protection expenditures and FDI outflows. Assuming firm's outward FDI decisions depend on firm's and host country's characteristics which are suggested as important determinants by previous studies[12], I estimate the following model:

$$FDI_{ikt} = \alpha_0 + \alpha_1 SIZE_{it} + \alpha_2 RD_{it} + \alpha_3 KL_{it} + \alpha_4 LABOR_{it} + \alpha_5 ENV_{it} + \alpha_6 PINDU_{it} + \alpha_7 PINDU_{it} ENV_{it} + \alpha_8 GDP_{kt} + \alpha_9 DWAGE_{kt} + \alpha_{10} LABOR_{it} DWAGE_{kt} + \alpha_{11} STRING_{kt} + \alpha_{12} ENV_{it} STRING_{kt} + \alpha_{13} PINDU_{it} ENV_{it}\, STRING_{kt} + D_{year} + D_{industry} + \varepsilon_{itk}$$

D_{year} and $D_{industry}$ are dummy variables for year fixed effect and industry-specific fixed effect. The dependent variable FDI_{ikt} denotes the logarithm of the flow of foreign direct investment for firm *i* investing in a host country *k* during year *t*. The independent variables include firm-level characteristics and the characteristics of the host country. Previous empirical studies on the determinants of *FDI* employ the following firm characteristics - firm size (*SIZE*), capital intensity (*KL*), R&D investment (*RD*), wages (*LABOR*), and environmental protection expenditure (*ENV*). *SIZE* is measured by firm sales in logarithmic form. A positive coefficient

[12] Refer to the section of 2.1 Introduction

implies that the advantages of accessing the target market are larger than the benefits of concentrating production in Taiwan. *RD* is measured as the logarithm of R&D expenditures, which proxies for firm's intangible assets. Firms with higher R&D investment are usually inclined to extend their market share via direct investment.

KL, *LABOR* and *ENV* are included as explanatory variables in view of the factor proportions theory. Since capital, labor, and pollution emission are taken as inputs in production, the higher input costs the firms face in Taiwan, the more incentives the firms have to look for lower factor prices elsewhere. *KL* is measured as the ratio of the net value of fixed assets to total employment. An expected positive relation with FDI implies that the cost of capital in Taiwan is relatively high such that capital-intensive firms tend to look for cost reduction through outward investment.[13] The variable *LABOR* is measured as the logarithm of the number of employees per firm. It is used as a proxy of each firm's wage bill. The variable *ENV* is the logarithm of environmental protection expenditure for each firm.

In terms of the host country's characteristics, I include the host country's GDP to control for market size. *DWAGE* is the wage differential between Taiwan and host country. Higher value of *DWAGE* denotes relatively lower cost of labor in the host country. I also use various measurements to proxy the host county's environmental stringency (*STRING*). GDP per capita, bureaucratic corruption and other pollutant emission intensities have been suggested by previous studies and are also employed in this paper[14]. The term *PINDU* is a dummy variable, which represents whether the firm (in Taiwan) belongs to a heavy polluting industry, and it takes the value of 1 if the firm is in the polluting industry[15]. It can be taken as a fixed effect between polluting and non-polluting industries.

[13] Capital-intensive firms are usually pollution-intensive, thus a positive relation might also imply that pollution-intensive firms in Taiwan tend to conduct more FDI.

[14] Cole and Elliott (2003) point out that national KL ratio, GDP per capita, and overall environmental stringency are highly correlated. That is to say, countries with high income levels are usually capital abundant and implementing stricter environmental regulations. I measure the degree of a host country's corruption by the corruption perceptions index (*CPI*), which is collected by the Global Competitiveness Report. A higher number implies lower possibility of corruption.

[15] According to the definition proposed by the World Bank (Nicita and Olarreaga, 2006), the following industries are classified as heavy polluters: pulp, paper and paper products, chemical material, chemical products, petroleum and coal product, non-metallic mineral products and basic metal industries.

The interaction term between *PINDU* and *ENV* captures the differential effect of environmental protection expenditure (*ENV*) between polluting (*PINDU* = 1) and non-polluting firms (*PINDU* = 0). Due to the industrial properties, the polluting industries have higher environmental protection expenditure than non-polluting industries do. I argue that the firms in polluting industries would more actively respond to increasing environmental protection expenditure through the FDI outflow than non-polluting firms would. Therefore, α_7 should be positive.

Since the positive coefficients of *LABOR* and *ENV* (i.e. PHE) represent the incentives for firms to look for lower costs of labor and environmental protection through FDI outflows, the interactions with host country's wage level (*LABOR**DWAGE*) and environmental stringency (*ENV**STRING*) would verify that Taiwanese manufacturing firms do seek for the cost reductions through FDI outflows in countries with lower levels of wage and environmental stringency. Again, the strength of motivation for polluting firms to seek for cost reduction in environmental protection expenditure may be different from that of non-polluting firms. So, the term of $PINDU_{it}ENV_{it}\ STRING_{kt}$ is to capture the differential levels in pollution-haven-seeking behavior between polluting and non-polluting firms.

2.4 Data Description

The data utilized in this study are taken from several sources including annual surveys on outward foreign direct investment and manufacturing operations conducted by the Ministry of Economic Affairs (MOEA), in Taiwan; datasets constructed by the World Bank, the International Monetary Fund, and the World Economic Forum. According to the statistics on outward investment reported by the Investment Commission of MOEA, the average amount of outward investment had rapidly increased at the rate of 41% per year in the period from 1991 to 2004. This study applies the firm-level data in manufacturing sectors from the year 2000 to 2003 of the period.

Table 2.3 summarizes variable definitions and basic statistics of data (before taking logarithm) used in our model estimation. The firm-level data on outward investment are collected by the Survey on Outward Foreign Direct Investment from 2000 to 2003[16], which includes information on domestic and foreign fixed assets, invested locations, and invested industries. The data on individual firm characteristics including revenues, number of employees, net value of fixed assets, environmental protection expenditures, and R&D expenditures, are collected in the Annual Survey on Manufacturing-Plant Operations. The environmental variables of host country, e.g. the emission of carbon dioxide, GDP per capita, are gathered from the World Bank dataset. Last, host country characteristics, such as GDP and corruption perceptions index (*CPI*), are taken from the International Financial Statistics and the Global Competitiveness Report in World Economic Forum.

To eliminate the disturbance caused by the stylized fact that small firms may not have capability to allocate their production across nations, I focus on establishments with more than 30 employees and sales of more than 3 million of NT dollars. There are about 1,076 firms and 1,677 observations included in the estimations eventually.

Many studies use the FDI data from the Investment Commission in MOEA. However, the criteria for the Investment Commission and the Survey on Outward FDI to identify FDI are different. Taiwanese outward investment over a certain amount needs to be approved by the Investment Commission. Outward investments approved by the Investment Commission actually measure large amounts of capital outflows from Taiwan. On the other hand, the FDI data I use from the Survey on Outward FDI is the survey on the increments of foreign fixed assets of Taiwanese manufacturing firms, which specifically identifies the outward investment as the change of foreign fixed asset, but may not identify the actual capital outflow from Taiwan. For example, foreign fixed asset increment may be the reinvestment from their foreign revenue. Nevertheless, both the data sources of FDI measure the change of foreign production controlled by Taiwanese firms.

I use three measurements to proxy the overall environmental stringency of host country. The first one is CO_2 per capita. Higher values of CO_2 per capita refer to stricter environmental stringency because countries with higher CO_2 per capita are usually the industrialized and developed countries. The second measurement is corruption perceptions index (*CPI*). According the definition, the *CPI* describes that a higher number implies lower possibility of

[16] Except in 2001 when the quinquennial Industrial and Commercial Census is conducted.

corruption. This index indirectly measures the environmental stringency in host country since countries that are more corrupt tend to ineffectively implement or implement less stringent environmental regulations. The third measurement is GDP per capita. According the conceptual model proposed by Antweiler et al. (2001), the emission price is determined by household income. Along with increasing income, the demand on environmental quality will increase and the public will ask the government to implement stricter environmental regulations.

The environmental stringency may be endogenously determined in host country, but it is considered as an exogenous factor to Taiwanese firm's FDI decision in our study. The potential endogeneity problem may exist due to the measurement error of environmental stringency proxies. Therefore, I use three different measures to verify the consistency of the empirical results. Another potential factor causing endogeneity problem is unobserved heterogeneity (omitted variables). To control the unobserved heterogeneity, I also incorporate year fixed effect and industry-specific fixed effect into our empirical models.

2.5 Empirical Results

In our empirical model, firm's FDI depends on firm's characteristics, host country's characteristics, and their interactive terms. Additionally, unobserved heterogeneity and heteroscedasticity are also controlled by fixed effects and adjusted standard errors. In general, time and group-specific fixed effects are used to control the difference over time and unobserved heterogeneity between groups in a panel data analysis. In Table 2.4, the results illustrate that the model with time-specific and firm-specific fixed effect (Model (2)) does not well specify our firm-level data. The possible reason is because the period of data coverage is too short. When firm-specific fixed effect is incorporated into the model, it absorbs most of the variation and leads to insignificance of the other variables. I also try to control for industry-specific and host-country-specific fixed effect (Model (3) and Model (4)). The R-squared of Model (3) suggests that the industry-specific fixed effect increases the specification ability better than host-country-specific fixed effect. Therefore, I incorporate the industry-specific fixed effect to control for the unobserved heterogeneity in our estimations hereafter.

In Table 2.5, I illustrate the results with controlling heteroscedasticity by different methods including clustered standard errors (column 1 to 4), robust standard errors (column 5, using the Huber-White sandwich estimators), and weighted least square regression (WLS in column 6). The column 1 to 4 are results of models incorporating time and industry-specific fixed effect, and corrected standard errors clustered by year (column 1), firm (column 2), industry (column 3), and host country (column 4). The model with corrected standard errors clustered by host country (column 4) better specifies the data than the rest of the others. The same adjustment of clustering by host country can be seen in Javorcik and Wei (2004).

After appropriately controlling the unobserved heterogeneity and heteroscedasticity, I use the other two measures to proxy the environmental stringency of host country. Consistent results obtained from the three models with different measurements of environmental stringency are summarized in Table 2.6. First, a larger size of a firm in Taiwan significantly and positively correlates to the higher FDI, which support the conceptual framework of the proximity-concentration trade-off between multinational sales and trade. It implies that the advantage of accessing the target market is larger than the benefit of concentrating production in one location. So that, Taiwanese manufacturing firms prefer to relocate their production to target markets oversea instead of extending their markets shares through international trade. Further, positive estimates of α_2 suggest that firms with higher R&D expenditure correspond to higher FDI, which supports the view point of intangible asset theory.

In terms of *KL* ratio, *LABOR*, and *ENV*, each of them captures firm' cost burden from capital, labor, and environmental regulatory compliance in Taiwan. The positive coefficients of *KL* and *LABOR* (α_3 and α_4) are consistent with the conclusions made by previous studies that the increasing outward FDI of Taiwanese manufacturing sector was induced by increasing production costs. However, the insignificant coefficient of α_{10} denotes that the empirical results do not provide significant evidence that manufacturing firms experiencing higher labor cost would have a propensity to invest in countries with lower wage levels.

As to the variable of our interest, environmental protection expenditure (*ENV*), the positive value of direct effect (α_5) and negative value of indirect effect (α_{12}**STRING*) consist with the statement of pollution haven hypothesis for non-polluting firm. On the contrary, polluting firms (*PINDU*=1) have a negative direct effect ($\alpha_5 + \alpha_7$) and a positive indirect effect (α_{12}

+ α_{13}) * *STRING*, which oppose against the prediction of the pollution haven hypothesis. The positive indirect effect suggests that the polluting firms experience higher environmental protection expenditure tend to invest more in countries with stricter environmental regulations. Our empirical results suggest a mixed phenomenon involving the pollution haven hypothesis and counter the pollution haven hypothesis. Surprisingly, the non-polluting firms act more like pollution haven seekers than polluting firms do.

The pollution-intensive firms presumably have stronger incentives to transfer their production through FDI due to higher environmental protection expenditure. Yet, these firms demonstrate the opposite behavior, which contradicts the prediction of the pollution haven hypothesis. The significant relationship appears in all three models with different measures of environmental stringency. The potential explanation is that the pollution haven effect is stronger in the early stage and diminishes over time while stricter environmental regulations are implemented. The data I use covers the period of the early 2000s while both environmental regulations and their enforcement had been enhanced since the early-1990s. That implies some polluting firms that could not stand for the stricter environmental regulations may have left the market in the early stage. In the later stage, the stricter environmental regulations in Taiwan enforce the polluting firms to equip the technology or knowledge that allows them to comply with stricter environmental regulations in host countries.

Another potential explanation is the effect of investment tax credit, which is offered by the Statute for Upgrading Industries (SUI). While the polluting firms spend more on the pollution control investment, they simultaneously obtain more tax credit and the benefit of technological upgrading. It turns out that polluting firms with higher levels of pollution protection expenditure truly face lower cost induced by environmental regulations and increase their competitiveness via technological upgrading. Therefore, our empirical results imply a counter effect induced by environmental regulations that lead to two possible versions of Porter's hypothesis[17].

[17] Porter's Hypothesis states that well-designed regulations can induce efficiency and encourage innovations that help improve commercial competitiveness.

2.6 Multinomial Logit Model

To avoid the misspecification induced by measurement error of environmental stringency and the aggregate variables of host country, I adopt a multinomial logit (MNL) model as a check of assertion concluded from the LSDV regression models. Given firm's direct investment in China is the baseline, let *j*= 0 if investing in China, *j*=1 if investing in U.S., *j*=2 if investing in Japan, *j*=3 if investing in Malaysia, *j*=4 if investing in Singapore, *j*=5 if investing in Thailand, *j*=6 if investing in Indonesia, and *j*=7 if investing in Philippines. Therefore, the probability of firm *i's* investing in *j* is :

$$\text{Prob}(Y_i = j) = \frac{e^{\beta'_j x_i}}{\sum_{k=0}^{7} e^{\beta'_k x_i}} \text{ , } j = 0, 1, 2,..,7$$

Given β_0 = 0, the probability of firm *i 's* investing in *j* = 0 (China) is

$$\text{P}_{i0} = \text{Prob}(Y_i = 0) = \frac{1}{1+ \sum_{k=1}^{7} e^{\beta'_k x_i}} \text{ , and}$$

$$\text{P}_{ij} = \text{Prob}(Y_i = j) = \frac{e^{\beta'_j x_i}}{1+ \sum_{k=1}^{7} e^{\beta'_k x_i}} \text{ ,}$$

then, the log-odds ratio is:

$$\ln \left[\frac{P_{ij}}{P_{i0}} \right] = X'_i(\beta_j - \beta_0) = X'_i \beta_j$$

, which indicates the relative probability of firms' investing in country *j*. The regressors (X'_i) are the firms' characteristics. So, a positive value of a coefficient suggests that the manufacturing firms tend to invest in host country *j* instead of investing in China. Along with the ranking of environmental stringency measurements, I are able to conduct pairwise comparisons between countries.

According to the ranking of environmental stringency measurements for the host countries (Table 2.7), environmental stringency in Indonesia and the Philippines is less stringent than that in China. The other countries are suggested to have stricter environmental stringency than China in terms of all three measurements[18]. Since the environmental stringency in Indonesia and the Philippines is less stringent than that in China, the positive coefficients of environmental protection expenditure (*ENV*) for these two pairwise comparisons should follow the prediction of PHH – firms experiencing higher environmental protection expenditure tend to invest in countries with less stringent environmental regulations (i.e., Indonesia and the Philippines). Contrarily, negative coefficients of *ENV* for other pairwise comparisons suggest the predictions of PHH because the other five countries are host countries with stricter environmental regulations than those in China.

Table 2.8 demonstrates the results of the MNL model distinguishing the marginal effects of environmental protection expenditure between polluting and non-polluting firms. For non-polluting firms' investment choices, investments in United States, Singapore, Malaysia , and Philippines follow the predictions of PHH. For these four investment choices comparisons, non-polluting firms have stronger preference to United States, Malaysia, and Philippines over China than polluting firms do. That is, non-polluting firms behave more like pollution-haven seekers than polluting firms do in United States, Malaysia , and Philippines.

The results also show polluting firms tend to invest in Japan, Malaysia, and Thailand over China when they experience higher *ENV*. According to our ranking of environmental stringency measurements, these three countries have stricter environmental stringency than China. Polluting firms experience higher environmental protection expenditure tend to invest more in countries with stricter environmental regulations in these three comparisons.

Not all the pairwise comparisons in our MNL model support the conclusions of the LSDV regression models: (1) polluting firms undergoing more environmental protection expenditure tend to invest more in countries with stricter environmental regulations, and (2) non- polluting firms are more likely to be pollution haven seekers than polluting firms are. However, it is

[18] Thailand has stricter environmental stringency in two out of three measures than China.

worth noting that China, United States, Malaysia, and Thailand are the top four FDI host countries and FDI in these four countries accounts for over ninety percent of the total FDI in our sample data. Taiwanese manufacturing firms' investment choice analyses for these four countries in MNL model are consistent with the conclusions of the LSDV regression models.

2.7 Remarks and Conclusion

The empirical results of this study are consistent with the conclusion from the conceptual framework of the proximity-concentration trade-off between multinational sales and trade. As for the factor proportions theory, I find that there is positive relationship between production costs and FDI. This result support the claim that increasing FDI in Taiwan is triggered by increasing production costs stemming from stricter environmental regulation. However, when I further examine the impact of cost reductions, I find no significant evidence that Taiwanese manufacturing firms facing higher wages at home would invest in countries with lower wage levels.

This study on the pollution haven hypothesis (PHH) using Taiwanese firm-level data leads to mixed and interesting conclusions. I find that the conclusions of PHH hold when I examine non-polluting firms, but they do not hold when I consider polluting firms. The empirical results suggest that polluting firms facing higher environmental protection expenditure would invest less overseas and more in countries with stricter environmental regulations. There are two possible explanations to the counter-PHH behavior of polluting firms in Taiwan.

First, stricter environmental regulations eliminates the polluting firms that cannot comply for strict environmental regulations in Taiwan. Therefore, the average level of environmental technology and knowledge rises. Polluting firms equip themselves with advanced environmental technology and knowledge to comply with stricter environmental regulations in host countries.

Another potential explanation is the effect of the investment tax credit, which is offered by the Statute for Upgrading Industries (SUI). While the polluting firms spend more on investment in pollution control, they simultaneously obtain more tax credit and the benefit of technological upgrading. For firms with lower levels of environmental protection expenditure (e.g., non-polluting firms) then PHH holds. For firms with higher levels of environmental protection expenditure (e.g., polluting firms) PHH does not hold.

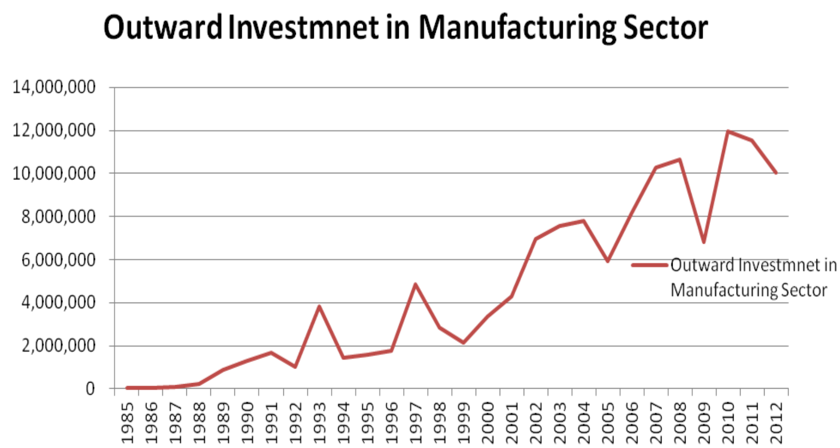

Figure 2.1: Statistics on approved outward investment by the Investment Commission in the Ministry of Economic Affairs (MOEA), Taiwan

Table 2.1: Average percentage of Taiwanese outward investment of year 2000, 2002, and 2003

code	Host Country (area)	Overall FDI (%)(all industries including manufacturing sector)	FDI (from manufacturing sector) of this study (%)
1	USA	6.98	8.37
2	Canada	0.04	0.00
3	Mexico	-	0.04
4	Middle-South America	26.08	0.00
5	Western Europe	-	0.00
6	Eastern Europe	-	0.00
7	Hong Kong	2.59	2.11
8	China	55.51	79.52
9	Japan	1.72	0.12
10	Malaysia	0.33	4.03
11	Singapore	1.11	0.34
12	Thailand	0.38	3.17
13	Indonesia	0.21	0.54
14	Philippines	0.34	0.81
15	Vietnam	0.87	0.96
16	South Asia	-	0
17	Australia and New	0.10	0
18	Zealand	0.18	0
19	Africa	-	0
	Others		

Note: The average percentages of Total FDI are obtained from Investment Commission in MOEA. The last column is based on our data set (2089 observations, 1221 firms), which is obtained from the Survey on Outward Foreign Direct Investment. The criteria for the Investment Commission and Survey on Outward FDI to identify FDI are different. The classification of host country follows the classification in the Survey on Outward Foreign Direct Investment.

Table 2.2: The status of outward investment (1,221 firms, 2089 observations, cross year 2000, 2002, and 2003)

Firms in Taiwan belong to polluting /non-polluting industry	No. of obs	Average outward investment flow (thousand NT $)	Average environmental protection expenditure (thousand NT $)
polluting	348	170,147.7	5,768.3
non-polluting	1741	175,176.8	1,855.6

According to the definition proposed by the World Bank (Nicita and Olarreaga, 2006), the following industries are classified as heavy polluters: pulp, paper and paper products, chemical material, chemical products, petroleum and coal product, non-metallic mineral products and basic metal industries.

Table 2.3: Variable Definition and Basic Statistics

Variables	Definition	Means	S.D.	Min	Max
FDI	logarithm of foreign investment in fixed assets (1000NT$)	209,726	1,273,617	0.3	3.80e+07
SIZE	logarithm of sales (1000NT$)	1,437,713	4,557,956	3770	1.05e+08
RD	logarithm of R&D expenditure (1000NT$)	36,500.86	185,893.4	0.01	4,102,630
KL	logarithm of net value of fixed assets to total employment ratio	2,469.83	3,358.63	0.01	39,371.36
LABOR	logarithm of number of employees	232.51	425.83	30	9,373
ENV	logarithm of environmental protection expenditure (1000NT$)	2,227.46	15,112.88	0.01	358,427
PINDU	=1 if firm in Taiwan belongs to polluting industries; =0, otherwise.	0.1616	0.3682	0	1
GDP	logarithm of host country's *GDP* (USD)	2.13e+12	2.67e+12	7.54e+10	1.10e+13
DWAGE	wage differential between Taiwan and host country (1000 USD / per month)	0.9025	0.6993	-2.0889	2.7073
Indexes for overall environmental stringency of host country (*STRING*):					
CPI	logarithm of corruption perceptions index (index for host country's corruption	3.9324	1.3721	1.9	9.4
CO2	the emission of carbon dioxide in the host country (tons / per capita)	4.1794	5.4767	1.03	20.66
GDPperca	logarithm of GDP per capita based on purchasing power parity (in constant 2005 international dollars)	7,249.28	11,250.33	2,623.04	40,618.68

Note: The statistics of firm's characteristics are based on the 1677 observations applied in our models. The statistics of host country's (area's) characteristics are based on the 8 countries' data during the covered years (2000, 2002, and 2003). The host countries (areas) include USA, China, Japan, Malaysia, Singapore, Thailand, Indonesia, and Philippines.

Table 2.4: Estimations with different group-specific fixed effects

Indep. Variables	Model (1)	Model (2)	Model (3)	Model (4)
SIZE (α_1)	0. 3199*** (4.78)	0.1732 (1.03)	0.3201*** (4.73)	0.3286*** (4.89)
RDS (α_2)	0. 0144* (1.72)	0.0227 (1.32)	0.0149* (1.73)	0.0159* (1.89)
KL (α_3)	0. 2040*** (4.87)	0.7207** (2.32)	0.1979*** (4.68)	0.2035*** (4.86)
LABOR (α_4)	0. 3391*** (2.99)	0.6079 (1.34)	0.3135*** (2.73)	0.3354*** (2.95)
ENV (α_5)	0. 0125 (0.96)	-0.0052 (-0.24)	0.0152 (1.15)	0.0124 (0.95)
PINDU (α_6)	-0.1037 (-0.71)	0.1265 (0.29)	-0.3077 (-1.15)	-0.0863 (-0.59)
PINDU ENV* (α_7)	-0.0381 (-1.38)	-0.0189 (-0.43)	-0.0442 (-1.56)	-0.0362 (-1.31)
GDP (α_8)	-0.0175 (-0.31)	-0.1611 (-1.03)	-0.0187 (-0.33)	-0.2972 (-0.21)
DWAGE (α_9)	0.2635 (0.63)	0.8071 (0.87)	0.2236 (0.52)	-0.1088 (-0.23)
*LABOR*DWAGE* (α_{10})	0. 0270 (0.38)	-0.2203 (-1.30)	0.0331 (0.46)	0.0204 (0.29)
CO2 (*STRING*) (α_{11})	0. 0092 (0.35)	-0.0734 (-1.38)	0.0055 (0.20)	0.0583 (0.17)
*ENV*CO2* (α_{12})	-0.0014 (-0.75)	-0.0001 (-0.01)	-0.0015 (-0.79)	-0.0013 (-0.71)
*PINDU*ENV*CO2* (α_{13})	0.0069* (1.92)	0.0089 (1.15)	0.0074** (2.03)	0.0068* (1.88)
Constant (α_0)	3.4410** (2.02)	5.2297 (0.87)	3.9790** (2.29)	10.2488 (0.30)
Number of Observations	1677			
R-squared	0.2297	0.8195	0.2438	0.2323

Note: Model (1) incorporating time fixed effect; Model (2) incorporating time and firm-specific fixed effect; Model (3) incorporating time and industry-specific fixed effect; Model (4) incorporating time and host-country-specific fixed effect.

*, **, *** indicate significance at the 10%, 5%, and 1% and values in parentheses are t-values.

Dependent variable: logarithm of foreign investment in fixed assets.

Table 2. 5: Models with adjusting standard errors to control heteroscedasticity

Indep. Variables	(1) clustering by year	(2) clustering by firm	(3) clustering by industry	(4) clustering by host country	(5) robust standard errors	(6) WLS
SIZE (α_1)	0.3201 (2.56)	0.3201*** (4.33)	0.3201*** (5.32)	0.3201*** (8.54)	0.3201*** (4.66)	0. 3891*** (5.21)
RDS (α_2)	0.0149 (1.16)	0.0149* (1.70)	0.0149 (1.50)	0.0149** (3.46)	0.0149* (1.74)	0. 0131 (1.36)
KL (α_3)	0.1979 (2.12)	0.1979*** (4.06)	0.1979*** (4.95)	0.1979*** (10.03)	0.1979*** (4.29)	0.3089*** (6.11)
LABOR (α_4)	0. 3135 (1.55)	0. 3135** (2.36)	0. 3135** (2.22)	0. 3135** (3.36)	0. 3135** (2.54)	0.3053** (2.55)
ENV (α_5)	0.0152 (1.00)	0.0152 (1.15)	0.0152 (1.18)	0.0152*** (3.69)	0.0152 (1.19)	0.0233 (1.59)
PINDU (α_6)	-0.3077 (-1.11)	-0.3077 (-1.33)	-0.3077 (-1.12)	-0.3077* (-2.02)	-0.3077 (-1.38)	-0.1559 (-0.44)
PINDU ENV* (α_7)	-0.0442 (-1.40)	-0.0442 (-1.46)	-0.0442 (-1.17)	-0.0442** (-2.72)	-0.0442 (-1.49)	-0.0754** (-2.55)
GDP (α_8)	-0.0187 (-0.95)	-0.0187 (-0.28)	-0.0187 (-0.29)	-0.0187 (-0.47)	-0.0187 (-0.32)	-0.0366 (-0.56)
DWAGE (α_9)	0.2236 (0.26)	0.2236 (0.43)	0.2236 (0.32)	0.2236 (0.42)	0.2236 (0.46)	0.2030 (0.46)
*LABOR*DWAGE* (α_{10})	0. 0331 (0.24)	0. 0331 (0.41)	0. 0331 (0.26)	0. 0331 (0.58)	0. 0331 (0.43)	-0.0022 (-0.03)
CO2 (*STRING*) (α_{11})	0.0055 (0.49)	0.0055 (0.19)	0.0055 (0.23)	0.0055 (0.18)	0.0055 (0.20)	-0.0208 (-0.67)
*ENV*CO2* (α_{12})	-0.0015 (-1.00)	-0.0015 (-0.76)	-0.0015 (-0.87)	-0.0015** (-2.46)	-0.0015 (-0.80)	-0.0007 (-0.39)
*PINDU*ENV*CO2* (α_{13})	0.0074* (3.30)	0.0074* (1.72)	0.0074** (2.29)	0.0074*** (7.94)	0.0074* (1.93)	0. 0081** (2.51)
Constant (α_0)	3.9790 (1.46)	3.9790** (1.96)	3.9790* (1.72)	3.9790** (2.66)	3.9790** (2.18)	2.8103 (1.42)

Table 2. 5: Continued

Number of Observations	1677					
R-squared	0.2438	0.2438	0.2438	0.2438	0.2438	0.2333

Note: *, **, *** indicate significance at the 10%, 5%, and 1%.
Dependent variable: logarithm of foreign investment in fixed assets
Values in parentheses are t-values

Table 2.6: LSDV regression models with time fixed effect and industry-specific fixed effect and control for the heteroscedasticity caused by clustering within host country

Indep. Variables	Model (1)	Model (2)	Model (3)
SIZE (α_1)	0.3201*** (8.54)	0.3180*** (8.51)	0.3213*** (8.76)
RDS (α_2)	0.0149** (3.46)	0.0155*** (4.15)	0.0155*** (3.65)
KL (α_3)	0.1979*** (10.03)	0.1981*** (10.13)	0.1976*** (10.06)
LABOR (α_4)	0. 3135** (3.36)	0.3162*** (3.69)	0.3025** (3.04)
ENV (α_5)	0.0152*** (3.69)	0.0516*** (4.33)	0.0534 (0.84)
PINDU (α_6)	-0.3077* (-2.02)	-0.3053* (-1.91)	-0.2928* (-1.96)
PINDU ENV* (α_7)	-0.0442** (-2.72)	-0.1880** (-3.17)	-0.3757** (-3.81)
GDP (α_8)	-0.0187 (-0.47)	-0.0175 (-0.44)	-0.0211 (-0.37)
DWAGE (α_9)	0.2236 (0.42)	0.1138 (0.30)	0.0839 (0.15)
*LABOR*DWAGE* (α_{10})	0. 0331 (0.58)	0.0330 (0.63)	0.0424 (0.72)
CO2 (*STRING*) (α_{11})	0.0055 (0.18)		
*ENV*CO2* (α_{12})	-0.0015** (-2.46)		
*PINDU*ENV*CO2* (α_{13})	0.0074*** (7.94)		
CPI (*STRING*) (α_{11})		-0.1958 (-0.74)	
*ENV*CPI* (α_{12})		-0.0323** (-3.15)	

Table 2.6: Continued

*PINDU*ENV*CPI* (α_{13})		0.1332** (3.11)	
GDPperca (*STRING*) (α_{11})			-0.0439 (-0.25)
*ENV*GDPperca* (α_{12})			-0.0053 (-0.64)
*PINDU*ENV*GDPperca* (α_{13})			0.0434*** (3.55)
Constant (α_0)	3.9790** (2.66)	4.3411** (2.61)	4.5650 (1.37)
Number of Observations	1677		
R-squared	0.2438	0.2489	0. 2338

Note: *, **, *** indicate significance at the 10%, 5%, and 1%.
Dependent variable: logarithm of foreign investment in fixed assets
Values in parentheses are t-values
All the models adjust the errors for the correlation within host country

Table 2.7: Ranking of the environmental stringency measurements

CO_2 per capita (tons)	*CPI*	*GDP per capita* (2003, 2002, 2000)		
United States (20.66)	Singapore (9.2)	United States	United States	United States
Singapore (14.06)	United States (7.6)	Singapore	Singapore	Singapore
Japan (9.33)	Japan (7.1)	Japan	Japan	Japan
Malaysia (5.85)	Malaysia (5)	Malaysia	Malaysia	Malaysia
Thailand (3.28)	China (3.5)	Thailand	Thailand	Thailand
China (2.19)	Thailand (3.2)	China	China	Indonesia
Indonesia (1.1)	Philippines (2.9)	Indonesia	Indonesia	China
Philippines (1.03)	Indonesia (1.9)	Philippines	Philippines	Philippines

Note: GDP per capita based on purchasing power parity (in constant 2005 international dollars)

Table 2.8: Multinomial Logit

	SIZE	*RDS*	*KL*	*LABOR*	*ENV*	*PINDU* ENV*	Constant
J=1 (United States)	.5162*** (11.23)	.0939*** (22.5)	.0916*** (16.15)	-.3666*** (-6.84)	-.0535*** (-17.88)	.0117* (1.85)	-8.167*** (-4.54)
J=2 (Japan)	.0558*** (4.92)	.1083*** (25.08)	-.0597*** (-3.55)	-.0625*** (-3.99)	.0577*** (20.56)	-.0285*** (-6.01)	-5.9289*** (-4.28)
J=3 (Malaysia)	-.0395*** (-2.28)	.0202*** (34.37)	.2404*** (19.95)	-.0940*** (-4.26)	-.0039*** (-2.88)	.0369*** (29.53)	-3.8747* (-2.45)
J=4 (Singapore)	-.2989*** (-15.89)	-.0132*** (-4.21)	.7866*** (21.36)	.5689*** (18.82)	-.1142*** (-41.32)	-.1015*** (-11.98)	-8.9561*** (-5.59)
J=5 (Thailand)	-.0916*** (-8.91)	-.0255*** (-18.18)	.1543*** (16.59)	-.1414*** (-7.94)	.0590*** (119.48)	-.0171*** (-8.21)	-2.4457 (-1.57)
J=6 (Indonesia)	-.0246 (-0.66)	-.0337*** (-16.32)	.1520*** (11.43)	-.4894*** (-6.25)	-.0412*** (-9.99)	.2107*** (102.99)	-1.7849 (-1.21)
J=7 (Philippines)	.2197*** (14.29)	-.0919*** (-22.90)	.2101*** (6.90)	-.1359*** (-5.88)	.1288*** (32.2)	-.0616*** (-10.94)	-7.5241*** (-4.17)

Note: *, **, *** indicate significance at the 10%, 5%, and 1%.

Dependent variable: logarithm of foreign investment in fixed assets

Values in parentheses are z-values

All the models include time fixed effect and adjust the errors for the correlation within host country

Chapter 3

Environmental Regulations and FDI Location Choice

In this paper I empirically analyze the determinants of FDI location choice by using Taiwanese manufacturing firm-level data covering the period from 2000 to 2003. In particular, I ask whether environmental regulatory stringency influences FDI location choice. To empirically answer this question, I use the conditional logit model developed by McFadden (1974). I find that Taiwanese manufacturing firms, on average, tend to invest in countries with less environmental regulatory stringency, but the estimated effect is similar for firms in polluting industries and those in non-polluting industries. In fact, I find that firms in polluting industries are relatively less attracted to countries with weak environmental regulatory stringency, which runs counter to the predictions of the Pollution Haven Hypothesis.

3.1 Introduction

The early theoretical literature captures the idea of pollution havens as differences in the comparative advantage of countries in the production of pollution intensive goods. Copeland and Taylor (1994) develop a static model of North-South trade to examine the relation between trade and the environment. By endogenising environmental policy such that it depends on national income, the lower income country does not maintain high environmental standards and specializes in relatively dirty goods. McGuire (1982) and Eskeland and Harrison (2003) develop models to show the similar results hold for capital flow. Environmental regulation will drive out the regulated industry from the more to the less regulated economy. It is worth noting that Eskeland and Harrison (2003) show that the effect may be ambiguous due to a possible complementarity between capital and pollution abatement.

In comparison to theoretical modeling of the pollution haven hypothesis, providing robust empirical support has proved more difficult. Due to data constraints, empirical studies on the pollution haven hypothesis analyze FDI flows by mainly looking at the data of developed countries. List and Co (2000) and Keller and Levinson (2002) both find evidence that increased environmental regulation is associated with lower FDI inflows into U.S. states. Analyzing FDI inflows into a developed country has the advantage of data availability while environmental regulations are known to differ across states (Manderson and Kneller, 2012).

As to the analyses of FDI inflows to non-developed countries, evidence to support the pollution haven hypothesis has been more mixed. For example, Waldkirch and Gopinath (2008) examine FDI inflows into Mexico and find a positive correlation between FDI and one of their measures of pollution (sulfur dioxide) although only for a few industries (in particular, those with large firms). In the case of other pollutants, and for other industries, the results suggest that environmental regulations enforcing a lower emission intensity may not necessarily deter FDI flows. Javorcik and Wei (2004) focus on FDI flows into Eastern Europe and the former Soviet Union. They find no systematic evidence that FDI from “dirtier” industries is more likely to go to countries with weak environmental regulations. Eskeland and Harrison (2003) find that abatement cost and pollution intensity do not affect FDI into Morocco, Côte d’Ivoire, Venezuela, and Mexico. The majority of the FDI inflows into these countries originated from the U.S. and France. They also find that foreign plants are significantly more energy efficient and use cleaner types of energy. Dean et al. (2009) examine FDI inflows into Chinese provinces and find an effect only for joint ventures in pollution intensive industries funded through Hong Kong, Macao, and Taiwan. Investment from OECD countries is attracted to regions with high pollution levies (which contradicts the prediction of the pollution haven hypothesis).

There are many hypothesis explaining why existing studies find little or no evidences for the pollution haven hypothesis. Eskeland and Harrison (2003) illustrate that the existing literature is primarily based on anecdotes and scattered case studies. Most of these studies make no attempt to control for other factors which may play a role in determining foreign investment, such as large protected markets. Levinson and Taylor (2004) suggest that many studies face problems such as unobserved heterogeneity, aggregation bias or possible endogeneity of proxies for environmental stringency that cause biased and counter-intuitive results. Ederington et al. (2005) indicate that the stringency of a country's environmental standards is only one, and perhaps not the most important, factor determining comparative advantage among countries. Some studies argue that expenditure associated with environmental regulations represents only a minor portion of total production cost. Hence, it is difficult to find evidence to support the pollution haven hypothesis.

According to the summary of the empirical results, I find that the studies analyzing FDI inflows into developed countries tend to provide more significant evidence than the studies analyzing FDI inflows into non-developed countries. I argue that this may be because FDI inflows from developed countries are usually accompanied by better pollution abatement technology. Since their technology can fit the stricter standards in their home countries, there is no reason for them to be concerned about the environmental regulatory stringency in other FDI locations, especially locations in developing countries.

The environmental awareness in Taiwan started to surge since the early 1990s. I believe that the tightening environmental regulatory stringency should influence manufacturing firms' FDI decisions and I investigate if this actually occurred using data covering the period of 2000 to 2003. In addition to avoiding aggregation bias, our data illustrates that firms from an emerging (non-developed) economy may act more like pollution haven seekers than those from developed countries.

There is a large literature on the determinants of FDI location choice, including market potential, wages, infrastructure, education, corruption, etc. The focus of this study is on the impact of environmental regulatory stringency on FDI location choice. To the best of our knowledge, this is the first paper applying the conditional logit model to the Taiwanese manufacturing firm-level data in this field.

The rest of the study is organized as follows. The empirical strategy is discussed in Section 3.2. The data and variables used are descripted in Section 3.3. Estimation results are discussed in Section 3.4. Section 3.5 concludes the study.

3.2 Discrete Choice Model for Location Choice of Taiwanese Multinationals

To investigate the impacts of environmental regulations on location choice of Taiwanese multinationals in different countries, I use the discrete choice model developed by McFadden (1974). The basic assumption of the discrete choice model is that the location chosen by a Taiwanese manufacturing firm must offer the highest profit over all other possible countries. Let π_{ijt} be the profit firm *i* derives from setting up a manufacturing operation in country *j* at time *t*. π_{ijt} is determined by a list of country *j's* characteristics at time *t-1*, X_{jt-1}, including the environmental regulatory stringency, and ε_{ijt} is a disturbance term:

$$\pi_{ijt} = \theta + \beta X_{jt-1} + \varepsilon_{ijt}$$

The probability of firm *i* locating in country *j* is given by:

$$\begin{aligned} P_i(j) &= \text{Prob}\{ \pi_{ijt} \geq \pi_{ikt} \} \text{ for all } k \neq j \\ &= \text{Prob}\{ \theta + \beta X_{jt-1} + \varepsilon_{ijt} \geq \theta + \beta X_{kt-1} + \varepsilon_{ikt} \} \text{ for all } k \neq j \\ &= \text{Prob}\{ \varepsilon_{ijt} - \varepsilon_{ikt} \geq \beta (X_{kt-1} - X_{jt-1})\} \text{ for all } k \neq j \end{aligned}$$

McFadden (1974) shows that, if and only if ε_{ijt} follows Type I extreme distribution, $P_i(j)$ can be further simplified to the following logit expression:

$$P_i(j) = \frac{Exp\ (\beta X_{jt-1})}{\sum_{k \in K} Exp\ (\beta X_{jt-1})}$$

Where *K* is the set of location choices faced by firm *i*. It can then be estimated by the conditional logit method, which has been used extensively in the FDI location literature (e.g. Coughlin et al. 1991; Head et al., 1995). The conditional logit method estimates how each country's characteristic increases or decreases the chances that a region will be chosen rather than all other potential countries available for choice. Since the dependent variable of conditional logit model depends on the profit the investor gets investing into a particular region, the set of explanatory variables is assumed to affect two basic factors which influence profit: the revenues accrued and costs borne by the investors.

3.3 Data and Variables

The Taiwanese FDI data is collected from the annual surveys on outward foreign direct investment conducted by the Ministry of Economic Affairs (MOEA), in Taiwan. According to the statistics on outward investment reported by the Investment Commission of MOEA, the average amount of outward investment had rapidly increased at the rate of 41% per year in the period from 1991 to 2004. This study employs firm-level data in the manufacturing sector from 2000 to 2003[19] of the period. To eliminate the disturbance caused by the stylized fact that small firms may not have capability to allocate their production across nations, I focus on establishments with more than 30 employees and sales of more than 3 million of New Taiwan dollars.

The dependent variable for our analysis is the location choice by the Taiwanese manufacturing firms during the sample period of 2000 to 2003. There are 1,076 firms and 1,677 cases of outward investments in eight countries included in this study. Those countries are USA, China, Japan, Malaysia, Singapore, Thailand, Indonesia, and Philippines. So, this produces a total of 13,416 observations (=1,677 investments times 8 location choices) in this conditional logit estimation.

The host country's characteristics has been selected according to the existing literature on location choices of FDI and data availability. In particular, I control for trade openness, market size, wage, infrastructure, education background, corruption, and environmental regulatory stringency in the host countries. Those country-level data are sourced mainly from the World Bank (World Development Indicators; WDI). Additionally, the education variable is collected from Barro and Lee's study (Barro and Lee, 2010); the corruption variable is collected from Transparency International; environmental regulatory stringency variable is collected from

[19] Excluding data from 2001 when the quinquennial Industrial and Commercial Census is conducted.

World Economic Forum. Next, I address the economic intuition for those explanatory variables in terms of FDI location choice.

Trade Openness

Brainard (1997) indicates that there are factors (other than intangible assets and factor prices) which make it desirable to locate near the target market. These factors include tariff barriers and transport costs. It is a synthesized consideration of trading off between the benefit of concentrating production in one location (e.g. scale economy) and the advantage of accessing the target market. In our location choice model, the trade barriers would increase the advantage of accessing the target market among the alternatives. Thus, I use a conventional measure of trade openness (i.e. total import and export divided by total GDP) to proxy the trade barriers of host countries. I expect the lower trade openness (i.e. higher trade barriers) would increase the opportunity of location choice to the host country.

Market Size

Larger sales would allow multinationals to recover the fixed set-up cost of foreign production (Basile et al., 2008; Ledyaeva 2009). So that, bigger market size should make multinationals' location more profitable. I introduce total GDP to measure the market potential.

Wage

Low production costs mainly reflected in low wage bills are widely regarded as a feature of Taiwanese manufacturing firms. Such that, wage rate is expected to be an important consideration to their FDI location choices. Previous studies (e.g. Bartik, 1985; Coughlin et al., 1991; Luger and Shetty, 1985; Little, 1978) provide some evidence that higher wage rates deter FDI in the U.S. cases. So, to investigate how the differentiation in wage rates affects FDI location choice of Taiwanese manufacturing firms, I include GDP per capita in current US dollar as the measure of host country's wage level in our regression model.

Infrastructure

It is widely reported in the literature that regions with superior infrastructure are more appealing to multinationals. Especially for the manufacturing sector, better transport networks increase productivity and reduce costs. Moreover, the transport system can support the country's integration into world markets (Donaubauer et al., 2014). I introduce the registered carrier departures in a country normalized by population to our regression model to estimate the transport infrastructures.

Education Background

I expect that better educated labor force would increase productivity and thus profitability of a firm's activities in a given region (Du et al., 2008; Coughlin et al., 1991, etc.). That is, the impact of population's educational background on location choice should be positive. Education background variable is measured by the percentage of complete tertiary schooling attained in population. The data is obtained from Barro and Lee's study (Barro and Lee, 2010) on educational attainment in the world. The data is built up at five years intervals from 1950 to 2010. So, the values for this variable are invariant during every five year intervals.

Corruption

The influence of corruption on FDI is suggested due to the supply-side impact on the level of public goods provided. The supporters of such hypothesis presume that foreign capital is attracted to locations with greater public funds. More widespread corruption reduces capital inflow through the theft of such funds (Wheeler and Mody, 1992; Hines, 1995; Wei, 2000; Fredriksson et al., 2003). Following the suggestions of Fredriksson et al. (2003), the corruption is also included in the regression model to explain the effects of corruption on FDI location choice. I use Corruption Perception Index (CPI)[20] to measure the corruption level of host country. The index values are ranked from 1 to 10. A higher value represents more transparent bureaucracy in host country.

[20] Data obtained from Transparency International : http://www.transparency.org/research/cpi/cpi_1999/0/

Environmental Regulatory Stringency

Environmental regulation stringency is regarded as an important factor to FDI location choice, especially to heavy polluting manufacturing industries, due to higher expenditure induced by environmental regulations. I introduce a variable, *environmental regulatory stringency*, to measure host country's overall environmental regulatory stringency. The variable is collected from World Economic Forum's Environmental Sustainability Index (ESI) survey in year 2001[21]. The survey questions ask about whether environmental regulations are among the world's most stringent. Survey Responses are ranged from 1 (Strongly Disagree) to 7 (Strongly Agree). A higher value presents more stringency of environmental regulations. I use this variable to measure the magnitude of environmental regulation stringency associated with firms' environmental expenditure in host country.

Due to our FDI dataset only covers the period from 2000 to 2003, I presume that the environmental regulatory stringency would not notably fluctuate during a short period[22]. So, this variable in our regression model is time invariant.

3.4 Empirical Results

To investigate the effects of various determinants of FDI on the location choice of Taiwanese manufacturing firms, I use the discrete choice model developed by McFadden (1974). I analyze the importance of seven determinants suggested by the literature – trade openness, market size, wage, infrastructure, education, corruption, and environmental regulatory stringency. Table 3.2 presents our main results when regressions are using the sample during the periods of 2000, 2002, and 2003[23].

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[21] The variable name in 2001 Environmental Sustainability Index is "Stringency and Consistency of Environmental Regulations". The original survey data is ranked from 1 (Strongly Disagree) to 7 (Strongly Agree). Here in our study it is presented in a standardized form as Z-score.

[22] Moreover, most regulatory stringency indices at the country level are cross-sectional estimates. The cross-sectional indices in different years are incomparable because (1) many of the survey questions have changed over time and (2) an index only ranks the order among countries at a given time point or period that does not address the dynamic of stringency magnitude (Brunel and Levinson, 2013).

[23] Due to the most of Taiwanese outward investments flow into China both in cases and amounts, I also exclude the cases of investing in China and weight individual investment choice with its investment amount to check the robustness of our estimations. The results do not change the conclusions to the impacts of *Environmental regulatory stringency*.

The explanatory variables, *trade openness, market size, wage, infrastructure, education background*, and *corruption*, all demonstrate results consistent with theoretical predictions and existing findings in the literature. Trade openness has positive coefficients for all specification models with statistical significance level of 1%. This result shows that trade barriers enhance the importance of proximity to target markets. Larger market, lower wage rate, superior infrastructure, and education are also significant characteristics that attract Taiwanese manufacturing firms. Positive coefficients on the corruption index indicate that Taiwanese manufacturing firms prefer to invest in countries with more transparent bureaucracy. However, the statistical significance is weak even though the estimates are consistent with the theoretical predictions.

Environmental regulatory stringency has a significantly negative coefficient in all specification models, which shows Taiwanese manufacturing firms prefer to invest in countries with less environmental regulatory stringency. While I want to examine whether firms with higher domestic environmental expenditures are relatively more attracted to host countries with weak environmental regulations (i.e. pollution haven hypothesis), I add an interactive terms to the models. *Env* in Table 3.2, model (2) stands for firm's environmental protection expenditure in Taiwan. A positive coefficient of its interactive term with host country's environmental regulatory stringency index, on the contrary, shows that firms with higher environmental expenditure are relatively less attracted to host countries with weak environmental regulations. Hence, the positive coefficient does not suggest that the firms with higher environmental expenditure are attracted to host countries with stricter environmental regulations because the overall effect of host country's *Environmental regulatory stringency* remain negative. It just illustrates that they would be relatively less attracted to weak environmental regulations, compared to firms with lower environmental expenditure.

When I use both environmental protection expenditure (model (2))and classification of polluting and non-polluting firms[24] (*Pindu* in model (3)) to capture the variation of firm's environmental expenditure in Taiwan, I still obtain no statistically significant conclusion for the pollution haven hypothesis. In model (4), I control for the invested industries with a dummy

[24] According to the definition proposed by the World Bank (Nicita and Olarreaga, 2006), the following industries are classified as heavy polluters: pulp, paper and paper products, chemical material, chemical products, petroleum and coal product, non-metallic mineral products and basic metal industries.

variable (*Piindu*) to identify whether the invested industries belong to polluting or non-polluting industries. With this model specification, I are able to confirm that firms with higher environmental expenditure are relatively less attracted to host countries with weak environmental regulations, which encounters the pollution haven hypothesis. On other hand, I do not obtain strong evidence to prove that firms are more attracted to host countries with weak environmental regulations when they invest in polluting industries.

In model (5), I use three dummy variables to identify four groups. Their interactive terms with host country's *Environmental regulatory stringency* specify the differential effects of *Environmental regulatory stringency* on these four groups. *D1* equals to one if firm in Taiwan belongs to non-polluting industry and invests in polluting industry in host country. *D2* equals to one if firm in Taiwan belongs to polluting industry and invests in non-polluting industry in host country. D3 equals to one if firm in Taiwan belongs to polluting industry and invests in polluting industry in host country. When all three dummy variables equal to zeroes, the coefficient of *Environmental regulatory stringency* estimates for the marginal effect for firms that belong to non-polluting industry in Taiwan and invest in non-polluting industry in the host country, which is a large part of our sample.

The negative coefficient on *D1* Environmental regulatory stringency* indicates that non-polluting firms investing in polluting industries look for less environmental regulatory stringency the most. Non-polluting firms investing in non-polluting industries take the second and polluting firms investing in polluting industries take the third. Polluting firms investing in non-polluting industries are significantly less attracted to host countries with weak environmental regulations.

According to the magnitudes of marginal effects of *Environmental regulatory stringency* among the subsamples, our empirical results imply that the "know-how" of pollution abatement dominates the pollution haven effect in Taiwanese FDI location choices. Taiwanese government began to execute stricter environmental statues and upgrade the effectiveness of environmental supervision since the early 1990s. I argue that polluting haven effect may dominate at the very beginning, but did not persistently maintain its dominancy. This may be because the pollution haven seekers gradually left the Taiwanese market. Those firms staying in the market are those that can put more resources to pursue cleaner technology. So that, the average environment-friendly technology level rises and the pollution haven effect decreases.

3.5 Conclusion

I empirically analyze the determinants of Taiwanese manufacturing firms' FDI location choice. The sample data includes 1,677 investment deals in 8 countries during the period from 2000 to 2003. For the conventional determinants of FDI, I find that manufacturing firms tend to invest in countries that have higher trade barriers, larger market size, lower wage rate, superior infrastructure, and higher educational attainment. The measure for corruption level is not significant in the conditional logit estimations.

This paper focuses the importance of environmental regulatory stringency. The empirical results show that Taiwanese manufacturing firms, on average, tend to invest in countries with less stringent environmental regulations. I do not, however, find evidence that firms in pollution-intensive industries have stronger tendency to invest in countries with less strict environmental regulations than do firms in other industries.

I argue that environmental protection expenditures may have two opposite effects on firms' FDI location choice. One is the so called "pollution haven effect", which suggests firms with higher environmental protection expenditures would have stronger incentives to look for locales with lower environmental regulatory stringency. On the other hand, firms with higher environmental protection expenditure are also equipped with better pollution abatement knowledge and technologies than are firms with lower environmental protection expenditure, and this may offset the pollution haven effect. This may help explain why many previous studies find no evidence to support the pollution haven hypothesis.

Table 3.1 : Variable Definition and Basic Statistics

Variables	Definition	Observations	Means	S.D.	Min	Max
Trade Openness	trade openness measured by percentage of imports and exports of goods and services in GDP.	24	115.0393	107.5318	18.75639	354.278
Market Size	market size measured by GDP in current US $.	24	2.06e+12	3.51e+12	7.63e+10	1.10e+13
Wage	wage level measured by GDP per capita in current US $.	24	12505.18	14819.51	679.7936	38165.99
Infrastructure	registered carrier departures in a country normalized by population.	24	.0078584	.0099667	.0004373	.0305024
Education	percentage of complete tertiary schooling attained in population.	24	11.38333	9.026033	1.1	26.4
Corruption	corruption perception index.	24	5.008333	2.485596	1.7	9.3
Environmental Regulatory Stringency	environmental regulatory stringency index.	24	-.12	1.156404	-1.3	1.37
Env	environmental protection expenditure	1,677	2,227.46	15,112.88	0.01	358,427

Note: The statistics of host country's characteristics are based on the 8 countries' data during the period (1999, 2001, and 2002) which is one year lagged to FDI location choice (2000, 2002, 2003). The host countries (areas) include USA, China, Japan, Malaysia, Singapore, Thailand, Indonesia, and Philippines. Due to data availability, the variable *Environmental Regulatory Stringency* is time invariant during the sample period.

Table 3.2 : Conditional logit estimation of FDI location choice decision of Taiwanese manufacturing firms

Indep. Variables	(1)	(2)	(3)	(4)	(5)
Trade Openness	-0.0368** (-2.32)	-0.0366** (-2.31)	-0.0368** (-2.32)	-0.0368** (-2.32)	-0.0368** (-2.32)
Market Size	3.85e-12*** (3.98)	3.85e-12*** (3.98)	3.85e-12*** (3.98)	3.85e-12*** (3.98)	3.85e-12*** (3.98)
Wage	-0.000415* (-1.69)	-0.000411* (-1.68)	-0.000415* (-1.69)	-0.000412* (-1.68)	-0.000412* (-1.68)
Infrastructure (air transportation capability)	368.8** (2.40)	373.3** (2.43)	367.7** (2.40)	364.7** (2.37)	364.6** (2.37)
Education	0.784*** (3.51)	0.782*** (3.50)	0.784*** (3.51)	0.783*** (3.51)	0.783*** (3.51)
Corruption	0.257 (0.57)	0.262 (0.58)	0.258 (0.57)	0.263 (0.59)	0.263 (0.59)
Environmental Regulatory Stringency	-21.56*** (-3.26)	-21.64*** (-3.28)	-21.57*** (-3.26)	-21.55*** (-3.26)	-21.55*** (-3.26)
*Env*Environmental Regulatory Stringency*		0.00000184 (1.18)			
*Pindu*Environmental Regulatory Stringency*			0.112 (1.37)	0.206** (2.05)	
*Piindu*Environmental Regulatory Stringency*				-0.189 (-1.57)	
*D1*Environmental Regulatory Stringency*					-0.207 (-0.96)
*D2*Environmental Regulatory Stringency*					0.202* (1.80)
*D3*Environmental Regulatory Stringency*					0.0206 (0.19)

Table 3.2 : Continued

Number of Observations	13,416	13,416	13,416	13,416	13,416
Pseudo R^2	0.6077	0.6079	0.6080	0.6083	0.6084

Note: *, **, *** indicate significance at the 10%, 5%, and 1%.
Values in parentheses are t-values.
The sample data includes 1,677 outward investment cases in 8 countries, i.e. 1677*8 observations.
All models include host country dummy variables and control for robust variance.
Due to the most of Taiwanese outward investments flow into China both in cases and amounts, I also exclude the cases of investing in China and weight individual investment choice with its investment amount to check the robustness of our estimations. The results do not change the conclusions to the impacts of *Environmental regulatory stringency*.

Conclusion

To test the Pollution Haven Hypothesis, previous studies use data on trade flows from developed countries due to the lack of environmental regulation data in developing countries. These studies typically consider trade flows for a single country. Some find empirical support for the pollution haven effect, but often they do not find the same effects on the country's trading partners so as to support the pollution haven hypothesis. In addition, a sizable empirical literature has developed that analyses investment flows (FDI) in search of evidence for the pollution haven hypothesis. Even though little evidence has been found to date to support the hypothesis, the focus of the literature has predominately been on the FDI from developed countries to non-developed countries. Only a handful of studies consider FDI from non-developed countries. This study starts with a cross-country analysis of trade flows in the first chapter. The empirical results allow us to come to conclusions about pollution-intensive production relocation that are more general, unlike a case study on a specific economy. In Chapter 2 and Chapter 3, I use firm-level data on FDI from the Taiwanese manufacturing sector to examine whether PHH holds by using different empirical models.

In Chapter 1, *Pollution Haven Hypothesis: Evidence from Trade Flows in the Manufacturing Sector*, I estimate a two-way error components regression model to analyze trade flows and changes in output composition in the most polluting manufacturing industries across many countries. The empirical results suggest that environmental regulatory stringency decreases net export and production share of the most polluting industries, which provides evidence for the pollution haven hypothesis. However, when I examine the interaction between environmental regulatory stringency and trade openness, I find that high income countries with high regulatory stringency do not lose their comparative advantage in pollution-intensive sectors as trade openness grows.

In Chapter 2 of this study, I use Taiwanese manufacturing firm-level data and contribute to the literature on PHH that focuses on FDI flows from non-developed countries. In that Chapter, a least squares dummy variable (LSDV) model is employed to analyze firm's outward FDI. In the regression model, FDI is determined by the firm's characteristic and the host country's traits and policies, including the firm's environmental protection expenditure in Taiwan and the host country's environmental stringency. The empirical results suggest that firms in less pollution-intensive industries are more likely to be pollution haven seekers. In addition, firms with higher domestic expenditure on environmental protection tend to invest more in countries with stricter environmental regulations.

In Chapter 3, I use a location choice model (conditional logit regression) developed by McFadden (1974) to examine whether environmental regulatory stringency influences the location choice of FDI. The results are consistent with the conclusions suggested by the LSDV model in Chapter 2. I find that firms in polluting industries are relatively less attracted to the countries with weak environmental regulatory stringency.

Using both cross-country evidence on trade and production as well as firm-level data on FDI from the Taiwanese manufacturing sector, this dissertation furthers our understanding of the pollution haven hypothesis. I uncover some evidence in favor of the hypothesis. Consistent with the findings in a large number of previous studies, I also find trade and FDI behavior that is contradictory to PHH. Finally, I offer some plausible reasons for the conflicting evidence from Taiwan.

REFERENCES

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

Barro, R. and J.W. Lee. April 2010. "A New Data Set of Educational Attainment in the World, 1950-2010." *Journal of Development Economics*, 104, 184-198.

Bartik, T.J. Januray 1985. "Business Location Decisions in the United States: Estimates of the Effects of Unionization, Taxes, and Other Characteristics of States." *Journal of Business and Economic Statistics*, 3, 14-22.

Basile, R., D. Castellani, and A. Zanfei. 2008. "Location Choices of Multinational Firms in Europe: The role of EU cohesion policy." *Journal of international economics*, 74, 328-340.

Brainard, S.L. 1993. "An Empirical Assessment of the Factor Proportions Explanation of Multinational Sales." National Bureau of Economic Research Working Paper Number 4583.

Brainard, S.L. September 1997. "An Empirical Assessment of the Proximity-Concentration Trade-Off between Multinational Sales and Trade." *The American Economic Review*, 87 (4):520– 544.

Brunel, C. and A. Levinson. May 2013. "Measuring Environmental Regulatory Stringency." OECD Trade and Environment Working Papers.

Cole, M.A., and R.J.R. Elliott. 2003. "Determining the Trade–Environment Composition Effect: the Role of Capital, Labor and Environmental Regulations." *Journal of Environmental Economics and Management*, 46, 363–383.

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

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

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

Coughlin, C.C., J.V. Terza, and V. Arromdee. 1991. "State Characteristics and the Location of Foreign Direct Investment within the United States." *Review of Economics and Statistics*, 73, 675–683.

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

Dasgupta, S., D Wheeler, S. Roy, and A. Mody. 2001. “Environmental Regulation and Development: A Cross-Country Empirical Analysis.” *Oxford Development Studies*, 29(2), 173-87.

Dean, J.M., M.E. Lovely, and H. Wang. 2009. “Are Foreign Investors Attracted to Weak Environmental Regulations? Evaluating the evidence from China.” *Journal of Development Economics*, *90*(1), 1-13.

Donaubauer, J., B. Meyer, and P. Nunnenkamp. June 2014. “A New Global Index of Infrastructure: Construction, Rankings and Applications.” Kiel Working Paper No. 1929.

Ederington, J., A. Levinson, and J. Minier. 2004. “Trade Liberalization and Pollution Havens.” *Advances in Economic Analysis and Policy*, 4(2).

Ederington, J., A. Levinson, and J. Minier. 2005. “Footloose and Pollution-Free.” *The Review of Economics and Statistics*, *87*(1), 92-99.

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

Esty, D.C. and M.E. Porter. 2005. “National Environmental Performance: An Empirical Analysis of Policy Results and Determinants.” *Environment and Development Economics*, 10: 391–434.

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

Fredriksson, P.G., J.A. List, and D.L. Millimet. 2003. “Bureaucratic Corruption, Environmental Policy and Inbound US FDI：Theory and Evidence.” *Journal of Public Economics*, *87,* 1407-1430.

Head, K., J. Ries, and D. Swenson. 1995. “Agglomeration Benefits and Location Choice: Evidence from Japanese Manufacturing Investments in the United States.” *Journal of International Economics*, 38, 223–247.

Hettige, H., P. Martin, M. Singh, and D. Wheeler. 1994. “The Industrial Pollution Projection System.” Environment, Infrastructure and Agriculture Division (PRDEI) of the Policy Research Department (Washington, D.C: World Bank).

Hines, Jr. J. 1995. “Forbidden Payment: Foreign Bribery and American Business After 1977.” NBER Working Paper 5266. National Bureau of Economic Research, Cambridge.

Hoffmann, R., C.G. Lee, B. Ramasamy, and M. Yeung. 2005. “FDI and Pollution: Granger Causality Test Using Panel Data.” *Journal of International Development*, 17, 311–317.

Hamamoto, M. 2006. “Environmental Regulation and the Productivity of Japanese Manufacturing Industries.” *Resource and Energy Economics*, 28, 299–312.

Jaffe, A. B. and K. Palmer. Nov. 1997. “Environmental Regulation and Innovation: A Panel Data Study.” *The Review of Economics and Statistics*, 79 (4):610-619.

Javorcik, B.S. and S.J. Wei. 2004. “Pollution Havens and Foreign Direct Investment: Dirty Secret or Popular Myth?” *The Economics of Pollution Havens*, *4*(2), Article 8, 277-309.

Kalamova, M. and N. Johnstone. 2011. “Environmental Policy Stringency and Foreign Direct Investment.” OECD Environment Working Papers, No. 33.

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

Keller, W. and A. Levinson. 2002. “Pollution Abatement Costs and Foreign Direct Investment Inflows to U.S. States.” *The Review of Economics and Statistics*, *84*(4), 691-703.

Kim, M.H. and N. Adilov. 2012. “The Lesser of Two Evils: An Empirical Investigation of Foreign Direct Investment-Pollution Tradeoff.” *Applied Economics*, 44(20), 2597-2606.

Ledyaeva, S. 2009. “Spatial Econometric Analysis of Foreign Direct Investment Determinants in Russian Regions.” *The World Economy*, 32(4):643-666.

Levinson, A. and M.S. Taylor. 2008. “Unmasking The Pollution Haven Effect.” *International Economic Review*, 49(1).

List, J.A. and C.Y. Co. 2000. “The Effect of Environmental Regulations on Foreign Direct Investment.” *Journal of Environmental Economics and Management*, *40*, 1-20.

Little, J.S. July/Aug. 1978. “Locational Decisions of Foreign Direct Investors in the United States.” *New England Economic Review*, 43-63.

Luger, M.I., and S. Shetty. 1985. “Determinants of Foreign Plant Start-Ups in the United States: Lessons for Policy Makers in the Southeast.” *Vanderbilt Journal of Transnational Law*, 18, 223-245.

Managi, S., A. Hibiki, and T. Tsurumi. 2009. “Does Trade Openness Improve Environmental Quality?” *Journal of Environmental Economics and Management*, 58, 346-363.

Manderson M. and R. Kneller. 2012. “Environmental Regulations, Outward FDI and Heterogeneous Firms: Are Countries Used as Pollution Havens?” *Environmental and Resource Economics*, 51(3), 317–352.

McFadden, D. 1974. “Conditional Logit Analysis of Qualitative Choice Behavior.” In: Zarembka, Paul (Ed.), Frontiers in Econometrics. Academic Press, New York, pp. 105–142.

McGuire, M. 1982. “Regulation, Factor Rewards, and International Trade.” *Journal of Public Economics*, 17(3), 335 - 354.

Porter, M.E. and C. van der Linde. 1995. “Toward a New Conception of the Environment-Competitiveness Relationship.” *The Journal of Economic Perspectives*, 9(4), 97-118.

Mulatu, A., R. Gerlagh, and D. Rigby. 2010. ”Environmental Regulation and Industry Location in Europe.” *Environmental Resource Economics*, 45, 459-479.

Nicita, A. and M. Olarreaga. 2006. “Trade, Production and Protection 1976-2004.” *The World Bank Economic Review*.

Taylor, M.S. 2004. “Unbundling the Pollution Haven Hypothesis.” *Advances in Economic Analysis and Policy*, *4*(2).

Timmins, C. and U. Wagner. 2009. “Agglomeration Effects in Foreign Direct Investment and the Pollution Haven Hypothesis.” *Environmental and Resource Economics*, 43(2):231-256.

Waldkirch, A. and M. Gopinath. 2008. “Pollution Control and Foreign Direct Investment in Mexico: An Industry-Level Analysis.” *Environmental and Resource Economics, 41*(3), 289-313.

Wei, S.J. 2000. “How Taxing is Corruption on International Investors?” *The Review of Economics and Statistics*, 82, 1–11.

Wheeler, D., and A. Mody. 1992. “International Investment Location Decisions: The Case of US Firms.” *Journal of International Economics*, 33, 57–76.

Xing, Y. and C.D. Kolstad. 1998. “Environment and Trade: A Review of Theory and Issues.” Working Paper No. 28-98, University of California Santa Barbara.

Xing, Y. and C.D. Kolstad. 2002. “Do Lax Environmental Regulations Attract Foreign Investment?” *Environmental and Resource Economics*, 21, 1–22.

Yang, C.H., Y.H. Tseng, and C.P. Chen. 2012. “Environmental Regulations, Induced R&D, and Productivity: Evidence from Taiwan’s manufacturing Industries.” *Resource and Energy Economics*, 34, 514-532.

Zarsky, L. 1999. “Havens, Halos and Spaghetti: Untangling the Evidence about Foreign Direct Investment and the Environment.” (Background document, OECD Conference on FDI and the Environment). Paris: Organization for Economic Cooperation and Development.

APPENDICES

Appendix A: List of the Countries

Developed Countries	Non-Developed
North America	**Latin America**
Canada	Argentina
United States	Chile
Asia	Colombia
Japan	Ecuador
Europe	Peru
Austria	Uruguay
Denmark	Venezuela
Finland	**Asia**
Italy	India
Norway	Korea
Spain	Malaysia
Sweden	Pakistan
United Kingdom	Philippines
Middle East	**Middle East**
Israel	Iran
Oceania	Turkey
Australia	**Europe**
	Greece
	Africa
	Egypt
	South Africa

Note:The criterion is based on the World Bank Classifications standards in 1990.
Developed countries are defined as high income countries with GNI per capita over 7,620 USD.

Appendix B: Categorization of Environment-related Technologies, cited from OECD, Indicator of Environmental Technologies.

A. GENERAL ENVIRONMENTAL MANAGEMENT

- Air pollution abatement (from stationary sources)
- Water pollution abatement
- Waste management
  - Solid waste collection
  - Material recycling
  - Fertilizers from waste
  - Incineration and energy recovery
  - Landfilling
  - Not elsewhere classified
- Soil remediation
- Environmental monitoring

B. ENERGY GENERATION FROM RENEWABLE AND NON-FOSSIL SOURCES

- Renewable energy generation
  - Wind energy
  - Solar thermal energy
  - Solar photovoltaic (PV) energy
  - Solar thermal-PV hybrids
  - Geothermal energy
  - Marine energy (excluding tidal)
  - Hydro energy - tidal, stream or damless
  - Hydro energy - conventional
- Energy generation from fuels of non-fossil origin
  - Biofuels
  - Fuel from waste (e.g. methane)

C. COMBUSTION TECHNOLOGIES WITH MITIGATION POTENTIAL (e.g. using fossil fuels, biomass, waste, etc.)

- Technologies for improved output efficiency (Combined combustion)
  - Heat utilization in combustion or incineration of waste
  - Combined heat and power (CHP)
  - Combined cycles (incl. CCPP, CCGT, IGCC, IGCC+CCS)
- Technologies for improved input efficiency (Efficient combustion or heat usage)

D. TECHNOLOGIES SPECIFIC TO CLIMATE CHANGE MITIGATION

- Capture, storage, sequestration or disposal of greenhouse gases
  - CO2 capture and storage (CCS)
  - Capture or disposal of greenhouse gases other than carbon dioxide (N2O, CH4, PFC, HFC, SF6)

E. TECHNOLOGIES WITH POTENTIAL OR INDIRECT CONTRIBUTION TO EMISSIONS MITIGATION

- Energy storage
- Hydrogen production (from non-carbon sources), distribution, and storage
- Fuel cells

Appendix B: Continued

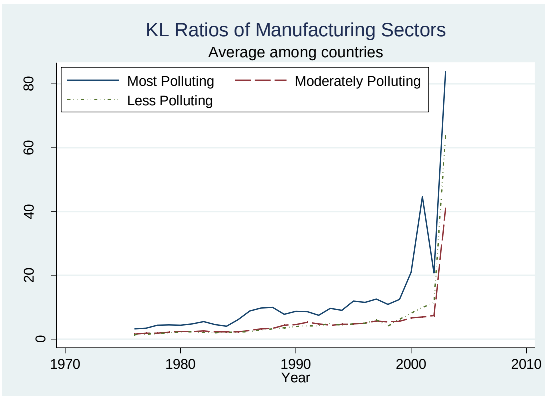
F. EMISSIONS ABATEMENT AND FUEL EFFICIENCY IN TRANSPORTATION

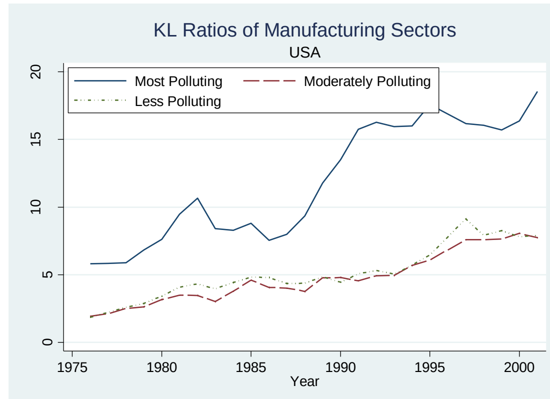
- Technologies specific to propulsion using internal combustion engine (ICE) (e.g. conventional petrol/diesel vehicle, hybrid vehicle with ICE)
    - Integrated emissions control (NOX, CO, HC, PM)
    - Post-combustion emissions control (NOX, CO, HC, PM)
- Technologies specific to propulsion using electric motor (e.g. electric vehicle, hybrid vehicle)
- Technologies specific to hybrid propulsion (e.g. hybrid vehicle propelled by electric motor and internal combustion engine)
- Fuel efficiency-improving vehicle design (e.g. streamlining)

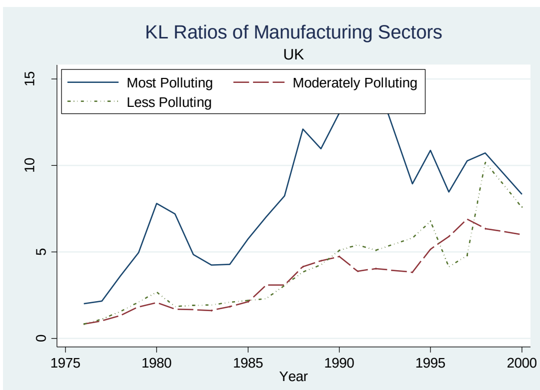
G. ENERGY EFFICIENCY IN BUILDINGS AND LIGHTING

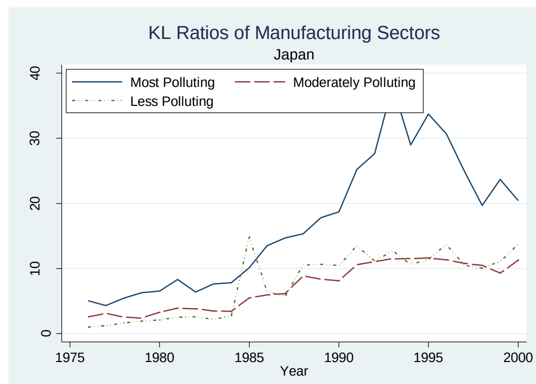
- Insulation (incl. thermal insulation, double-glazing)
- Heating (incl. water and space heating; air-conditioning)
- Lighting (incl. CFL, LED)

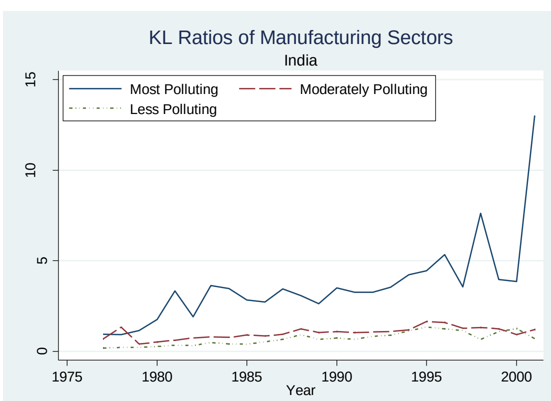
Appendix C: Industrial Average KL over Time for Individual Countries and for Over All Countries**.**

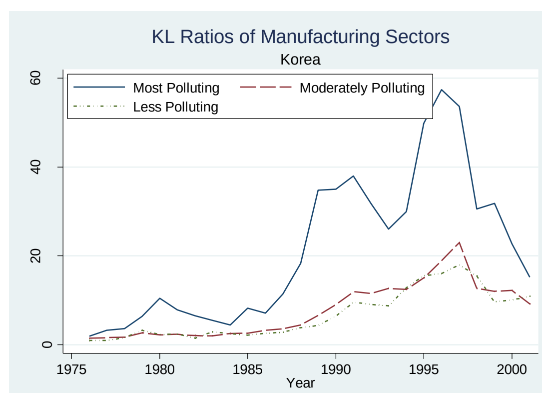




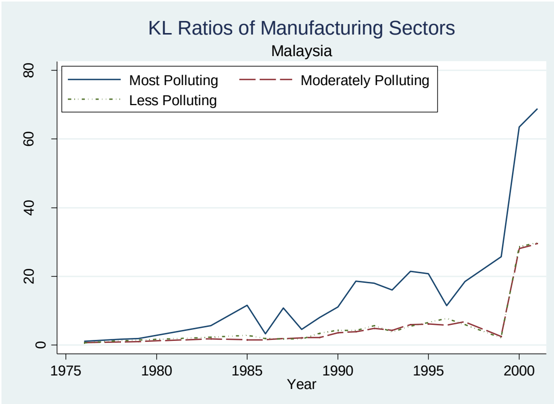


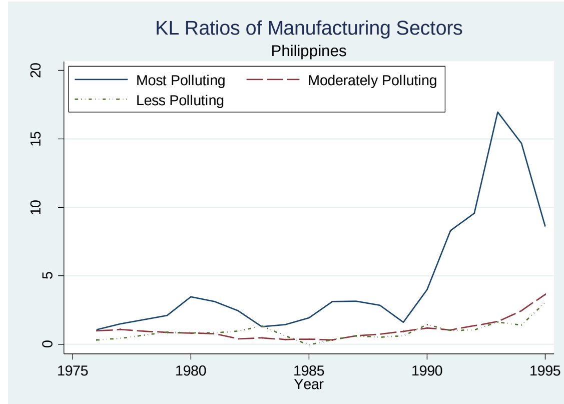


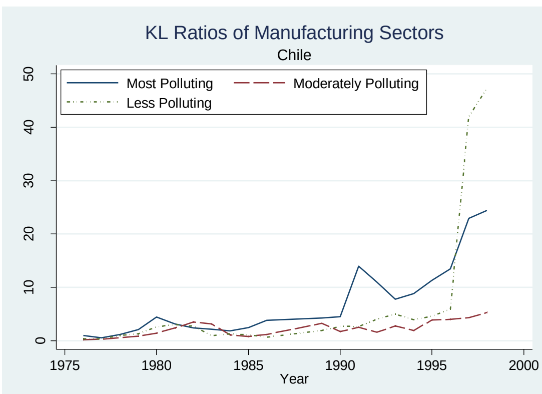


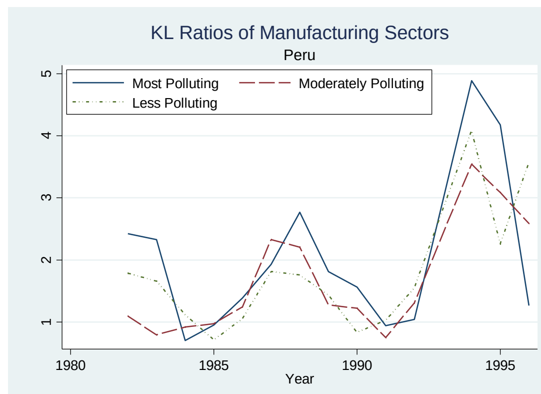


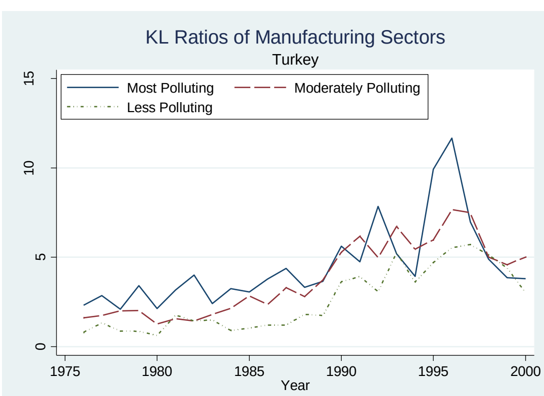
Appendix C: Continued

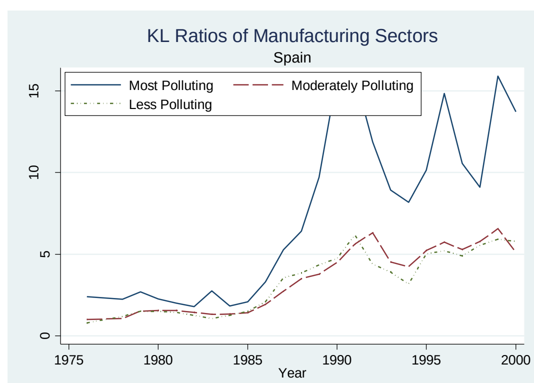












Appendix D: Empirical literature review of PHH

Table 1: Empirical studies on PHH / PHE via HECKSCHER–OHLIN theory and/or Gravity model without controlling trade barrier or exposure to international competition

Study	Dependent	Measurement of Regulation Stringency	# of countries / year periods	Notes / Results
Tobey (1990)	Net exports (of five industries) (HOV model)	1976 UNCTAD survey index (1~7)	23 / 1975	No significant PHE. Not support PHH. Individually regress each industry on the country endowments.
Lu (2009)	Net exports of five industries (HOV model)	CIESIN(2005), GNI per ca	95, 42 / 2005	Control the industrial heterogeneity by individually regress each industry.
Mangee et al. (2010)	Bilateral Trade (Gravity model)	ERRI from GCE, ESI, World Bank	39 / 1999	Embed comparative advantage concept in gravity model. The empirical results are kind of blurred to connect to race-to-the-bottom and PHH.
Grether et al. (2011)	Bilateral pollution content of imports (PCI)	relative lead content per gallon of gasoline	48 / 1987 (10 pollutants, 79 industries)	Compare to other determinants, capital abundance and environmental stringency have only marginally affected the PCI at the late 80’s.

Appendix D: Empirical literature review of PHH

Table 2: Empirical studies on PHH / PHE via the theory and/or Gravity model under controlling trade barrier or exposure to international competition

Study	Dependent	Measurement of Regulation Stringency	# of countries / year periods	Notes / Results
Beers et al. (1997)	Bilateral Trade (Gravity model)	composite index compiled from OECD data	30 / 1992, 1975	Three estimations for (1) total bilateral trade; (2) bilateral trade in pollution-intensive industries; (3) bilateral trade in pollution-intensive and foot-loose (non-resource based) industries. Two dummy variables to control trade barrier (EU Community member and EFTA member)
Ederington et al (2003)	U.S. industrial net imports and environmental regulation	the proportion of total direct cost (from PACE survey)	1 / 1978-92	two equations simultaneously specify PHE and race-to-the-bottom hypothesis
Kahn & Yoshino (2004)	Bilateral Trade (Gravity model)	GDP per ca	128 / 1980-97 (34 manufacturing industries)	trade barrier is controlled by a dummy of regional trade agreement (RTA)
Mulatu et al. (2004)	net export of industry i at time t in country c (Germany, Netherlands, U.S.)	PACE (pollution abatement capital expenditure)	3/1977-1992	Regressions for individual countries. PHE exists, but not examine for PHH
Ederington et al (2004)	industrial imports of U.S.	industrial pollution abatement operating cost	1/ 1978-1994	industrial imports are determined by industrial abatement cost (PHE), tariff, and their interaction(PHH); and other industrial characteristics
Ederington et al (2005)	industrial imports of U.S.	industrial pollution abatement operating cost	1/1978-1992	The marginal effect of PHE may be offset by other factors that make the relocations immobile.
Levinson & Taylor (2008)(manuscript in 2003)	U.S. industrial net imports from Canada and Mexico	industrial pollution abatement operating cost (PAOC)	1/1977-1986	A model demonstrates how heterogeneity, endogeneity, and aggregation bias the estimation. The empirical results support PHE.

Table 2: Continued

Mulatu et al (2010)	Relative size of industry i across countries. (16 industries)	Environmental Sustainability Index	13 / ave of 1990-1994	Johnson-Neyman technique, regress the dependant on the interactions of industry and country characteristics.

Appendix E: The Empirical Results for using country-level gross capital formation (flow) divided by labor force as the KL ratio

Table 1: The determinants of the export of most polluting industries (dependent variable = export value of most polluting industries / export value of total manufacturing industries)

Variables	Model (1)	Model (2)	Model (3)	Model (4)
KL	.0012551	.0012765	.0056457	.1187744***
KL^2			.0079212***	-.0006441
I	-.0017242	-.0024663	-.0548644***	-.1151713***
I^2			.0030417***	.0025684
INNOV	-.3486106	-.3115395	2.104913**	3.310647**
$INNOV^2$			-6.30217*	-7.306443*
KL*I			-.0076737**	-.0021521
KL*INNOV			.1947353	.0511099
I*INNOV			-.0913858	-.0815221
O		-.0007342	-.0013399	.0006567
O*RKL				-.0048329***
$O*RKL^2$				.0009191
O*RI				.00505*
$O*RI^2$				.0004326
O* RINNOV				-.0007549
$O* RINNOV^2$				.0000373
O*RKL*RI				-.0012091
O*RKL* RINNOV				.0000143
O*RI* RINNOV				.0003107
Number of countries	30			
Observations	476			
Log-likelihood	138.3497	138.62208	157.05144	167.60553
LR test/ chi2(df)	.54475767	36.858715***	21.108174**	
Prob > chi2	.46046766	1.876e-06	.01217868	

*, **, *** indicate significance at the 10%, 5%, and 1%.

Appendix F: The Empirical Results for using country-level gross capital formation (flow) divided by labor force as the KL ratio

Table 2: The determinants of the import of most polluting industries (dependent variable = import value of most polluting industries / import value of total manufacturing industries).

Variables	Model (1)	Model (2)	Model (3)	Model (4)
KL	-.0354644***	-.0353822***	-.0847317***	-.059609***
KL^2			.007016***	.0047265*
I	.0085204***	.0056721**	.0271868***	.0030593
I^2			.0007829	.0009176
INNOV	-.4141456*	-.2718696	-1.51471***	-3.126704***
$INNOV^2$			3.558192**	5.46076***
KL*I			-.0050179***	-.0036022
KL*INNOV			.1250345*	.0771459
I*INNOV			-.0503234	-.0410424
O		-.0028178***	-.0027604***	-.0039426***
O*RKL				-.0010634
$O*RKL^2$				.0003819
O*RI				.0022496
$O*RI^2$				.0000631
O* RINNOV				.0032239***
$O* RINNOV^2$				-.0004232***
O*RKL*RI				-.0006584
O*RKL* RINNOV				.0002939
O*RI* RINNOV				7.30e-07
Number of countries	30			
Observations	476			
Log-likelihood	441.03931	455.79109	477.11362	504.46934
LR test/ chi2(df)	29.503564***	42.645055***	54.711444***	
Prob > chi2	5.581e-08	1.371e-07	1.382e-08	

*, **, *** indicate significant at the 10%, 5%, and 1%.

Appendix G: The Empirical Results for using country-level gross capital formation (flow) divided by labor force as the KL ratio

Table 3: Elasticities from Model (4) in Table 1 and Table 2		
Elasticity	Export share of the most polluting industries	Import share of the most polluting industries
Total effect of KL	0.104 (1.63)	-0.2255*** (-7.1487)
Direct effect of KL	0.4044*** (3.2628)	-0.1881*** (-3.0792)
Trade-induced effect of KL	-0.3003*** (-3.0722)	-0.0374 (-0.7777)
Total effect of I (PHE)	-0.342*** (-3.4605)	0.1049** (2.1542)
Direct effect of I	-0.6817*** (-4.684)	0.0077 (0.1077)
Trade-induced effect of I (PE_{OI})	0.3397** (2.2506)	0.0972 (1.3068)
Total effect of INNOV	0.0837** (1.9714)	0.0326 (1.5589)
Direct effect of INNOV	0.0935** (2.1363)	-0.1099*** (-5.0962)
Trade-induced effect of INNOV	-0.0098 (-0.2076)	0.1425*** (6.1314)
Total effect of O	0.0063 (0.0580)	0.0192 (0.3578)
*, **, *** indicate significant at the 10%, 5%, and 1%. Values in parentheses are t-values.		