Environmental Regulation and Competitiveness:

Evidence from Trade and Production in the Manufacturing Sector

Tsung Yu Yang

North Carolina State University
Department of Economics

Campus Box8110, Raleigh
NC27695-8110
tyang4@ncsu.edu

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Abstract

Previous empirical studies of the pollution haven hypothesis (PHH) have not reached a consistent conclusion. The existing literature is primarily based on anecdotes and scattered case studies. This study analyzes the trade flows and composition change of the most polluting industries in manufacturing sectors among countries in order to offer a more general conclusion. This study finds that stricter environmental regulation stringency decreases the net export and production share of the most polluting production, which provides the evidence for pollution haven effect (PHE). However, we find no evidence to support PHH. Contrary, we find stricter environmental regulation stringency corresponds to larger net export and polluting production as trade openness increases. We also find that the ability to innovate in environmental-related technology creates a comparative advantage in polluting production. This finding implies that governments do not have to constrain their policies on the tradeoff between pollution control and international competitiveness since the innovative ability may both obtain the goals of pollution control and strengthening international competitiveness.

1. Introduction

The impact of trade liberalization on environment has been debated since early 1970. Opponents of trade liberalization argue that the concentration of polluting production in developing countries that implements laxer environmental regulations would cause harsh impacts to the environments, and developed countries enjoy the polluting commodities with lower prices due to the underestimated pollution costs. The phenomena that polluting production concentrates in some countries or areas to take advantage of the laxer environmental regulations is usually referred to the pollution haven hypothesis (PHH). Along with the trend in globalization of economic activities during 1990, it has been the motivation for environmental addenda to trade agreements such as the North American Free

Trade Agreement (NAFTA), United Nations Conference on Environment and Development (UNCED), GATT Uruguay Round. In 1999, President Clinton's Executive Order 13141, Environmental Review of Trade Agreements, requires that the United States "factor environmental considerations into . . . its trade negotiating objectives."

The empirical studies of PHH are mainly conducted either through the analysis of foreign director investment (FDI hereafter) behavior or through the analysis of trade flow determinants. The studies conducted through the analysis of FDI try to find the connection between the measurements of environmental regulation stringency and FDI choice. They connect the relation between measurements of environmental regulation stringency of host countries or regions and developed-country FDI outflows and, developing-country inflows, or plant location choices to provide the evidence of PHH. While previous studies look for evidence of the PHH through the analysis of FDI behavior, we return to the core of the question — is uneven stringency of environmental regulations one of the determinants leading to the relocation? While FDI shifts a part of polluting production from countries to countries, it is more likely the case that the relocation occurs via non-internationals' entering and existing the pollution-intensive markets. Thus, the analysis of FDI decision may underestimate the impact of environmental regulations on the relocation of polluting production. Therefore, even though one may not find significant evidence from the analysis of FDI, it is not that supportive to infer the PHH does not hold.

As to the trade flows and environmental stringency studies, they can be classified into two groups. Of the first group, those empirical studies conducting the trade flows and environmental stringency issues are based on the H-O theoretical foundation. In addition to factor endowments, lax environmental regulations also contribute to the comparative advantage of polluting production. Hence, the connection between the changes of (net) export or import (across countries and/or industries) and the measurements of environmental stringency is examined and the results are used to conclude the

PHH. Early in 1990, Toby individually examined whether the net exports of five polluting industries across countries were determined by countries' factor endowments and environmental stringency. The similar studies are conducted with different sample data, such as those in Table 1 in Appendix E.

Those studies account for the trade flows of polluting commodities via comparative advantage caused by differential endowments (including time-invariant nature resources endowments and time-variant physical capital and human capital) and environmental stringency, but neglect the role of trade openness. Even though there are differential endowments and environmental stringency among countries, the comparative advantage and disadvantage must be induced by trade openness. To account for the misspecification, the second group of studies (see Table 2 in Appendix E) focuses on the interactions between those determinants and trade openness.

Antweiler et al (2001) and Copeland and Taylor (2003) present a unified framework where the comparative advantage arguments of the standard H-O models and PHH are nested. They decompose the change of pollution emission into scale, composition, and technique effect. The interactions of the determinants (factor endowment and environmental stringency) and trade openness are imposed to measure an unobserved composition change, which is defined as 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 supposedly capital-intensive as well (Mulatu et al, 2004).Referring to their model specification, this study sets up a model where trade flows are determined by some factors that may contribute comparative advantage to polluting production and by the interactions of those factors with trade openness. The merit of the functional form is to specify the opposite contributions of a determinant in different levels responding to trade openness.

Previous studies apply the data of trade flows from developed countries due to the lack of environmental regulation data in developing countries. Those studies conduct case studies on the imports or exports of specific countries. They may unilaterally find empirical support for pollution haven effect (PHE) [1], but typically do not find the same effects on their trading partners to support PHH (Mulatu et al., 2004; Ederington et al., 2004, 2005). Therefore, this study conducts a multi-country analysis, which allows us to come to conclusions that are more general on the issue of polluting production relocation, not just a case study of a specific economy.

Another characteristic of our study is to examine the relation between trade flows and innovative ability in environmental-related technology. Previous studies on the relation 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 to a significant effect on productivity growth. Therefore, we argue that the innovative ability may also contribute to the comparative advantage of polluting production via increasing its industrial productivity.

The targets of this study are twofold. First, this study examines the presence of PHE and PHH through the analyses of trade flows of most polluting industries. Second, this study also examines whether innovative ability in environmental-related technology would contribute to the comparative advantage of polluting production. The empirical strategy is presented in next section. In section 3, some issues related to the dataset are discussed. The empirical results are presented in section 4 with a detailed discussion. Conclusions are given in the final section.

2. Model

Given a closed economy, the cost of pollution-intensive production is determined by factor endowment (END), environmental regulation (ENV). The production is determined by the cost and productivity, and is a function of END, ENV, and Productivity.

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[1] 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.

Cost= Cost(END, ENV)

Production = Productivity*f(END, ENV)

To an open economy, they are thus considered as the sources of comparative advantage. Therefore, we can consider trade flow is a function of END, ENV, Productivity, and trade openness (O).

Trade Flow = h(END, ENV, Productivity, O)

Among the potential determinants, capital abundance and environmental regulations are highly correlated with the comparative advantage of pollution-intensive production as suggested by previous studies. Yet, as we can observe, countries with higher incomes are usually capital abundant, implement stricter environmental regulations. Thus, the comparative advantage and disadvantage caused by the determinants may offset each other. Failing to isolate those effects may not find concrete evidence to support the PHH.

According to the Rybczyinski theorem, an increase in the supply of a factor will lead to an increase in the output of commodities using that factor intensively. We argue that the pollution intensive industries tend to be capital intensive due to the fact that more fixed capital would consume more energy and resources, and then generate more waste and pollution[2]. On the other hand, stricter environmental regulation is also considered as a source of firms' production cost. In addition to capital abundance and environmental regulations, we argue that innovative ability in environment related technology is the outcome of environmental policy, technology policy, R&D and human capital, which

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

may contribute to the industrial productivity (Hamamoto, 2006; Yang et al., 2012) and cause comparative advantage to the pollution-intensive industries[3].

To test the arguments and the determinants contributing to comparative advantages, we use two-way error component regression model to control the unobserved country-specific (μ_i) and time-specific fixed effect[4] (λ_t), and regress net export of the most pollution industries on these determinants.

$$\ln(NetEXPO_{it}) = \alpha_0 + \alpha_1 KL_{it} + \alpha_2 (KL_{it})^2 + \alpha_3 I_{it} + \alpha_4 (I_{it})^2 + \alpha_5 INNOV_{it} + \alpha_6 (INNOV_{it})^2 + \alpha_7 KL_{it} I_{it} + \alpha_8 KL_{it} INNOV_{it} + \alpha_9 I_{it} INNOV_{it} + \gamma_0 O_{it} + \mu_i + \lambda_t + \varepsilon_{it} \text{ , --(1)}$$

$NetEXPO_{it}$ is the net export scaling by the output value of the most polluting industries among the manufacturing industries for country i at year t. KL_{it} is the capital-labor ratio of the whole manufacturing sector, which refers to country i's capital abundance in its manufacturing industry at year t. I_{it} is one period lag GDP per capita that represents the environmental regulation stringency. $INNOV_{it}$ 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. Due to the quantity of innovative output is highly associated with the country size, it is scaled by GDP. O_{it} measures trade openness (percentage of nation's total imports plus exports in GDP)[5]. The effects of capital abundance, environmental regulation stringency, and innovative ability may be different at different levels of those determinants, given a certain level of trade openness. Therefore, we impose nonlinearity assumption into the model.

[3] The reason we focus on the environmental-related technology is because it might contribute differential productivity improvement to pollution intensive production comparing to its contribution to non-pollution intensive production.

[4] Country-specific fixed effect is to control the unobserved effect which is time invariant, but variant across countries, such as natural resource endowments. In contrary, time-specific fixed effect is to control time-variant unobserved. In our study, capital stock and GDP per capita are measured in current values. So, time-specific fixed effect could adjust the influence caused by inflation.

[5] This study focuses on trade exposure rather than trade liberalization. We do not study the effect of reduction of tariffs schedules on pollution intensive commodities.

If Rybczyinski theorem holds, we can expect a positive α_1 and a negative α_2. That indicates countries with more capital abundance tend to produce more in the polluting industries and export more and the effect would increase at a decreasing rate. I_{it} represents the environment regulation stringency that raises the production cost to the polluting industries. Such that α_3 is negative and positive α_4 indicates a decreasing rate of the negative effect. Innovative ability in environmental-related technology strengthens the productivity of polluting industries, therefore, α_5 is positive, and α_6 is negative.

Further, since the capital abundance and environmental regulation have opposite effects to the net export of polluting production, a negative α_7 denots an increase of income raising the stringency of environmental regulations offsets the advantage caused by capital abundance. On the other hand, it may also refer an increase of capital abundance amplifies the disadvantage caused by stricter environmental regulations. In the same manner, we can expect a negative sign of α_9 and a positive sign of α_8.

Taylor (2004) points out the difference between two concepts of "Pollution Haven Effect (PHE)" and "Pollution Haven Hypothesis (PHH)". PHE relates the cost of meeting environmental policy to the resulting trade flows. PHH predicts that when trade barriers reduce, the polluting productions would relocate from countries with stricter environmental regulations to the countries with laxer environmental regulations. Equation (1) specifies the effects of the determinants without considering their interactions with trade liberalization. Since the determinants in high and low levels would lead to opposite effects to the competitiveness of polluting production corresponding to increasing trade liberalization, ignoring their interactions with trade liberalization may misspecify PHE in our multi-country analysis.

To illustrate PHH and specify the interactive effects between the determinants and trade liberalization, we refer to the functional form of Antweiler et al. (2001) and Cole et al. (2003), and add the trade-induced effects into equation (1). Because the comparative advantage is a relative concept, the determinants in the trade-induced effect are expressed as the ratios relative to the world averages. $O_{it}\mathrm{RK}L_{it}$ is an interaction of trade openness with a country's relative capital-labor ratio (relative to world average capital-labor ratio). $O_{it}\mathrm{R}I_{it}$ is an interaction of trade openness with country i's one period lag relative income[6] (relative to world average GDP per ca). Similarly, $O_{it}\mathrm{R}INNOV_{it}$ represents the interaction of trade openness, and relative innovative ability.

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

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

The direct effect of trade openness (O_{it}) depends on the countries are importers or exports of polluting commodities such that γ_0 may not be significant. γ_1<0, γ_2>0 denotes that countries with lower capital abundance would have comparative disadvantage in producing polluting commodities such that an increase in trade openness corresponds to a fall to the net export of polluting commodities. In contrary, countries in higher levels of capital abundance would correspond to an increase of the net export of polluting commodities. In the same manner, γ_5<0 and γ_6 >0 demonstrate that the innovative ability does contribute comparative advantage to the polluting production. Different from capital abundance and innovative ability in environmental-related technology, environmental stringency is considered as a factor causing comparative disadvantage in polluting production. Therefore, γ_3 >0 denotes that countries with laxer environmental regulations would have the comparative advantage and

[6] It is assumed that there is a time lag between the implement of stricter environmental regulations and the public's demand for higher environmental quality accompanying with increasing income. Using the lag terms may also reduce the endogeneity problem in a way.

an increase in trade openness corresponds to an increase to the net export of polluting commodities. On the other hand, γ_4<0 means an increase in trade openness corresponds to a fall to the net export of polluting commodities in higher levels of environmental stringency. Both positive γ_3 and negative γ_4 provide the evidence for PHH.

By taking derivative of equation (2) w.r.t. O_{it} and I_{it}, we can identify the effect of environmental stringency (I_{it}) through trade openness (O_{it}) as

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

Recall that $RI_{it} = I_{it} / W_t$, where, W_t = World average of I_{it} at year t. E_{OI} predicts the change of polluting commodity net export caused by environmental regulation (I_{it}) through an increase of trade openness (O_{it}). According to the theoretical prediction, γ_3 is positive and γ_4 is negative. Therefore, the effect of environmental regulation through trade openness depends on its relative magnitude to the world average and the interactions with RKL_{it} and $RINNOV_{it}$. Given RI_{kt} is small, E_{OI} might be positive, which means that trade openness leads an increase to its net export of polluting commodities in a low-income country with laxer environmental regulations. Contrary, trade openness would lead a decrease to the net export of polluting production in 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}

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

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 trade-induced effect, $O_{it} * E_{OI}$.

The total effect of trade openness (O_{it}) can be estimated as:

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

4. Data

Combining data sets from World Bank and the database collected by Nicita and Olarreaga in 2006, this study applies the country-level data cover the period from 1978 to 2001, including 35 developed and non-developed countries[7], and 494 individual observations. Some data related issues would be discussed in the following paragraphs.

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

Capital-labor ratio (K/L): The KL ratio is total fixed capital stock dividing by labor force, which is to measure a country's capital abundance. However, the gross fixed capital formation provided by World Bank is the domestic investment, which represents fixed capital as "flow", not stock. Some cross-section data analysis may assume an average life for fixed capital and accumulate the gross fixed

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

capital formation with a depreciation rate[8]. In our unbalanced panel analysis, such a methodology could either lose lot of observations or raise the bias due to an identical depreciation rate. Hence, this study use the industrial level gross fixed capital stock built by Nicita and Olarreaga to construct KL ratio for the manufacturing sector in each country.

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

The most polluting industries: To classify different trade sectors by pollution intensity (emission per unit of output), this study used 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. The following table lists the classified industries with three-digital 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).

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

Table 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)

Patent counts in environment-related innovations: To construct countries' stock of innovative outputs, we apply OECD's patents statistics in environment-related technologies (refer to Appendix B). The patent counts are subject to the applications to European Patent Office (EPO). They are sorted by inventors' country in order to measure the technological innovativeness of researchers and laboratories located in a given county. Also, the patents 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, there are some criticisms to patents as indicators of innovative activity[9]. The major criticism is assuming each count of the patents has the same contribution to the 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." This study attempts to build up an index to measure the synthetical outcome of other

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

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

We should be aware of that the counts of patents for each country under the records of EPO, USPTO, or other International Searching Authority (ISA) are not the counts of patents applied to or granted by individual national patent offices even though nearly all patents are first filed in the home country of the inventors. Therefore, the index we build up 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 gather appropriate pools to compare the levels of innovative activity of environment-related technology across countries. Since the process of adopting environmental technologies are not in the realm of this paper, it is reasonable to assume that countries with higher innovative capability would apply cleaner or more advanced technologies.

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 multiple 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.

4. Empirical Results

Table 2 demonstrates the specification ability of the determinants to the changes of net export of most polluting industries in manufacturing sector. In Model (1), we simply assume the linear relations between net export and its determinants. The impacts of those determinants on the trade flows highly depend on the trade openness, and thus we control trade openness in Model (2). Since Model (1) is nested in Model (2), Likelihood-ratio test (LR test) is applied to test the specification ability of the variable of trade openness (O_{it}). The likelihood ratio (2*(448.223 - 447.76547) = .91505514) follows Chi-squared distribution with one degree of freedom, and does not reject the null hypothesis that O_{it} does not improve the model specification. This is due to direct effect of trade openness (O_{it}) is opposite to the importers and exports of polluting commodities.

Furthermore, there is no much evidence to believe that the impacts of the determinants would keep steady at different levels, such that the quadratic terms and the interactive terms are added in Model(3). The LR test (LR = 23.539086) verifies the specification ability is statistically significantly improved. The coefficient (0.00032) of I^2 is significantly positive and that indicates the impact of environmental regulation is decreasing as environmental regulation is getting stricter.

By adding the trade-induced effects into Model (3), the log-likelihood value in Model (4) is significantly gained that supports the specification ability of trade-induced effects on the change of net export. We only obtain significantly negative γ_1 and insignificantly positive γ_2, which do not allow us to conclude that trade openness will increase the net export of most polluting industries in those countries with high levels of relative capital-labor ratios (RKL).Meanwhile, positive γ_3 suggests that trade openness will increase the net export of most polluting industries in those countries with low levels of relative environmental stringency (RI). However, γ_4 are positive but insignificant.

Nevertheless, relative capital-labor ratio (RKL) is composed of KL and the world average ($RKL_{it} = KL_{it} \Big/ \frac{\sum_i KL_{it}}{N_t}$). If we take derivative of ln(NetEXPO$_{it}$) with respect to O_{it} and KL_{it} instead of RKL_{it}. We can obtain

$$\frac{\partial \ln(\text{NetEXPO}_{it})}{\partial O_{it}\partial \text{KL}_{it}} = \gamma_1 * \frac{\partial \left({KL_{it}} \Big/ {\frac{\sum_i KL_{it}}{N_t}} \right)}{\partial \text{KL}_{it}} + 2\gamma_2 * \text{RKL}_{it} * \frac{\partial \left({KL_{it}} \Big/ {\frac{\sum_i KL_{it}}{N_t}} \right)^2}{\partial \text{KL}_{it}} + \gamma_7 *(\,.\,) + \gamma_8 *(\,.\,)$$

We can ignore the second, third, and fourth term since γ_2, γ_7, γ_8 are relatively small and statistically insignificant in Model (4). Then we rewrite the derivative as

$$\frac{\partial^2 \ln(\text{NetEXPO}_{it})}{\partial O_{it}\partial \text{KL}_{it}} = \gamma_1 N_t \left(\frac{1}{\sum_i KL_{it}} - \frac{KL_{it}}{(\sum_i KL_{it})^2} \right),$$

Whereas the empirical result suggest that γ_1 is significantly negative, the derivative is negative in low levels of KL and positive in high levels that indicates – trade openness reduces the net export in lower levels of KL and increase the net export in high levels of KL. This result is hence consist of our previous statement - countries with lower capital abundance would have comparative disadvantage in producing polluting commodities such that an increase in trade openness corresponds to a fall to the net export of polluting commodities and countries with higher capital abundance would have comparative advantage in producing polluting commodities such that an increase in trade openness corresponds to a rise to the net export of polluting commodities. In the same way, by take derivative of $\ln(\text{NetEXPO}_{it})$ with respect to O_{it} and I_{it}, we can obtain a positive derivative in a lower level of I_{it} and a negative derivative in a higher level of I_{it} that support the PHH – when trade barriers reduce, countries with laxer environmental regulations will specialize in polluting production.

To verify the conclusions, we redo the regression without using the normalized variables in the trade-induced effects. The results of Model (5), shown in Table 2-1 consistently support the main conclusions from Model (4) except the interactive effect between trade openness and the quadratic term of environmental stringency (I_{it}). The significantly positive γ_4 denotes trade openness will increase net export even more in higher levels of environmental stringency than that in lower levels. This result is counter to the prediction of PHH since environmental regulation is considered as a factor leading comparative disadvantage to the polluting industries.

In Model (5), we also notice that the interactive term of KL and I is significantly positive, which is opposite to what we previously expect. That might suggest that the marginal impact of environmental regulation is lessened in higher levels of KL ratio. So, we might subsume that in the countries with higher levels of KL ratio and environmental stringency, which usually refer to developed countries, the marginal impact of environmental regulation would be very minor as KL and I keep increasing. In contrary, the marginal impact of KL ratio would be strengthened as KL and I are increasing. A similar conclusion can be made on the interactive term of INNOV and I. On the other hand, the interactive effect between KL and INNOV is negative. Those cross terms with trade openness are oppositely signed that indicates that the interactive effects are diminishing as the trade openness goes up.

Table 2: Two-way error component regression model for the net export of most polluting industries

Dependant 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 (α_1)	4.206578* (1.78)	4.062727* (1.72)	14.33949** (2.53)	37.39947*** (3.73)
KL^2 (α_2)			-469.6727 (-1.54)	-970.0226** (-2.28)
I (α_3)	-.0052408*** (-2.71)	-.0057058*** (-2.85)	-.0264065*** (-4.83)	-.0591095*** (-7.09)
I^2 (α_4)			.00032* (1.95)	.0007422*** (2.94)
INNOV (α_5)	.4842964** (2.34)	.5068176** (2.43)	1.308775** (2.45)	1.895*** (2.73)
INNOV^2 (α_6)			-3.301168* (-1.73)	-4.800554** (-2.26)
KL*I (α_7)			.3823955 (0.69)	.4651659 (0.54)
KL*INNOV (α_8)			-17.42269 (-0.22)	-90.6536 (-0.76)
I*INNOV (α_9)			.0182146 (0.52)	.0183112 (0.44)
O (γ_0)		-.000507 (-0.88)	. -.0007905 (-1.37)	-.0010306 (-1.11)
O*RKL (γ_1)				-.0018787** (-2.04)
O*RKL^2 (γ_2)				.0000719

				(0.28)
O*RI (γ_3)				.0031066*** (3.09)
O*RI^2 (γ_4)				.0000445 (0.21)
O* RINNOV (γ_5)				.0001902 (0.58)
O* RINNOV^2 (γ_6)				-8.85e-06 (-0.70)
O*RKL*RI (γ_7)				.0001696 (0.35)
O*RKL* RINNOV (γ_8)				-.0000586 (-0.28)
O*RI* RINNOV (γ_9)				.0000409 (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 are t-values.

Table 2-1: 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

Dependant 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 (α_1)	37.39947*** (3.73)	KL (α_1)	48.32937*** (3.55)
KL^2 (α_2)	-970.0226** (-2.28)	KL^2 (α_2)	-4711.069*** (-3.83)
I (α_3)	-.0591095*** (-7.09)	I (α_3)	-.1132996*** (-9.42)
I^2 (α_4)	.0007422*** (2.94)	I^2 (α_4)	-.0010882 (-1.47)
INNOV (α_5)	1.895*** (2.73)	INNOV (α_5)	10.92425*** (5.31)
INNOV^2 (α_6)	-4.800554** (-2.26)	INNOV^2 (α_6)	-18.63195 (-1.65)
KL*I (α_7)	.4651659 (0.54)	KL*I (α_7)	10.56459*** (3.88)
KL*INNOV (α_8)	-90.6536 (-0.76)	KL*INNOV (α_8)	-1918.173*** (-3.02)
I*INNOV (α_9)	.0183112	I*INNOV (α_9)	.4694507**

	(0.44)		(2.32)
O (γ_0)	-.0010306 (-1.11)	O (γ_0)	-.0017453* (-1.81)
O*RKL (γ_1)	-.0018787** (-2.04)	O*KL (γ_1)	-.7098287*** (-3.01)
O*RKL^2 (γ_2)	.0000719 (0.28)	O*KL^2 (γ_2)	74.33112*** (3.40)
O*RI (γ_3)	.0031066*** (3.09)	O*I (γ_3)	.0014246*** (6.16)
O*RI^2 (γ_4)	.0000445 (0.21)	O*I^2 (γ_4)	.0000306** (2.30)
O* RINNOV (γ_5)	.0001902 (0.58)	O* INNOV (γ_5)	-.1477607*** (-4.39)
O* RINNOV^2 (γ_6)	-8.85e-06 (-0.70)	O* INNOV^2 (γ_6)	.271617* (1.73)
O*RKL*RI (γ_7)	.0001696 (0.35)	O*KL*I (γ_7)	-.1621014*** (-3.71)
O*RKL* RINNOV (γ_8)	-.0000586 (-0.28)	O*KL* INNOV (γ_8)	28.28863*** (3.00)
O*RI* RINNOV (γ_9)	.0000409 (0.33)	O*I* INNOV (γ_9)	-.0077766** (-2.54)
Number of countries	35		
Observations	394		
Log-likelihood	488.67313		508.28544
Likelihood Ratio	57.361164***		96.585786***
Prob > chi2(df)	4.309e-09		7.701e-17

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

We further investigate the effects of these determinants individually on export, import, and production of the most polluting commodities. In Table 3 and Table 3-1, we observe that the influences on net export mainly come from the impacts on import. Also, those influences on the output share of the most polluting industries in manufacturing sector (Production 1) are consistent with the influences on the net export (see Model (5)), which verifies that those determinants are related to the competitiveness of pollution intensive production in terms of its net export and composition change.

In sum, our empirical results confirm the direct effects of capital abundance and innovative ability in environmental-related technology and their indirect effects through international trade. The results also confirm the pollution haven effect (PHE), but the evidence for pollution haven hypothesis (PHH) is still subtle.

Table 3: 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

Dependant Variable	Export	Import	Production 1	Production 2
Independent Variables				
KL	-5.356457	-42.75593***	2.301841	18.15001
	(-1.23)	(-4.22)	(0.25)	(1.41)
KL^2	561.3424***	1531.365***	-172.5419	-864.2522
	(3.03)	(3.56)	(-0.44)	(-1.58)
I	.0073275**	.066437***	-.0461296***	-.0522854***
	(2.02)	(7.88)	(-6.04)	(-4.87)
I^2	-.0000207	-.0007628***	.0005232**	.0005999*
	(-0.19)	(-2.98)	(2.26)	(1.84)
INNOV	.5811627*	-1.313837*	.6379992	1.231658
	(1.92)	(-1.87)	(1.00)	(1.38)
$INNOV^2$	-1.037121	3.763432*	-2.969072	-3.697596
	(-1.12)	(1.75)	(-1.53)	(-1.35)
KL*I	-.5735951	-1.038761	.7000167	.6481476
	(-1.54)	(-1.20)	(0.90)	(0.59)
KL*INNOV	92.60411*	183.2577	-50.22221	-28.90103
	(1.79)	(1.53)	(-0.46)	(-0.19)
I*INNOV	-.0270641	-.0453753	-.0005846	-.0235469
	(-1.48)	(-1.07)	(-0.02)	(-0.44)
O	.0021808***	.0032114***	-.0017913**	-.0013517
	(5.40)	(3.42)	(-2.11)	(-1.13)
O*RKL	-.0001498	.0017289*	-.0016417*	-.0037088***
	(-0.37)	(1.85)	(-1.95)	(-3.13)
$O*RKL^2$	-.0001055	-.0001774	.0003689	.0008308**
	(-0.94)	(-0.68)	(1.57)	(2.51)
O*RI	-.0006656	-.0037721***	.0005351	.0006803
	(-1.52)	(-3.70)	(0.58)	(0.52)
$O*RI^2$	.0000695	.0000249	.0000329	.0000904
	(0.76)	(0.12)	(0.17)	(0.33)
O* RINNOV	.0001251	-.0000651	6.43e-06	-.0000431
	(0.88)	(-0.20)	(0.02)	(-0.10)
$O* RINNOV^2$	-8.12e-06	7.24e-07	-8.43e-06	-2.97e-06
	(-1.48)	(0.06)	(-0.73)	(-0.18)
O*RKL*RI	.0002068	.0000373	.0001057	.0002522
	(0.99)	(0.08)	(0.24)	(0.41)
O*RKL* RINNOV	-.0000722	-.0000136	-.0002029	-.0002609
	(-0.78)	(-0.06)	(-1.04)	(-0.95)
O*RI* RINNOV	.0000642	.0000233	.0002302**	.0002448
	(1.19)	(0.19)	(2.03)	(1.54)
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 3-1: 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

Dependant Variable	Export	Import	Production 1	Production 2
Independent Variables				
KL	7.178833	-41.15054***	1.632692	-13.42918
	(1.18)	(-3.01)	(0.13)	(-0.72)
KL^2	-69.64392	4641.425***	-3491.075***	-2467.842
	(-0.13)	(3.77)	(-3.04)	(-1.46)
I	.0107085**	.1240081***	-.0807508***	-.0720673***
	(1.98)	(10.27)	(-7.18)	(-4.36)
I^2	.0005184	.0016066**	-.0011934*	-.0010867
	(1.56)	(2.16)	(-1.72)	(-1.07)
INNOV	.0850222	-10.83923***	7.640318***	7.683283***
	(0.09)	(-5.26)	(3.98)	(2.72)
$INNOV^2$	-.0311653	18.60079	-17.52904*	-21.30884
	(-0.01)	(1.64)	(-1.66)	(-1.37)
KL*I	-2.363924*	-12.92851***	9.046464***	8.125956**
	(-1.93)	(-4.73)	(3.55)	(2.17)
KL*INNOV	634.2819**	2552.455***	-1260.109**	-991.2286
	(2.23)	(4.01)	(-2.12)	(-1.14)
I*INNOV	-.2209403**	-.690391***	.3060344	.2167942
	(-2.44)	(-3.40)	(1.62)	(0.78)
O	.0030573***	.0048026***	-.0032065***	-.004557***
	(7.07)	(4.97)	(-3.56)	(-3.44)
O*KL	-.2850594***	.4247693*	-.2573644	.042128
	(-2.69)	(1.79)	(-1.17)	(0.13)
$O*KL^2$	11.27421	-63.05691***	67.15107***	44.64979
	(1.15)	(-2.87)	(3.28)	(1.49)
O*I	-.0001247	-.0015493***	.0006212***	.0003774
	(-1.20)	(-6.68)	(2.87)	(1.19)
$O*I^2$	-5.76e-06	-.0000363***	.0000353***	.000033*
	(-0.97)	(-2.73)	(2.85)	(1.81)
O* INNOV	.0120505	.1598111***	-.1156094***	-.1080243**
	(0.80)	(4.73)	(-3.67)	(-2.34)
$O* INNOV^2$	-.0345758	-.3061928*	.2601995*	.2933339
	(-0.49)	(-1.94)	(1.77)	(1.36)
O*KL*I	.0305747	.1926762***	-.1412948***	-.1203218**
	(1.56)	(4.40)	(-3.46)	(-2.01)
O*KL* INNOV	-8.414629**	-36.70326***	18.17175**	13.77936
	(-1.99)	(-3.88)	(2.06)	(1.06)
O*I* INNOV	.0032669**	.0110435***	-.0045072	-.002884
	(2.38)	(3.60)	(-1.58)	(-0.69)
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.

5. Conclusion

Other than previous studies, this study tries to examine the pollution haven effect (PHE) and pollution haven hypothesis (PHH) with a more general base. This study analyzes the net export of most polluting industries in manufacturing sector with 35 countries during 1978 to 2001. The results can be summarized into few conclusions.

First, capital abundance creates comparative advantage to polluting production and net export. This finding is consistent with the finding of Antweiler et. al. (2001) and Cole and Elliot (2003). However, in their study the capital endowment effect is projected onto the environmental performance through the unobserved change of production composition. In our study, we further identify that the endowment effect did influence the composition change in manufacturing sector.

Second, the environmental regulation stringency (proxied by GDP per ca.) have comparative disadvantage to polluting production. The PHE is significant to the net export and composition change of polluting commodities in manufacturing sector. However, empirical results do not support the PHH. Contrary, we find stricter environmental regulation stringency corresponds to larger net export and polluting production as trade openness increases.

Third, country's innovative ability in environment-related technology creates comparative advantage to the polluting production has an important implication to policy suggestion. That suggests governments have a better option other than environmental regulation itself for the purpose of pollution control. Environmental regulation may effectively control pollution levels, but also raise the concern of losing competitiveness against their trading partners. On the other hand, to foster country's innovative ability in environmental-related technology could not only fortify the industrial competitiveness, but also reach the purpose of pollution control. At that time, tightening environmental regulations merely reflect the lower bound of the technology level.

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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

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 utilisation 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

F. EMISSIONS ABATEMENT AND FUEL EFFICIENCY IN TRANSPORTATION

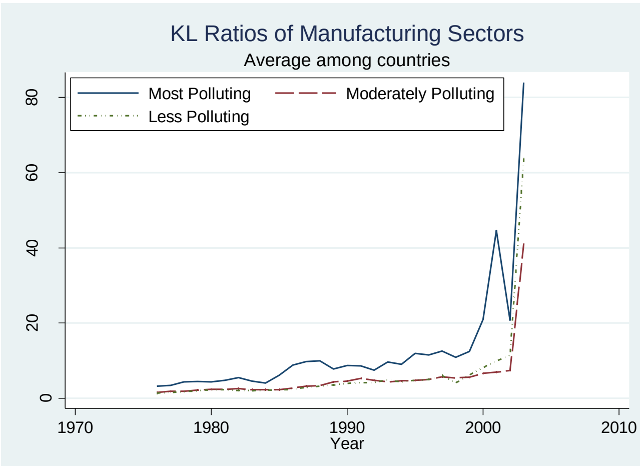
- Technologies specific to propulsion using internal combustion engine (ICE) (e.g. conventional petrol/diesel vehicle, hybrid vehicle with ICE)

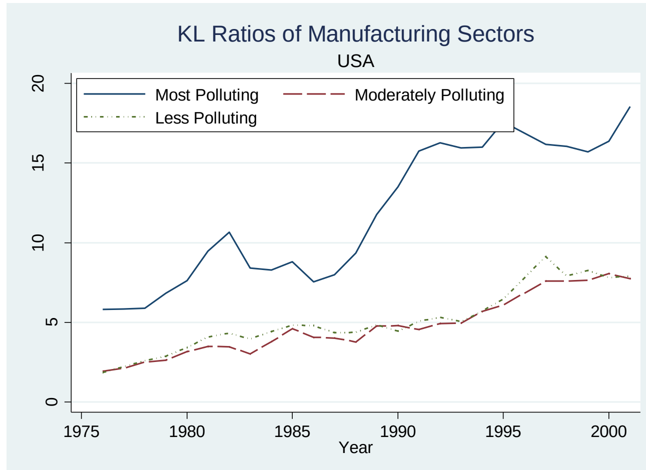
    - Integrated emissions control (NOX, CO, HC, PM)
    - Post-combustion emissions control (NOX, CO, HC, PM)
- Technologies specific to propulsion using electric motor (e.g. electric vehicle, hybrid vehicle)
- Technologies specific to hybrid propulsion (e.g. hybrid vehicle propelled by electric motor and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

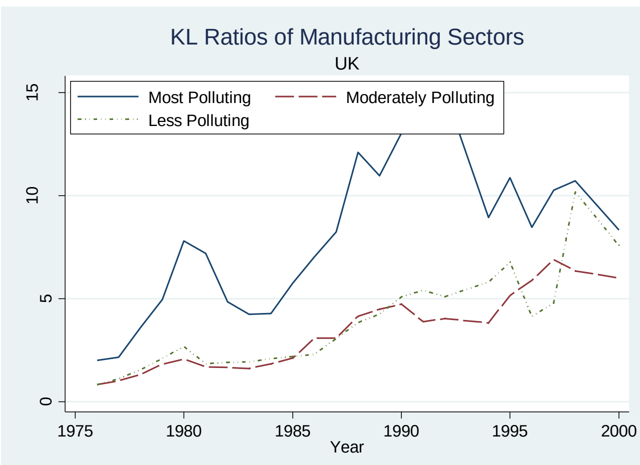
G. ENERGY EFFICIENCY IN BUILDINGS AND LIGHTING

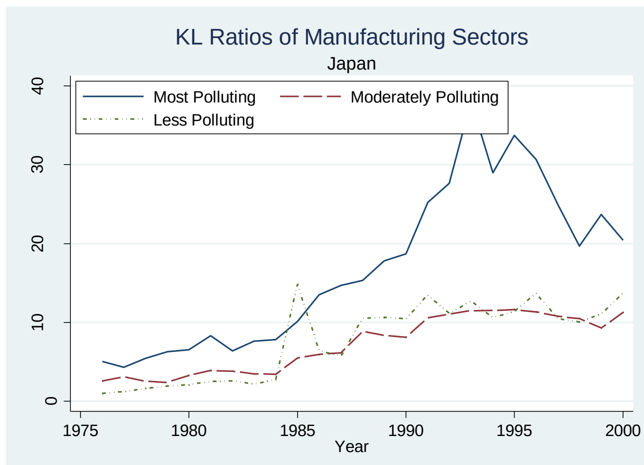
- Insulation (incl. thermal insulation, double-glazing)
- Heating (incl. water and space heating; air-conditioning)
- Lighting (incl. CFL, LED)

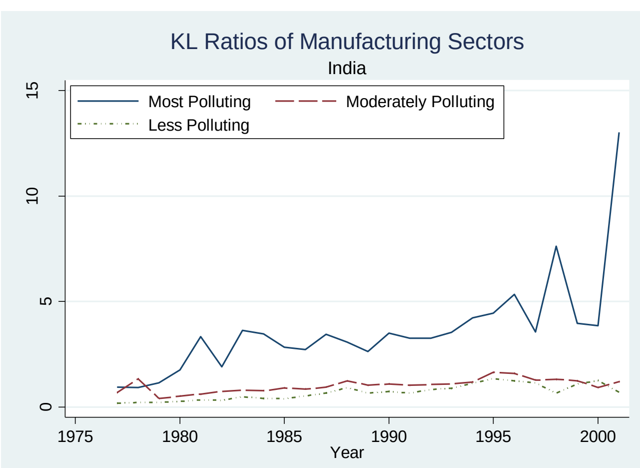
Appendix C: Industrial average KL over time for individual countries and for over all countries.

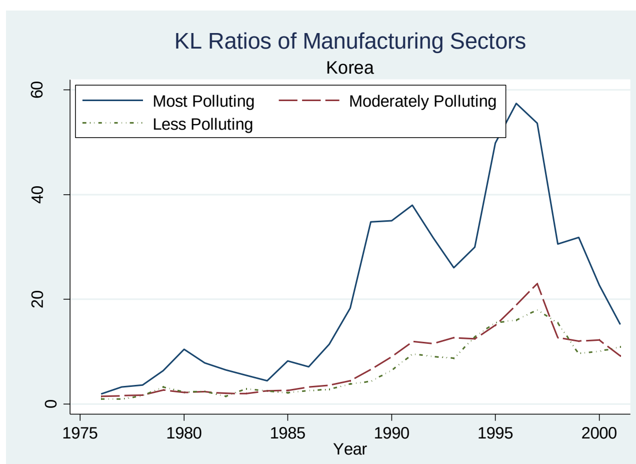


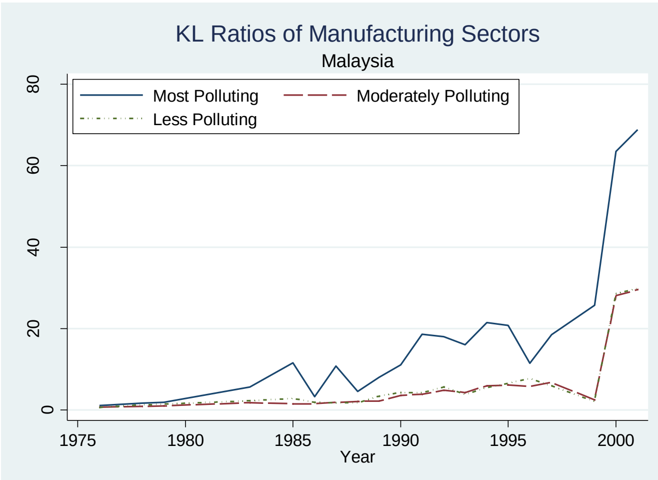


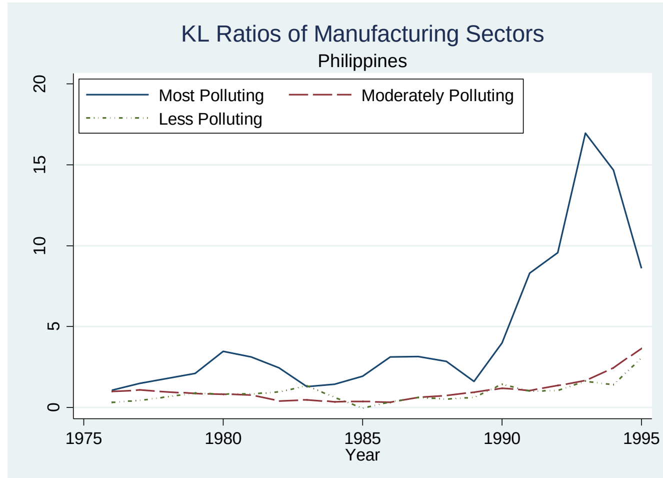


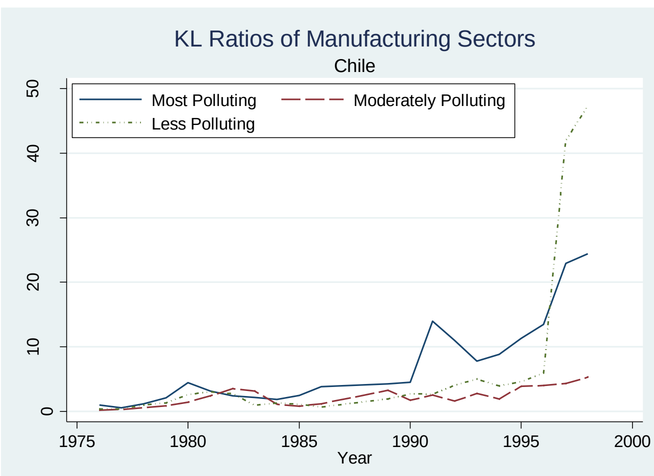


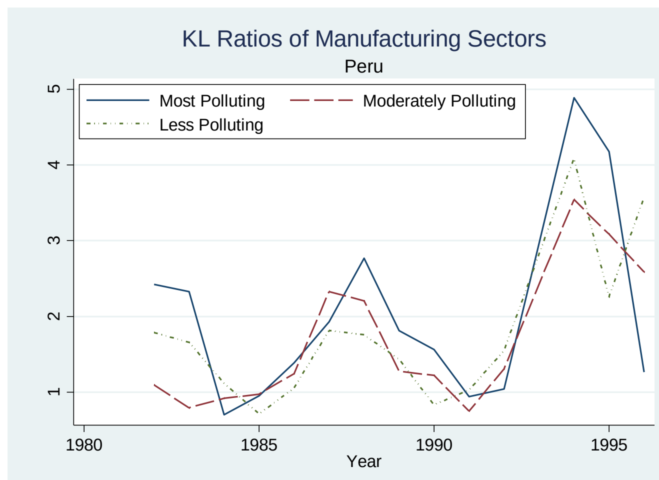


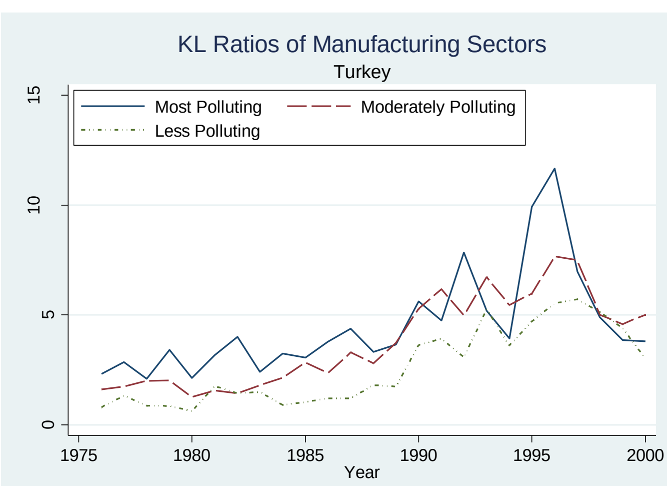


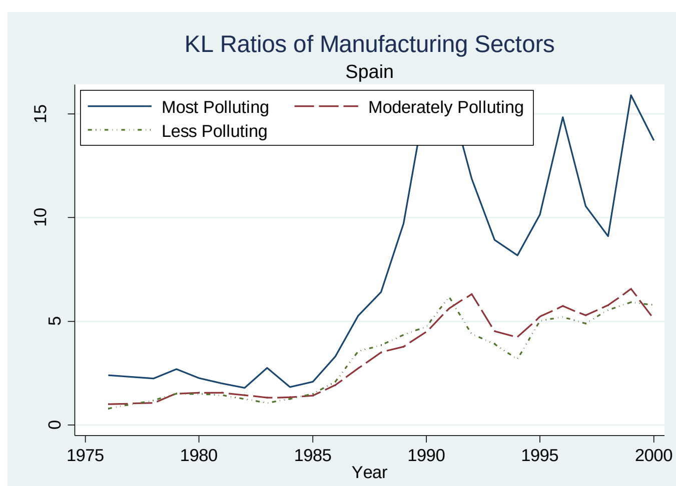

KL Ratios of Manufacturing Sectors
Malaysia
Most Polluting
Moderately Polluting
Less Polluting
0
20
40
60
80
1975
1980
1985
1990
1995
2000
Year


KL Ratios of Manufacturing Sectors
Philippines
Most Polluting
Moderately Polluting
Less Polluting
0
5
10
15
20
1975
1980
1985
1990
1995
Year


KL Ratios of Manufacturing Sectors
Chile
Most Polluting
Moderately Polluting
Less Polluting
0
10
20
30
40
50
1975
1980
1985
1990
1995
2000
Year


KL Ratios of Manufacturing Sectors
Peru
Most Polluting
Moderately Polluting
Less Polluting
1
2
3
4
5
1980
1985
1990
1995
Year


KL Ratios of Manufacturing Sectors
Turkey
Most Polluting
Moderately Polluting
Less Polluting
0
5
10
15
1975
1980
1985
1990
1995
2000
Year


KL Ratios of Manufacturing Sectors
Spain
Most Polluting
Moderately Polluting
Less Polluting
0
5
10
15
1975
1980
1985
1990
1995
2000
Year

Appendix D: Descriptive statistics (Obs. = 476)

Variable	Definition	Mean	Std. Dev.	Min	Max
EXPO	the share of export value of most polluting industries in total manufacturing sector	.3925809	.2040125	.068757	.983137
IMPO	the share of import value of most polluting industries in total manufacturing sector	.3155105	.0616035	.184484	.5427012
KL	national capital-labor ratio (thousand USD per labor)	4.094973	4.046694	.1444192	22.41048
I	one period lag GDP per ca. (thousand USD per ca)	7.823799	8.435482	.2244799	41.96765
INNOV	accumulated patent stock of environment-related technologies with 5% obsolescence rate divided by GDP. (stock per hundred million USD)	.0409288	.0701496	0	.3886603
O	total import and export / GDP (%)	50.53803	27.37972	12.34638	217.5709
RKL	national capital-labor ratio / world average	1.726891	1.593264	.0637095	7.872415
RI	one period lag GDP per ca. / world average	1.473513	1.444486	.0428457	5.883289
RINNOV	INNOV / world average	.9772369	1.568904	0	7.07915

Appendix E: Empirical literature review of PHH

Table 1: Empirical studies on PHH / PHE via H-O theory and/or Gravity model without controlling trade barrier or exposure to international competition

Study	Dependant	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.
Grether et al. (2003)	Bilateral RCA (Gravity model)	difference in GNP per ca.	52 / 1981-98	
Cole & Elliott (2003a)	Intra-industry trade (IIT) (index constructed by bilateral trade)	ENVREG (index based on survey questions) ENVPOL (energy use / GDP)	60 / 1995	
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.

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

Study	Dependant	Measurement of Regulation Stringency	# of countries / year periods	Notes / Results
Hettige et al. (1992)				
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)
Busse (2004)		CIESIN(2003)	60 / 1995	
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.
Ederington (2007)				Comments on Stern's and Dominguez-Brown's papers
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.
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 F: 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 (dependant 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%.

Table 2: The determinants of the import of most polluting industries (dependant 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%.

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	-0.2255***
	(1.63)	(-7.1487)
Direct effect of KL	0.4044***	-0.1881***
	(3.2628)	(-3.0792)
Trade-induced effect of KL	-0.3003***	-0.0374
	(-3.0722)	(-0.7777)
Total effect of I	-0.342***	0.1049**
(PHE)	(-3.4605)	(2.1542)
Direct effect of I	-0.6817***	0.0077
	(-4.684)	(0.1077)
Trade-induced effect of I (PE_{OI})	0.3397**	0.0972
	(2.2506)	(1.3068)
Total effect of INNOV	0.0837**	0.0326
	(1.9714)	(1.5589)
Direct effect of INNOV	0.0935**	-0.1099***
	(2.1363)	(-5.0962)
Trade-induced effect of INNOV	-0.0098	0.1425***
	(-0.2076)	(6.1314)
Total effect of O	0.0063	0.0192
	(0.0580)	(0.3578)

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