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Did International Trade Become Dirtier in Developing Countries? On the Composition Effect of International Trade on the Environment

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Abstract

Utilizing the world panel dataset for the pollution emission embedded in international trade for the period between 1988 and 2009, we investigated whether the composition of international trade of a country moved away from pollution-intensive industries as its income level rises. The empirical evidence suggests that the income levels of countries are negatively related to export pollution intensity, but we also find that income is negatively related to import pollution intensity. Thus, the composition effect of international trade on the environment is only consistent with the pollution haven hypothesis on the export side, which predicts that developing countries export more of dirtier industries and import more of cleaner industries after trade liberalization. Further investigation reveals that the lower-middle income countries experienced an increase in the pollution emission of exports and a decrease in the pollution emission of imports, whereas the countries in the lowest income group experienced increases in the pollution emission embodied in both exports and imports.

Keywords: Composition effect; Environment; International trade; Pollution emission; Pollution haven hypothesis.
JEL Classification Codes: F18; O13; Q56.

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1. Introduction

In the past two decades, trade liberalization has been aggressively pursued in both multilateral and bilateral frameworks. By creating the World Trade Organization (WTO) in 1995, introducing a single European currency (the Euro), and creating regional and bilateral free trade agreements, trade barriers from both tariff and non-tariff obstacles were substantially reduced. Consequently, the volume of international trade increased in the world[1]. For countries considering trade policy reforms, it also becomes an important issue that policy makers in appropriately evaluate the effects of international trade on their economies. The effect of international trade on growth is especially important for developing countries[2].

Empirical studies investigating the effects of international trade on the environment also draw much attention from both policy makers and researchers. The common fear among environmentalists upon trade liberalization was the pollution haven hypothesis wherein the production of dirty industries shifts toward developing countries where environmental regulations are either relatively lax or nonexistent. Recent empirical studies examining the pollution haven hypothesis can be classified into two indirect approaches. The first approach, suggested by a seminal work of Antweiler et al. (2001), regresses the pollution emission of national production on variables representing scale, technique, and composition effects. The second approach examines changes in the value of international trade with respect to environment variables; see Levinson and Taylor (2008). Neither approach can use the direct measures of pollution emission embodied in international trade simply due to the lack of data on these measures in the world panel database.

On the other hand, some recent studies attempt to calculate the pollution emission embodied in international trade directly. For example, Ederington et al. (2004) calculate the pollution emission embodied in the international trade of the US by applying the Industrial Pollution Projection System (IPPS), the World Bank, pollution emission intensity coefficients of US industries. Fæhn and Bruvoll (2009), Pan et al. (2008), and Peter and Herwich (2006), among others use an input-output table and national CO2 emission data to calculate the CO2 emissions embodied in the international trade of developed countries.

Following the methodology pursued by Ederington et al. (2004) and other studies, we use the world panel dataset constructed by Honma and Yoshida (2011) for

[1] see for example Subramanian and Wei (2007) for WTO role in promoting international trade

[2] See López (2005) and Singh (2011) for recent surveys on trade and growth.

the pollution emission embedded in international trade for the period between 1988 and 2009. The main objectives of Honma and Yoshida (2011) are to construct the world panel dataset for pollution emission embodied in international trade, to provide the summary statistics for each country and to discuss the groupings of countries by the directions of the composition shifts. This dataset contains the pollution emission directly linked to the production of exports (and imports) for a worldwide set of countries, which was constructed under the restricting assumption that the pollution intensity by each industry is fixed during the sample period. Specifically, the values of international trade data at six-digit commodities are mapped onto four-digit industries and multiplied by corresponding industry pollution intensity coefficients. This assumption is too restrictive for assessing the overall effect of the pollution haven hypothesis because there are three channels by which international trade may affect the environment of countries, namely, the scale effect, the technique effect, and the composition effect. However, this assumption is reasonable and useful in assessing the composition effect of international trade on the environment, as was used in this study. By implementing a new and much wider dataset, this paper complements the previous studies in the literature.

The empirical investigation provides evidence that income levels of countries are negatively related to export pollution intensity, but we also find that income is negatively related to import pollution intensity. Thus, the composition effect of international trade on the environment is only consistent on the exports side with the pollution haven hypothesis, which predicts that developing countries export more of dirtier industries and import more of cleaner industries after trade liberalization. Our finding provides strong evidence that developed countries are likely to experience a decline in pollution intensity in both exports and imports, while developing countries are likely to face increased pollution intensity in both exports and imports. Further investigation reveals that lower-middle income countries experienced an increase in pollution emission of exports and a decrease in pollution emission of imports, whereas countries in the lowest income group experienced increases in the pollution emission embodied in both exports and imports.

The structure of the rest of this paper is as follows. Section 2 briefly reviews the literature on the effects of international trade on the environment. Section 3 describes the worldwide dataset of pollution emission embodied in international trade and provides the empirical results. The implication of the results to the validity of the pollution haven hypothesis is thoroughly examined. Section 4 provides a discussion and conclusions.

2. Pollution emission in international trade

The effects of international trade on pollution emission are classified into three separate mechanisms by Grossman and Krueger (1993), who distinguish three sources by which a change in trade can induce a change in the level of pollution: scale, composition, and technique. The scale effect increases pollution emission due to expanded production in the economy if international trade stimulates economic growth. The composition effect affects the level of pollution emission through a change, due to (partial) specialization in industry induced by international trade, in the industry structure of the economy. The pollution haven hypothesis stresses the international relocation of pollution-intensive industries from countries with strict environmental regulations to countries with lax environmental regulations. The technology effect reduces pollution emission by adopting new production processes.

Antweiler et al. (2001) examine the effect of international trade on pollution emission by regressing pollution emission on scale, technique, and composition factors and studying the interaction terms of these factors with the trade openness measure; see also Cole and Elliot (2003) and Managi et al. (2009). Antweiler et al. (2001) find evidence that free trade with the combined effect of all three factors is beneficial for developing countries, although international trade causes a composition shift toward dirtier industries for developing countries. Frankel and Rose (2005) overcome the endogeneity problem of trade openness by using instrumental variable estimation. Using energy intensive trade and toxic intensive trade data, Cave and Blomquist (2008) find a partial support for the pollution haven hypothesis in the EU imports.

There exists another approach to investigating a change in international trade due to tariff and pollution abatement costs. By regressing the value of net imports on environmental regulation variables, Ederington et al. (2004) find that stricter regulation in US industry increases imports in that industry. Levinson and Taylor (2008) also find that US imports from Canada and Mexico increase in industries with higher pollution abatement costs. On the other hand, Tobey (1990), one of the earlier studies, find that the more stringent environmental regulations in developed countries do not affect the trade pattern of pollution intensive commodities.

Instead of investigating the relationship between international trade and the environment in the reduced form of the structured model, efforts were made to calculate the pollution emission incurred in producing products for international trade. The World Bank project develops the IPPS database for calculating the pollution intensity in US industries (Lucas et al., 1992 and Hettige et al., 1995). The pollution intensity for industry j is defined as the following:

$$\eta_j = \frac{\text{pollution emission in industry } j}{\text{value of } j\text{th industry output}}. \quad (1)$$

By imposing that pollution intensity is invariant, the amount of pollution emission can be calculated and compared across time and countries by simply calculating $\eta_j \times$ the value of output or trade flow. This database is used extensively in the following studies. Mani and Wheeler (1999) examine the pollution haven hypothesis for the period between 1960 and 1995 and find that the displacement of pollution-intensive industries from developed countries to developing countries is self-limiting and only transient. Muradian et al. (2002) calculate the pollution embodied in international trade for the US, Japan, and Western Europe by multiplying the trade volume by using the IPPS database, although only 11 out of 79 sectors are used for the calculation. Ederington et al. (2004) calculate the pollution embodied in US exports and imports by using all 79 IPPS sectors and corresponding pollution intensity coefficients and find that the compositions of both exports and imports of the US shifted toward cleaner industries. Levinson (2009) also used the IPPS pollution emission coefficients to calculate the pollution embodied in US international trade from 1987 to 2001, using input-output tables to account for intermediate inputs to imports.

Ederington et al. (2004) calculate the pollution emission embodied in US international trade from 1972 to 1994. Industries are defined as four-digit US SIC codes (459 industries). Industry pollution intensity, η_j, is held constant at the 1987 level, which is provided by the IPPS, the World Bank. This calculation, with constant pollution intensity, provides interesting insights, although it is only chosen by the lack of availability of pollution intensity data. By holding the pollution intensity (technique) constant, a one percent increase in trade value should also raise pollution by one percent, if the composition of industries does not change. Any deviation of pollution emission growth from trade growth only comes from the change in industry composition in trade. For example, the pollution emission growth rate is less than the trade growth rate if the composition of trade moves more toward cleaner industries. Interestingly, the calculation reported in Ederington et al. (2004) shows that both US exports and imports moved toward cleaner industries, although the composition shift is more drastic in US imports. Furthermore, Levinson (2009) revisits the shift in US production and international trade to cleaner industries for the more recent period between 1987 and

2001 by incorporating the input-output table of the US to examine the possible role of intermediate inputs.

In this study, we use the worldwide dataset of Honma and Yoshida (2011), in which the pollution emission embodied in international trade is calculated in a manner similar to that reported by Ederington et al. (2004) and Levinson (2009), for the period between 1988 and 2009 in over 150 countries. This dataset provides an opportunity to examine to what extent the composition shifts in international trade are consistent with the pollution haven hypothesis, applying the same methodology to both developed and developing countries.

3. Income, International Trade, and Pollution

Before we present the empirical results, in section 3-1 we briefly describe the methodology used in constructing Honma and Yoshida's (2011) worldwide database of pollution embodied in international trade. The main empirical results of an investigation of the relationship between the pollution emission embodied in international trade and the income levels of countries in the world panel dataset are provided in section 3-2. The results of further investigations made by separating the four income groups of countries are presented in sections 3-3 and 3-4.

3-1. The World International Trade Pollution Dataset

Honma and Yoshida (2011) constructed the worldwide dataset of pollution emission embodied in international trade. The values of international trade data for six-digit commodities, taken from the UN Comtrade database, are mapped onto four-digit industries and multiplied by corresponding industry pollution intensity coefficients, taken from the IPPS, the World Bank. The correspondence tables between different classifications are readily available from the United States Statistical Division. For each HS 6-digit export for a given year, we find a matching ISIC industry code and calculate an estimated pollution emission in pounds. For example, HS 873323 (automobile with engine size between 1,500 cc and 3,000 cc) is matched with ISIC 3843 (manufacture of motor vehicles), and IPPS provides an estimate of SO2 emission as 279 pounds per US million dollars.

Following the methodology in Ederington et al. (2004), Honma and Yoshida (2011) construct the panel of the estimated pollution emission that is directly related in the production of exports as follows:

$$\overline{E}_{it} = \sum_{j=1}^{79} \eta_{j,1987} E_{ijt} \ , \tag{2}$$

where $\overline{E}_{it}$ is the pollution emission embodied in exports in terms of pounds per US million dollars in year *t*, $\eta_{j,1987}$ is the pollution intensity coefficient in industry *j* from the IPPS, and E_{ijt} is the value of exports in industry *j* from country *i* in year *t*. By holding the pollution intensity (technique) constant, a 10% increase in exports value should also raise pollution 10% if the composition of industries does not change. Similarly for imports, Honma and Yoshdia (2011) construct the panel of pollution emission embodied in the production of imports as follows:

$$\overline{M}_{it} = \sum_{j=1}^{79} \eta_{j,1987} M_{ijt} \tag{3}$$

where $\overline{M}_{it}$ is the pollution emission embodied in imports in terms of pounds per US million dollars in year *t* and M_{ijt} is the value of imports in industry *j* from country *i* in year *t*.

Several caveats in this empirical methodology should be noted. First, we impose that all countries have the same pollution intensity coefficients as in the US because such data are not available for many countries. The estimation results, therefore, need to be interpreted with great care. Due to the lack of pollution emission data at the industry level, especially for developing countries, this study should be interpreted as the first attempt, with the best effort to approximate, to examine the worldwide changes in the composition of industries from the perspective of pollution emission. Second, however, time-invariant coefficients are necessary to address the effect of changes in industry composition for international trade. The sole focus in this paper is to examine the composition effect and not the other scale and technique effects. Third, the actual requirement in the underlying assumption need not be the same pollution intensity coefficients for all countries. This empirical exercise will be valid as long as there are only moderate differences in pollution intensity coefficients, such that the ordering of industries in pollution intensity are similar in all countries. Grossman and Krueger (1993) similarly apply the US pollution intensity coefficients to Mexico and Canada to assess the impact of NAFTA on these countries. Fourth, we do not account for the imported intermediated products in exports as other studies using input-output tables, see Fæhn and Bruvoll (2009), Pan et al. (2008), and Peter and Herwich (2006).

3-2. Export pollution intensity and Import pollution intensity

We investigated the possible relationship between pollution emission intensity in international trade and income level by applying panel data analysis to the database of Honma and Yoshida (2011). The pollution haven hypothesis predicts a negative correlation between pollution emission intensity in aggregate exports and income level of countries. Note that pollution emission intensity in aggregate exports declines only when the composition of exports moves toward cleaner industries. By dividing the pollution emission embodied in aggregate exports by the aggregated export value, we obtain the pollution intensity in aggregate exports. We estimate the following estimation model:

$$\frac{\overline{E}_{it}}{\sum_{j=1}^{79} E_{ijt}} = \beta \mathrm{GDPPC}_{\mathrm{it}} + \lambda_{\mathrm{i}} + \varepsilon_{\mathrm{it}} \qquad (4)$$

The dependent variable is the pollution intensity in aggregate exports, the explanatory variable is (PPP, constant 2005 international) GDP per capita, and the error term consists of individual specific and individual time-specific errors. We estimate equation (4) by both the fixed effect and the random-effect model and provide Hausman test statistics.

Table 1 shows the estimated results for 6 different pollutants, namely, SO2, NO2, CO, VOC, fine particulate, and TS particulate. Note that the number of countries is reduced to 119 after we exclude those countries with less than or equal to 11 annual observations. The first row provides fixed-effect estimates for GDP per capita and the third row provides random-effect estimates. All estimated coefficients are negative except for the random-effect estimate for VOC, and the negative coefficients of income are statistically significant for most of the pollutants. To interpret the magnitude of the income effect, an estimated -0.000043 for SO2, for example, indicates that the difference per one thousand dollars in GDP per capita creates a pollution intensity gap of 0.043 pounds per US million dollars of exports. For the US in 2009, the total exports covered by 79 ISIC industries in the IPPS are approximately 700 billion dollars. Therefore, an increase of one thousand dollars in US income per capita reduces SO2 emissions embodied in US exports by 30,100 pounds.

One implication is from the cross-sectional aspect of the world. Poor countries have higher pollution intensity in exports, and rich countries have lower pollution intensity in exports. This result is consistent with the pollution haven hypothesis. Our use of the panel dataset also provides an implication for the growth aspect of developing countries. As a poor country grows, the pollution intensity of its exports in general declines.

We also estimated the regression equation for import pollution intensity in equation (5), and the result is shown in Table 2.

$$\frac{\overline{M}_{it}}{\sum_{j=1}^{79} M_{ijt}} = \beta \mathrm{GDPPC}_{\mathrm{it}} + \lambda_{\mathrm{i}} + \varepsilon_{\mathrm{it}} \qquad (5)$$

The pollution haven hypothesis predicts a positive correlation between the pollution emission embodied in imports and income level. Surprisingly, a very similar result to that for export regression is also obtained for import regression. For many pollutants, the estimated coefficients are negative and statistically significant. For SO2, NO2 and VOC, both estimates of fixed- and random-effect models are negative and statistically significant. For CO, fine particulate, and TS particulate, only the estimated coefficients of the random-effect model are negative and statistically significant. The overall fitness of the regression is also more satisfactory compared with the export regression result.

The implication of this result, that poor countries import dirtier products whereas rich counties import cleaner products, contradicts the pollution haven hypothesis. Moreover, based on both regression results, this finding seems to suggest that poor countries (relative to rich countries) trade heavily in dirtier products in both exports and imports. We return to this issue in subsection 3-4.

3-3. Robustness check

Based on the results in previous subsections, we confirmed that the pollution haven hypothesis may hold at least for the exports side. In this subsection, we further examine the validity of the pollution haven hypothesis on the exports side. One important aspect of this hypothesis is the asymmetricity in the income level of countries; it is likely to occur in North-South trade but not between North-North or South-South trade. The construction of the panel dataset only determines the income level of the exporting country for the exports equation. The destination market is the aggregate of all importing countries. To consider a possible effect of the income level of the importing country in the exports equation, we reconstruct the dataset for the four groups of destination countries by income level, as classified by the World Bank[3]. Table 3 reports the estimated coefficients for income per capita of the regressions for pollution intensity in exports, separately by the destination countries' income level. The negative slope for the income level of the exporting country remains robust for each group, although there is a slight difference in magnitude. Therefore, the pollution haven

[3] See the Appendix for the definition of income groups.

hypothesis still holds for exports, even if we control for the income group of the importers.

The validity of the pollution haven hypothesis on exports can be further tested with different income groups of importers. Note that pollution intensity is a positive value, and it is likely to be higher for a pair of South-exporter and North-importer countries than for a pair of South-exporter and South-importer countries. To help understanding of the argument for intercept terms, we provide a simple illustration for the case of two income groupings in Figure 1. For the pollution intensity (as the vertical axis) and exporters' income (as the horizontal axis) coordinates in Figure 1, the intercepts are expected to be higher for the high-income importer group[4]. Table 4 shows the estimated intercepts from the random-effect model by the importer's income groups[5]. Contrary to the implication of the pollution haven hypothesis, the intercepts are generally higher for low-income importers. Even the exports side may not be consistent with the pollution haven hypothesis when we carefully examine the implicit asymmetricity of income level between trade partners.

We also conducted similar exercises for an import regression, and the results are reported in Tables 5 and 6. The negative slope is persistent even when we run import pollution intensity regressions for the disaggregated partners' (in this case, exporters' income level). For the corresponding figure of import pollution intensity, the pollution haven hypothesis predicts the higher intercept for the low-income group of exporters; the locations of the curves of high- and low-income groups are simply exchanged. As shown in Table 6, we find that the higher intercepts are obtained for the middle-income group, and this evidence does not match with the North-South feature of the pollution haven hypothesis. For the import pollution intensity, our results are inconsistent with the pollution haven hypothesis in terms of both the intercepts and the slope of the income level of countries.

3-4. Revisiting the pollution haven hypothesis

Utilizing the world international trade pollution dataset for the period between 1988 and 2009, we examined how the pollution intensity of international trade is related

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[4] Strictly speaking, the pollution haven hypothesis only predicts the relative heights of line segments (A) and (D). The relative heights of (A) and (B) can be discussed only by assuming the two lines never crosses each other.

[5] The random-effect model is chosen because we want to examine the difference in intercepts, whereas the fixed-effect model does not provide an intercept. In addition, the Hausman tests are not rejected for almost all cases, supporting the use of the random-effect model over the fixed-effect model.

to the income level of countries. So far, we showed that the pollution intensity in both exports and imports declines with respect to the income level of countries. This finding contradicts the assumption of the pollution haven hypothesis, in which high-income countries move toward the production of cleaner industries and therefore export cleaner products and import dirtier products with more liberalization of international trade. The analysis of the world dataset reveals the opposite for imports, while the hypothesis is only consistent on the exports side with the limitations raised in the previous subsection.

The pollution haven hypothesis is not based on observations from the worldwide dataset when the hypothesis was first proposed. It is interesting to view the development of international trade in terms of pollution emission based on the income level of countries in the last two decades. We provide an overview of the composition shifts in both exports and imports of countries classified into four income-level categories of the World Bank. Table 7 provides a summary of the SO2 pollution emission growth of exports and imports by the income level of countries. For example, the first column, ex(+)im(+), indicates that the 15 percent of high income countries experienced an increase in pollution emission intensity of both exports and imports. Figure 2 shows four plots for each country by income level along with one figure with all countries combined. By looking at both exports and imports, four outcomes (dirtier exports and dirtier imports, dirtier exports and cleaner imports, cleaner exports and cleaner imports, and cleaner exports and dirtier imports) are possible.

By investigating the composition shifts of international trade by each income group, we find the following three results. First, there exists a relatively high concentration of one outcome type for each income group. For high-income and upper-middle income group, the pollution emission embodied in international trade declined in both exports and imports. This result is consistent with our regression results and with results from previous studies using US data. For the lower-middle income group, the pollution emission in exports increases while the pollution emission in imports decreases, which is typical of the pollution haven hypothesis if the lower-middle income group is identified as developing countries. For low-income countries, pollution emission in both exports and imports increased over the sample years. Therefore, from the perspective of developing countries, including both lower-middle and low-income countries, the composition of exports moved toward dirtier industries. However, note that for low-income countries, the composition of imports also moved toward dirtier industries.

Second, however, the analysis reveals that all four possible outcomes are observed for each income level of countries. Therefore, we can argue for the most likely outcome of the composition shift in international trade for a given income group, but we can also expect to observe different outcomes. We also need to keep exploring possible causes for shifts in the pollution content of international trade in addition to the income level of countries.

Third, we cannot exclude the possibility that the composition shift effect is negligible for some countries. Even with the small bandwidth, some countries are classified as no change in composition effect as we move to the lower panels in Table 7. Note that the shift is only the net effect of composition changes in industries, so there may be a large composition change in trade structure, although the net effect is very small.

4. Discussion and conclusions

Utilizing the world panel dataset for the pollution emission embedded in international trade for the period between 1988 and 2009, we investigated whether the composition of international trade for a country moved toward pollution-intensive industries as the income level of countries increased.

However, we should note that the analysis of this research needs to be interpreted with some caution. First, the overall effect of international trade on production needs to consider both the direct effect on domestic production for exports and the indirect effect on production, which is induced by specialization due to trade opening, for domestic consumption. We only investigated the direct effect. Second, applying the US pollution emission coefficient to other countries, especially to developing countries, produced a bias in evaluating the composition shifts. However, the bias need not be large if the rankings of industries in pollution emission are similar in countries across the world. We presumed the same industries are classified as dirty in both developed and developing countries. Third, this study only investigated the composition effect defined by Grossman and Krueger (1993), and the net effect needs to consider the other two effects, namely, the technique effect and the scale effect. Antwiler et al. (2001) conclude that the net effect of international trade improves the environment, and Levinson (2009) argues that the largest effect is the technique effect.

Within the limitations mentioned above, the empirical evidence reveals that the income level of countries is negatively related with export pollution intensity and also negatively related with import pollution intensity. Thus, the composition effect of international trade on the environment is only consistent with the pollution haven hypothesis on the export side, which predicts that developing countries export dirtier industries and developed countries export cleaner industries after trade liberalization.

This partial support of the pollution haven hypothesis only from the exports side is consistent with previous studies. Ederington et al. (2004) also find that the US experienced a decline in both export and import pollution intensity.

Further investigation, using four groups of income level for trade partners, reveals that high-income countries and upper-middle income countries are likely to experience a decline in international trade for pollution-intensive industries in both exports and imports, whereas lowest income countries are likely to have a higher proportion of pollution-intensive industries in international trade[6].

Our finding supports the conclusion that the composition effect of international trade leads developing countries to shift their exports and imports to dirty industries. However, we should note that the overall effect of international trade on the environment in developing countries also depends on the reduction in pollution intensity due to the introduction of new technology from developed countries[7].

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[6] It is also possible to use a bilateral gravity equation as in Tsurumi et al. (2011) to investigate bilateral pollution emissions embodied in trade. This analysis is left for a future research.

[7] Note that technology diffusion from the North to the South does not always improve the environment of the South as shown by Di Maria and Smulders (2004).

Appendix:

Pollution emission data

We use the worldwide panel dataset of pollution emission embodied in international trade in Honma and Yoshida (2011). The following original data sources are used for constructing the dataset; see details in Honma and Yoshida (2011).

Correspondence tables

The correspondence table between the HS (ver.1996) and the ISIC (ver.3) is taken from the United Nations Statistical Division. The corresponding table between ISIC (ver.3) and ISIC (ver.2) is also taken from the same source.

Pollution intensity data

The World Bank, under the IPPS and in collaboration with the Center for Economic Studies of the US Census Bureau and the US Environmental Protection Agency, developed estimates of pollution intensity for each of 79 sectors for the International Standard Industrial Classification (ISIC). The estimates for 14 categories of pollutants are constructed from approximately 200,000 factories in all regions of the US.

Export data

The United Nations (UN) Comtrade database provides detailed exports at Harmonized System (HS) 6-digit level for over 200 countries and regions. For each country with exports data available, the values of exports to the world in terms of US dollars for each HS 6-digit products are obtained for the period between 1988 and 2009. The total size of the dataset exceeded ten gigabytes.

Income data and grouping by WDI

Country grouping by income level is provided in the World Development Indicators (WDI), the World Bank. The World Bank classifies countries into low, lower middle, upper middle, and high-income countries. We obtained these data for 1988, 1995, and 2009 from the issues in 1990, 1997, and 2010, respectively. The matching between the UN Comtrade and WDI requires careful procedures. The most updated UN Comtrade database keeps former country names, whereas the WDI delete those country names in the updated database. We chose the 1995 data for the WDI country classification because these data represent a fairly middle of the sample period. The 1988 WDI data misses 103 countries appearing in the later issues of the WDI, and the 2009 data may bias the initial income level of countries with relatively rapid growth. Out of 224 countries (including former countries), 206 countries appeared at least two times in the three sample years. The change in income classification occurred for 77 countries, of which more than one rank change are observed for only 5 countries. In the followings, countries are classified into four income groups and only those with more than 11 observations in either exports or imports sample are listed. Note that countries with + are not included in some (or all) of export samples and countries with * are not included in some (or all) of import samples.

High income (26 countries)
Australia, Austria, Canada, Cyprus, Denmark, Finland, France, Germany, Hong Kong SAR, Iceland, Ireland, Israel, Italy, Japan, Republic of Korea, Macao SAR, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, United Kingdom, USA.

Upper-middle income (20 countries)
Argentina, Brazil, Chile, Croatia, Czech Rep, Gabon, Greece, Hungary, Malaysia, Malta, Mauritius, Mexico, Oman, Saint Kitts and Nevis, Saint Lucia, Saudi Arabia, Seychelles, Slovenia, Trinidad and Tobago, Uruguay.

Lower-middle income (40 countries)
Algeria, Bolivia, Belize, Bulgaria, Belarus, Cape Verde+, Colombia, Costa Rica, Dominica, Ecuador, El Salvador, Estonia, Grenada, Guatemala, Indonesia, Jamaica, Jordan, Lebanon, Latvia, Lithuania, Maldives, Rep of Moldova, Morocco, Panama, Paraguay, Peru, Philippines, Poland, Romania, Russian Federation, Saint Vincent and the Grenadines, Slovakia, Suriname, Thailand, Tunisia, Turkey, Ukraine, TFYR of Macedonia, Egypt, Venezuela.

Low income (35 countries)
Albania, Azerbaijan, Bangladesh, Armenia, Burundi, Cameroon+, Central African Rep+, Sri Lanka, China, Comoros+, Ethiopia, Georgia, Ghana+, Guinea, Guyana, Honduras, Cote d'Ivoire, Kenya, Kyrgyzstan, Madagascar, Malawi, Mali, Mongolia*, Nicaragua, Niger, Nigeria, Rwanda, Senegal, India, Sudan, Togo, Uganda, United Rep of Tanzania, Burkina Faso, Zambia.

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Table 1. Panel estimates of pollution intensity in exports

	SO2	NO2	CO	VOC	Fine Particulate	TS Particulate
Fixed	-0.000043*	-0.000023*	-0.000024	-0.000002	-0.000009	-0.000009
	(0.000022)	(0.000013)	(0.000021)	(0.000006)	(0.000010)	(0.000009)
Adj. R2	0.59	0.63	0.77	0.76	0.50	0.59
Random	-0.000047**	-0.000024**	-0.000016*	0.000000	-0.000029**	-0.000025*** -
	(0.000019)	(0.000009)	(0.000008)	(0.000004)	(0.000014)	(0.000009)
Adj. R2	0.01	0.01	0.00	0.00	0.02	0.05
Hausman	0.1	0.0	0.1	0.1	0.0	0.0
No. of countries	119	119	119	119	119	119
NOB	1981	1981	1981	1981	1981	1981

Note: The estimated coefficients for income per capita are reported. The number of countries is 119 after excluding countries with less than or equal to 11 observations. The standard errors are in parenthesis and robust for fixed-effect regressions. The statistical significance at the one, five, and ten percent levels are indicated by ***, **, *, respectively.

Table 2. Panel estimates of pollution intensity in imports

	SO2	NO2	CO	VOC	Fine Particulate	TS Particulate
Fixed	-0.000032***	-0.000027***	-0.000006	-0.000013***	0.000008**	-0.000002
	(0.000007)	(0.000005)	(0.000008)	(0.000003)	(0.000004)	(0.000003)
Adj. R2	0.83	0.80	0.60	0.56	0.84	0.84
Random	-0.000055***	-0.000039***	-0.000021***	-0.000015***	-0.000008*	-0.000013***
	(0.000007)	(0.000003)	(0.000004)	(0.000002)	(0.000005)	(0.000003)
Adj. R2	0.32	0.37	0.19	0.20	0.18	0.24
Hausman	313.4***	15.5***	4.1**	1.1		
No. of countries	120	120	120	120	120	120
NOB	2005	2005	2005	2005	2005	2005

Note: The estimated coefficients for income per capita are reported. The number of countries is 120 after excluding countries with less than or equal to 11 observations. The standard errors are in parenthesis and robust for fixed-effect regressions. The statistical significance at the one, five, and ten percent levels are indicated by ***, **, *, respectively.

Table 3. Pollution intensity in exports by destination countries' income group

	SO2	NO2	CO	VOC	Fine Particulate	TS Particulate	NOB (countries
Fixed							
High	-0.000055**	-0.000030**	-0.000025	0.000002	-0.000023**	-0.000016*	1977
	(0.000024)	(0.000013)	(0.000022)	(0.000005)	(0.000010)	(0.000009)	(119)
Upper Middle	-0.000048	-0.000029*	-0.000030	-0.000002	-0.000005	-0.000014	1961
	(0.000030)	(0.000017)	(0.000035)	(0.000009)	(0.000010)	(0.000009)	(119)
Lower Middle	-0.000056**	-0.000033**	-0.000025	-0.000011*	-0.000012	-0.000021*	1951
	(0.000025)	(0.000013)	(0.000020)	(0.000006)	(0.000016)	(0.000012)	(119)
Low	-0.000109*	-0.000046	-0.000060	-0.000018*	-0.000064	-0.000032	1977
	(0.000056)	(0.000029)	(0.000040)	(0.000010)	(0.000043)	(0.000026)	(119)
Random							
High	-0.000037***	-0.000022***	-0.000013	0.000004	-0.000014***	-0.000019***	1977
	(0.000010)	(0.000006)	(0.000009)	(0.000004)	(0.000005)	(0.000005)	(119)
Upper Middle	-0.000041**	-0.000026***	-0.000019	-0.000007	-0.000017*	-0.000026***	1961
	(0.000017)	(0.000009)	(0.000012)	(0.000005)	(0.000009)	(0.000007)	(119)
Lower Middle	-0.000050***	-0.000030***	-0.000018	-0.000011**	-0.000025**	-0.000027***	1951
	(0.000018)	(0.000009)	(0.000012)	(0.000005)	(0.000011)	(0.000008)	(119)
Low	-0.000114***	-0.000052***	-0.000045***	-0.000017***	-0.000072***	-0.000047***	1977
	(0.000029)	(0.000014)	(0.000015)	(0.000006)	(0.000022)	(0.000013)	(119)

Note: The estimated coefficients for income per capita are reported. The standard errors are in parenthesis and robust for fixed-effect regressions. The statistical significance at the one, five, and ten percent levels are indicated by ***, **, *, respectively.

Table 4. The constant term in a random-effect model for pollution intensity in exports by importers' income group

Random	SO2	NO2	CO	VOC	Fine Particulates	TS Particulate	NOB (countries
High	3.41***	2.29***	2.30***	1.24***	0.92***	1.68***	1977
	(0.24)	(0.14)	(0.22)	(0.10)	(0.09)	(0.12)	(119)
Upper Middle	4.30***	2.90***	2.97***	1.75***	1.12***	1.83***	1961
	(0.31)	(0.17)	(0.25)	(0.10)	(0.15)	(0.13)	(119)
Lower Middle	4.65***	3.10***	3.07***	1.77***	1.44***	1.92***	1951
	(0.33)	(0.17)	(0.25)	(0.11)	(0.18)	(0.15)	(119)
Low	7.15***	4.20***	3.98***	2.03***	3.05***	2.85***	1977
	(0.58)	(0.29)	(0.31)	(0.12)	(0.43)	(0.26)	(119)

Note: The estimated constant terms are reported. The standard errors are in parenthesis. The statistical significance at the one, five, and ten percent levels are indicated by ***, **, *, respectively.

Table 5. Pollution intensity in imports by source countries' income group

	SO2	NO2	CO	VOC	Fine Particulate	TS Particulate	NOB (countries
Fixed							
High	-0.000036***	-0.000025***	-0.000020***	-0.000007***	0.000002	-0.000008***	1992
	(0.000007)	(0.000005)	(0.000007)	(0.000002)	(0.000004)	(0.000003)	(119)
Upper Middle	-0.000105***	-0.000068***	-0.000050**	-0.000017*	-0.000039***	-0.000044***	1992
	(0.000022)	(0.000013)	(0.000020)	(0.000010)	(0.000012)	(0.000011)	(119)
Lower Middle	-0.000093**	-0.000061***	0.000035	-0.000015**	-0.000041	-0.000035*	1992
	(0.000039)	(0.000018)	(0.000023)	(0.000007)	(0.000030)	(0.000019)	(119)
Low	0.000022	0.000003	0.000081***	-0.000002	0.000020	0.000011	1991
	(0.000018)	(0.000009)	(0.000017)	(0.000004)	(0.000013)	(0.000008)	(119)
Random							
High	-0.000032***	-0.000021***	-0.000011***	-0.000007***	-0.000004	-0.000009***	1992
	(0.000005)	(0.000003)	(0.000004)	(0.000001)	(0.000003)	(0.000002)	(119)
Upper Middle	-0.000125***	-0.000077***	-0.000052***	-0.000024***	-0.000055***	-0.000053***	1992
	(0.000019)	(0.000009)	(0.000008)	(0.000004)	(0.000015)	(0.000009)	(119)
Lower Middle	-0.000164***	-0.000092***	-0.000011	-0.000020***	-0.000092***	-0.000063***	1992
	(0.000039)	(0.000018)	(0.000010)	(0.000003)	(0.000033)	(0.000019)	(119)
Low	-0.000034*	-0.000027***	0.000003	-0.000017***	-0.000019	-0.000015*	1991
	(0.000018)	(0.000008)	(0.000006)	(0.000003)	(0.000014)	(0.000008)	(119)

Note: The estimated coefficients for income per capita are reported. The standard errors are in parenthesis and are robust for fixed-effect regressions. The statistical significance at the one, five, and ten percent levels are indicated by ***, **, *, respectively.

Table 6. The constant term in a random-effect model for pollution intensity in imports by exporters' income group

Random	SO2	NO2	CO	VOC	Fine Particulate	TS Particulate	NOB (countries
High	3.27***	2.41***	2.33***	1.64***	0.67***	1.09***	1992
	(0.11)	(0.06)	(0.07)	(0.03)	(0.07)	(0.05)	(119)
Upper Middle	7.42***	4.75***	4.16***	2.34***	2.75***	3.18***	1992
	(0.37)	(0.18)	(0.15)	(0.07)	(0.28)	(0.18)	(119)
Lower Middle	10.47***	5.96***	4.78***	2.16***	5.17***	4.22***	1992
	(0.86)	(0.39)	(0.21)	(0.07)	(0.74)	(0.42)	(119)
Low	4.44***	2.97***	1.99***	1.62***	1.89***	1.81***	1991
	(0.42)	(0.19)	(0.11)	(0.05)	(0.32)	(0.20)	(119)

Note: The estimated constant terms are reported. The standard errors are in parenthesis. The statistical significance at the one, five, and ten percent levels are indicated by ***, **, *, respectively.

Table 7. Distribution of countries by composition changes and income group

width=0.0	ex(+) im(+)	ex(+) im(-)	ex(-) im(-)	ex(-) im(+)
high	0.15	0.18	0.50	0.18
upper middle	0.24	0.24	0.37	0.16
lower middle	0.25	0.38	0.21	0.17
low	0.45	0.10	0.10	0.35

width=0.1	ex(+) im(+)	ex(+) im(-)	ex(-) im(-)	ex(-) im(+)
high	0.15	0.19	0.46	0.19
upper middle	0.25	0.28	0.40	0.08
lower middle	0.27	0.39	0.20	0.15
low	0.47	0.13	0.13	0.27

width=0.5	ex(+) im(+)	ex(+) im(-)	ex(-) im(-)	ex(-) im(+)
high	0.22	0.11	0.44	0.22
upper middle	0.21	0.21	0.53	0.05
lower middle	0.26	0.39	0.22	0.13
low	0.67	0.00	0.17	0.17

Note: Pollutant is SO_2. Width indicates the threshold value of changes in the absolute term. The number of countries is 153. For width=0.1, the number of countries with changes greater than 0.1 in both exports and imports is 122. For width=0.5, the number of countries with changes greater than 0.5 in both exports and imports is 57.

Figure 1. The predicted relationships between exports pollution intensity and income level

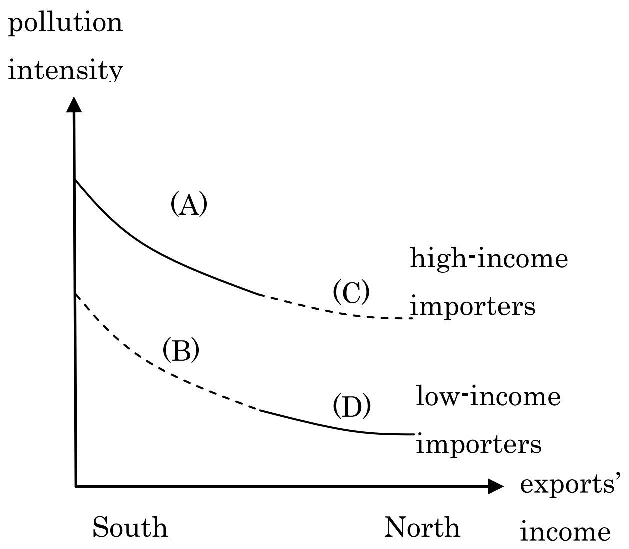
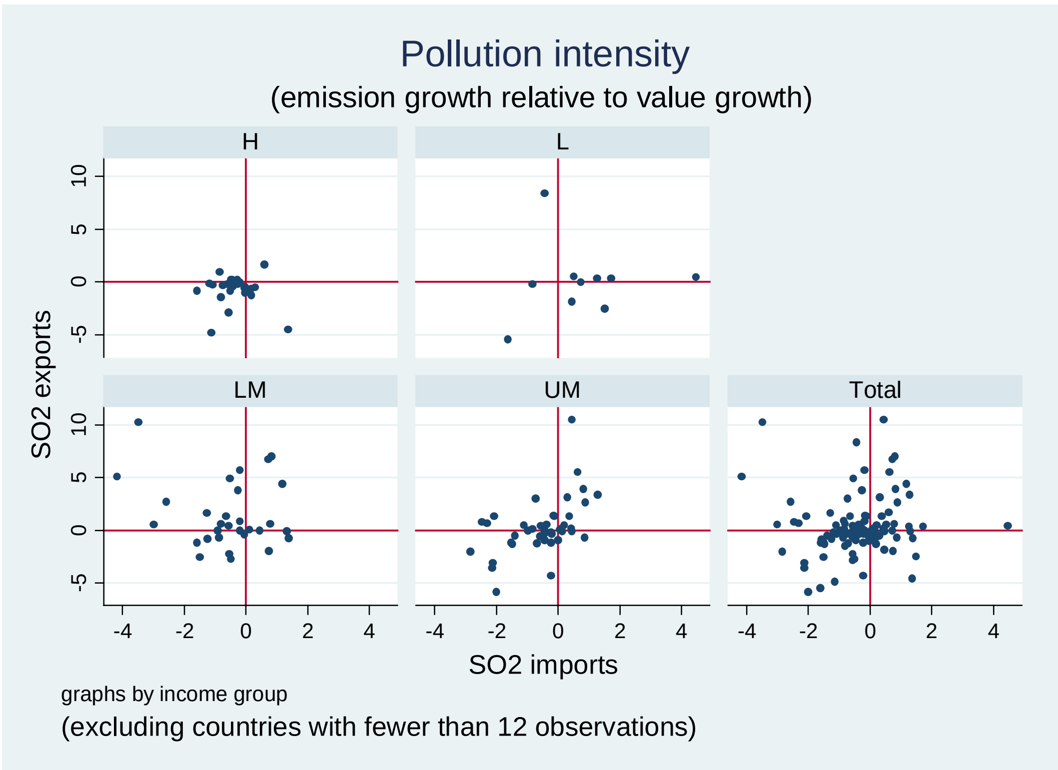


Figure 2. The composition changes in exports and imports by country groups



Note: The high values of emission growth in exports of Togo (40.5), Uganda (139.2), and Rwanda (116.5) in the low-income group are suppressed from the plots for the sake of presentations.