Water Pollution from Industrial Sources: Is Dirty the New Clean?

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Abstract

This study analyzes the economic activity-BOD (Biochemical Oxygen Demand) relationships of the so-called 'dirty' and 'clean' water polluting industries, during the period 1995-2005. Results indicate the economic activity-environment trade-off of 'dirty' and 'clean' industrial sectors has been altered during the period of study. On average, pollution-intensive 'dirty' industries in the poorest nations were found to benefit – in terms of BOD emissions – from extra exports and openness to trade. The opposite was true for 'clean' sectors where increased trade openness seems to have contributed to a wider gap between poor and rich nation's pollution intensities. With openness to trade skewing innovations away from industrial activities in which the poorest countries specialize and those 'clean' sectors becoming the largest emitters and fastest growing sources of emissions, this trend is likely to continue. More attention should be paid to 'clean' sectors as little global improvement in emission reductions is likely to be achieved if the so-called 'clean' industries and especially the ones identified as 'cleaner' sectors are not considered.

Keywords: Trade openness; Economic growth; Biochemical oxygen demand, Environmental degradation.

JEL: F_{18}, O_{14}, Q_{53}

1. Introduction

In an increasing integrated world, falling barriers to trade and decreasing transportation costs mean that the role trade has on environmental quality is greater than ever. Over the period 1995-2005, world merchandise trade as a share of global gross domestic product increased from 34.5 to 46.0 percent, a significantly larger expansion than the one seen in the previous decades, from 28.8 percent in 1975 to 30.7 percent in 1985 (World Bank, 2014). This unprecedented increase in economic integration across the globe most likely affected industrial pollution-intensities in the poorest nations' 'dirty' and 'clean' industrial categories. Those changing

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patterns of pollution intensity can have significantly impacted the magnitude of the effects ‘dirty’ and ‘clean’ industries place on the environment.

In this paper, we examine the impact of trade-induced economic growth on pollution intensities from ‘dirty’ and ‘clean’ industrial categories in poor and richer nations, for the period 1995-2005.[2] As countries become more economically integrated and specialize in activities in which they enjoy a comparative advantage, different industrial sectors are expected to display different economic activity-pollution patterns. Previous studies on the economic activity-BOD relationship did not recognize the changes in pollution-intensity in the poorest nations’ ‘dirty’ and ‘clean’ industrial sectors as they expanded their levels of economic activity. Results will indicate whether environmental quality gains can be expected in ‘dirty’ and ‘clean’ industrial sectors with further economic integration.

The interaction between trade openness and environmental degradation is one of the most controversial issues in the environmental economics literature due to trade’s potentially mixed environmental effects. Trade leads to an increase in the size of the economy and may exacerbate environmental degradation, but also motivate its reduction. Trade affects pollution emissions through the interaction of three elements: the scale, composition, and technique effects (Grossman and Krueger, 1991; World Bank, 1992; Copeland and Taylor, 2004). The scale effect is triggered by additional industrial production that results from trade liberalization. The composition effect results from changes in the structure of the economy due to trade specialization and could be positive or negative depending on the country’s source of comparative advantage. The technique effect refers to the result of trade liberalization leading to the adoption of better and cleaner sets of technologies.

[2] If erasing national borders and the reduction of transaction costs lead to significant changing patterns of water pollution industries’ environmental performance, the evidence should emerge and be more evident during the period 1995-2005 in which globalization expanded the most.

Earlier studies on the effect of trade openness on pollution intensities can be divided into three strands of research. The first concentrates on the relationship between economic growth and the environment, and it is mainly dedicated to testing the validity of the Environmental Kuznets Curve hypothesis (Grossman and Krueger, 1991).[3] For the inverse U-shape curve to occur, the impact of the income-induced technique effect should be sufficiently strong so as to more than neutralize the adverse effects of the scale effect.[4] The second strand of research is mostly devoted to the analysis of the trade-environmental composition effect (Antweiler et al., 2001; Copeland et al., 2004; Cole et al., 2004, 2005; Levinson, 2010; Neumayer, 2001; Muradian et al., 2002). The majority of this growing body of literature is devoted to investigating whether the changes in aggregated pollution intensities resulted from changes in the composition of the output mix caused by the relocation of pollution intensive 'dirty' industries to countries with lax environmental regulations (the pollution haven hypothesis).[5] The third strand and most recent theory and empirical studies investigate if aggregated pollution intensity indicators, measured as emissions per capita and per unit of GDP, tend to converge over time across countries as trade integration promotes the diffusion of best practice technologies (Strazicich et al. 2003; Brock et al., 2004; Stern, 2005a, 2005b).

Trade liberalization enables developing countries, which as a group undertake little domestic research and development (R&D), to access and adopt the more productive technology that is available in other countries whether through foreign direct investment or not.[6] Developing nations are believed to be well-placed for an 'environmental catch-up' with developed countries

[3] Dinda (2004) and Stern (2004) summarize the state of knowledge on the EKC.
[4] The role of the technique effect, particularly technological progress, as the main cause of reduce emissions per capita has being well established in the literature (Porter, 1990; Grossman and Krueger, 1995; Copeland et al., 2004)
[5] For an extensive review survey on the pollution haven hypothesis see Taylor (2004).
[6] Countries in deciles 1 to 5 represented only 2.9 percent of total world expenditures on R&D, in 1995. The remaining 97.1 percentage pertains to countries in deciles 6 to 10 (UNESCO Institute for Statistics, 2014).

(Abramovitz, 1986; Brock et al., 2004) as they benefit from the 'latecomer's advantage,' absorbing and diffusing new technologies through their economies faster than early adopting countries (Iwami, 2005; Perkins, 2005). The latter argument rests on the assumption that foreign firms have a technological advantage vis-à-vis domestic firms in those developing countries.

This present article has several distinguishing features. First, attention is focused on the relationship between trade-induced economic growth and pollution intensities from 'dirty' and 'clean' industrial categories, during the period 1995-2005. Earlier studies focus their attention toward pollution-intensive 'dirty' sectors not adequately recognizing the importance of the so-called 'clean' industries especially the ones identified as the 'cleanest' categories. Despite being labeled as the 'cleanest' industrial sectors, categories 32 and 38-39 were the fastest growing and the largest contributors of industrial BOD emissions over the period 1995-2005. Those categories increased from representing 45 percent of total BOD industrial emissions coming from industrial water polluting sectors in 1995 to about 56 percent in 2005 (World Bank Database, 2014).

Second, by standardizing the results, the methodology permits us to identify patterns of pollution intensity in 'clean' and 'dirty' industrial sectors in poor and richer nations. It also allows detecting changes in levels of regressivity on economic activity-BOD emissions relationships. Declining levels of the regressivity would suggest the poorest countries' environmental performance to be converging over time with the richer nations. The methodology used also helps determine if, as frequently asserted, pollution-intensive sectors grew faster in the poorest countries, changing the composition of their output.

The third difference pertains to country coverage. This study covers 30 OECD and 40 non-OECD countries, the largest number of countries for which data on 'dirty' and 'clean' industrial BOD emissions is available.[7] This extensive country coverage will provide a comprehensive picture of the effects of trade integration on industrial pollution intensities over the period 1995-2005.[8] Finally, rather than comparing BOD emissions with various polynomial specifications of per capita income, this study compares pollution emissions with levels of economic activity (GDP, industrial value added, exports, and trade) over time and across industrial sectors.[9] The environmental goal should be to reduce pollution emissions relative to economic activity, not relative to per capita income. The findings in this paper are potentially of large practical importance to developing effective environmental policies. A better understanding of the environmental quality–economic activity relationships from 'clean' and 'dirty' industrial sectors will support the formulation of more effective policies to reduce global emissions.

2. Methodology and Data

In this paper, the Suits' index serves as a measure of collective progressivity of pollution to study the accumulated water pollution concentrations relative to levels of economic activity. Similar to the Gini coefficient, the index serves as a summary measure of the observed pollution shares among countries across the entire income scale during the period 1995-2005.

Table 1 ranks countries in ascending order according to their per capita GDP and groups them in deciles based on per capita income. Figures are then converted from percentages and accumulated. For the Lorenz curve, the cumulative percent of total pollution is calculated and plotted on the vertical axis against the cumulative percent of the total GDP on the horizontal axis.

[7] Data for year 1995 for some countries refer to a later year.
[8] For example, Grossman and Krueger (1995) have only 58 countries in their sample, Hettige et al. (1997) 15 countries, Sigman (2002) 49 countries, Clark (2002) 110 countries for 1998, Cole (2004) 11 countries, Gürlük (2009) covers BOD emissions for 15 countries, Tsuzuki (2009) 42 countries.
[9] BOD emissions are measured by standard procedures helping guarantee consistency in data quality across countries and making it a reliable water pollution indicator for inter-country comparisons (See Sigman, 2002).

Figures 4-7 are Lorenz curves that relate BOD emissions to GDP, IVA, exports, and trade openness.

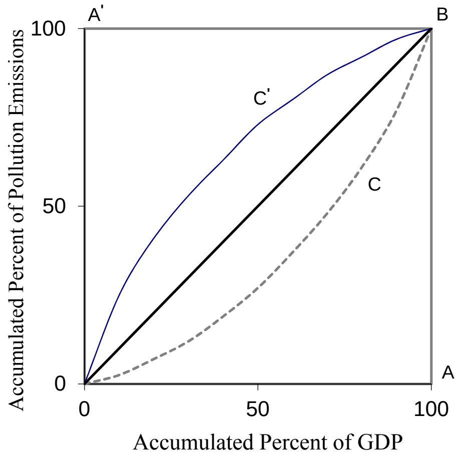

Figure 1
Lorenz Curves for Pollution

The Suits' index is calculated by comparing the area under the Lorenz curve to the area under a proportional line. The accumulated percent of economic activity, y_i, is measured on the horizontal axis of Figure 1. On the vertical axis, we measure the corresponding accumulated percent of total emissions. The index can be expressed as $S_x = (K - L)/K = 1 - (L/K)$, where K represents the area below the line of proportionality (the area of triangle $0AB$), L_x denotes the area below or above the Lorenz curve, and $E_x(y)$ the level of emission x.[10] Values of $E_x(y)$ for ten deciles and for $y_0 = 0$ provide a close approximation to the value of the integral as:

$$L_x = \int_0^{100} E_x(y)dy = \sum_1^{10} (1/2)[E_x(y_i) + E_x(y_{i-1})](y_i - y_{i-1}) \quad (1)$$

And the index for emission x is given by:

$$S_x = 1 - (1/K) \sum_1^{10} (1/2)[E_x(y_i) + E_x(y_{i-1})](y_i - y_{i-1}) \quad (2)$$

[10] Mathematical properties of the index are discussed in Suits D.B. (1977).

Since the base and the height of Figure 1 are both 100, the area K = 5,000 for all pollutants. For a regressive pollution, $S_x < 0$, the Lorenz curve arches above the line of proportionality, making the area L_x larger than K. Values of the index can vary from $-1 \leq S_x \leq +1$. A proportional pollution has $S_x = 0$. $S_x = -1$ indicates that pollution is completely regressive, and $S_x = +1$ indicates a progressive pollution where all pollution derives from high-income countries.

Water pollution on BOD emissions is extracted from the World Development Indicators (WDI) of the World Bank and is available for 70 countries spanning the entire range of per capita income.[11] Industrial shares of BOD refer to emissions from manufacturing industries according to the two-digit divisions of the International Standard Industrial Classification ISIC Rev.2 as defined by the United Nations Statistics Division (UNSD). Due to the non-availability of 3-digit data on BOD emissions, we divide 'dirty' and 'clean' industrial emissions based on broader (2-digit) categories, which can slightly differ from what would be concluded from the 3-digit data. BOD emissions pertain to ISIC Categories 31-39: Food Industry (31), Textile Industry (32), Wood Industry (33), Paper and Pulp Industry (34), Chemical Industry (35), Non-metallic Mineral Products (36), Metal Industry (37), Fabricated Metal Products and Professional Goods (38), and other Industries (39).

Two approaches have been used in the literature to identify pollution-intensive 'dirty' sectors. The first approach uses levels of abatement expenditure per unit of output; the second uses levels of pollution intensity (emissions per unit of output). 'Dirty' industries have been identified as those sectors with the highest level of pollution abatements in the US and other OECD countries (Robison, 1988; See Tobey, 1990) and highest pollution intensities (See Hettige

[11] The data were obtained from Hettige H., M. Mani, and D. Wheeler (1998) "Industrial Pollution in Economic Development: Kuznets Revisited" and updated by the World Bank's Development Research Group through 2004.

et al., 1995; Mani et al., 1998; Gallagher et al., 2000).[12] Four sectors have emerged as water pollution-intensive leading candidates using those classification criteria: Food industries (31), Pulp and Paper (34), Industrial Chemicals (35), and Iron and Steel and Non-Ferrous Metals (37).[13] On the other hand, the sectors with the lowest pollution intensities are textile, wearing apparel and leather industries (32), manufacture of fabricated metal products (38) and other manufacturing industries (39). Despite the lack of comprehensive data on pollution-intensities in developing countries, we reasonably assume that 'dirty' sectors in richer countries are the most pollution-intensive sectors across both rich and poor countries. Organic water pollutant emissions are reported in thousand kilograms per day.

Measures of economic activity including GDP, IVA, exports, and trade openness pertaining to 2005 and 1995 are measured in constant 2000 U.S. dollars. Data on GDP and IVA are extracted from the World Bank. Exports and imports are retrieved from UN Comtrade using the Standard International Trade Classification (SITC) Rev. 3 at a two-digit level. The data is converted from SITC Rev. 3 to ISIC Rev. 2 using Maskus (1989) conversion factors.[14] The resulting data is complemented with the CEPII Trade, Production and Bilateral Protection Database.[15]

Tables 1 and 3 are arranged according to income deciles in a manner that facilitates the calculation of Suits' indices. Table 1 compares the distribution of water pollution emissions from industrial 'clean' and 'dirty'-sectors to measures of economic activity. Table 3 shows the

[12] Hettige et al. (1998) used emission intensities from US industries at the 3-digit SIC (Standard Industrial Classification) level computed by the World Bank in collaboration with the U.S. Environmental Protection Agency and U.S. Census Bureau.
[13] Similar rankings for the 'cleanest' and 'dirtiest' industrial sectors were produced when using pollution abatement and pollution intensity as classification criteria.
[14] Conversion factors from SITC Rev. 3 to ISIC Rev. 2 are extracted from Maskus, Keith E. (1989) in: Hooper and Richardson, International Economics Transactions, The University of Chicago Press.
[15] Production figures are based on the World Bank dataset "Trade, Production and Protection" and complemented with figures by OECD and UNIDO.

accumulated concentrations of BOD emissions from ISIC divisions 31-39. Tables 2 and 4 pertain to Suits' index measures of the concentration of BOD emissions in terms of economic activity for 'clean' and 'dirty' sectors and each individual industrial ISIC category. Figures 4-7 relate BOD emissions with GDP, IVA, exports and trade shares from 'clean' and 'dirty' sectors for 1995 and 2005, respectively.

3. Results and Discussion

Table 1 shows the accumulated percentage of countries, marked off in deciles, with the accumulated percentage of total GDP reported in column 2. The accumulated percentages of other measures of economic activity, such as industry value added, exports, and trade openness are shown in columns 3 through 7. Columns 8 and 9 report BOD emissions from 'clean' and 'dirty' industries, respectively.[16] For example, the fifth line of the table, corresponding to the 50 percent of nations with the lowest per capita income, shows that the countries in decile 1 to 5, henceforth the poorest 50 percent of countries, account for 13.2 percent of GDP, 19.9 percent of IVA, 22.6 percent of exports from 'clean' industrial sectors, 20.0 percent of exports from 'dirty' industrial sectors, 20.7 percent of trade from 'clean' industries, and 19.8 percent of trade from 'dirty' industries. Remarkably, it also shows that the same 50 percent of countries contributes 64.9 percent of BOD emissions from 'clean' industrial categories and 61.4 percent of 'dirty' industrial categories.[17]

[16] A useful property of the Suit's index is that the index of regressivity of BOD emissions, consisting in our case of several industrial sectors grouped as 'dirty' and 'clean' industries, is a weighted average of their individual indexes.
[17] Results and conclusions do not alter when grouping the sample data into non-OECD (deciles 1 to 6) and OECD countries (deciles 7 to 10).

Table 1 – Concentration of BOD Emissions in Terms of Economic Activity (Accumulated %)

Decile (1)	GDP (2)	IVA (3)	Exports (4)	Exports (5)†	Trade (6)	Trade (7)†	BOD (8)	BOD (9)†
Emissions 2005								
1	0.25	0.30	0.33	0.51	0.39	0.63	2.72	1.99
2	7.39	12.81	14.38	7.20	12.20	8.27	47.16	40.57
3	8.17	13.83	14.64	9.71	12.83	10.21	48.75	43.05
4	10.87	17.29	17.88	16.16	16.18	15.51	59.80	56.59
5	13.23	19.98	22.64	20.03	20.78	19.86	64.92	61.48
6	14.98	21.98	24.64	23.28	23.20	22.68	66.86	64.56
7	18.13	25.74	29.95	27.42	27.93	27.53	69.36	66.69
8	35.98	42.15	59.28	58.14	56.23	57.56	80.82	78.72
9	47.08	52.39	76.31	80.30	74.61	76.62	85.61	85.02
10	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Emissions 1995								
1	0.18	0.16	0.19	0.35	0.27	0.44	1.40	0.65
2	4.65	7.05	5.22	4.85	5.19	5.39	22.72	52.88
3	5.31	7.85	5.40	6.34	5.63	6.72	24.78	54.72
4	7.96	11.24	7.95	12.10	8.76	11.91	40.39	64.86
5	10.02	13.47	11.36	14.81	12.46	15.18	46.30	68.66
6	11.79	15.37	12.43	17.54	13.90	17.58	49.20	70.94
7	14.64	18.45	17.42	20.84	18.71	22.13	53.15	72.57
8	34.55	37.01	49.59	52.52	48.61	54.22	68.18	81.12
9	45.15	47.75	68.35	76.06	68.61	75.20	75.28	86.10
10	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Note: Economic activity variables include gross domestic product (GDP), industry value added (IVA), exports (Exports), and degree of openness (Trade). Data on China's BOD emissions for 1995 was collected from the World Bank WDI 2002 CD-ROM. (†) is used to identify industrial 'dirty' water polluting sectors ISIC 31, 34, 35, and 37.

Results, presented in Table 1, show the accumulated percent of BOD emissions from 'dirty' and 'clean' industrial categories (see column 8 and 9) exceeds the accumulated percent of GDP (see column 2) by a wide margin throughout the entire income scale. Similar results are found when IVA (see column 3) is used as the measure of economic activity although the accumulated percentage of IVA rises faster as developing countries expand their industrial sector. These results indicate that IVA is more equally distributed than GDP. Pollution is found to be slightly less concentrated among lower income countries when economic activity is measured using the IVA. Figures 4–5 are Lorenz curves that relate industrial BOD emissions with GDP and IVA. The curvilinear relationship between BOD-GDP and BOD-IVA shown in

Figures 4 and 5 (See Appendix) suggests water pollution to be highly concentrated among lower income countries.[18]

Now turning to our trade variables, the accumulated share of 'clean' and 'dirty' exports for countries in the fifth decile increased from 11.3 to 22.6 and 14.8 to 20.0 percent or by 11.3 and 5.2 percentage points, respectively, during the period 1995-2005 (See columns 4 and 5). More interestingly, the poorest nations switched from being net importers to become net exporters of 'clean' and 'dirty' products. This trend is more noticeable on their 'clean' industrial exports where the accumulated percentage share of exports exceeds the percentage share of trade (exports plus imports) by a larger percentage (see columns 4 and 6).

Despite the percentage shares of 'clean' and 'dirty' export as a proportion of total ISIC 31-39 exports remaining constant over the period 1995-2005, some considerable changes occurred to countries in deciles 1 to 5. An informal look at the data indicates 'clean' and 'dirty' industrial exports in the poorest countries, those between deciles 1 to 5, grew at a compounded average annual rate of 14.3 and 10.0 percent, respectively. As a result, their 'clean' exports, as a proportion of water polluting sectors ISIC 31-39, increased from nearly 59 percent in 1995 to about 68 percent in 2005. This relative percentage change in the composition of those countries' exports towards 'clean' industrial products comes almost exclusively from the expansion of the so-called 'cleanest' industrial sectors 32 and 38.[19] This suggests that the poorest nations have focused their manufacturing to the so-called 'clean' industries rather than 'dirty' industries. During the period 1995-2005, 'clean' and 'dirty' exports in the richest nations grew at a

[18] The economic activity-BOD emissions relationship departs from the line of proportionality. The greater the inequality in the economic activity-BOD emissions relationship the farther the Lorenz curve bows away from the diagonal. The ideal balance of economy-pollution relationship is to keeping Lorenz curves closer to the diagonal.

[19] There is a general consensus that among the so-called 'clean' industries the three 'cleanest' industrial sectors, those with the lowest pollution intensities, are ISICs 32, 38, and 39 (Hettige et al., 1994; 1995; Mani et al., 1998; and Gallagher et al., 2000).

compounded average annual rate of 5.02 and 6.04 percent, respectively. As a result, 'dirty' industrial exports as share of total exports from ISICs 31-39, for countries in deciles 6 to 10, increased from roughly 34 percent in 1995 to about 35 percent in 2005 (UNComtrade, 2014). This indicates that specialization in 'dirty' industries does not appear to be lower nor declined in the richer nations during the period 1995-2005.

It is important to notice that over the period of study, greater openness to trade encouraged a significantly large expansion of the so-called 'clean' industrial sectors in countries pertaining to deciles 1 to 5. Moreover, during the period of study, the poorest nations have focused their manufacturing exports on a 'cleaner' mix of industries (UNComtrade, 2014). This suggests global specialization to be occurring in line with factor abundance as richer nations specialize in capital-intensive 'dirty' industries whilst the poorest nations specialize in labor-intensive 'clean' industrial sectors.

Table 2 – Concentration of BOD Emissions in Terms of Economic Activity

Economic Indicators	Year (1)	GDP (2)	GDP (3)†	IVA (4)	IVA (5)†	Exports (6)	Exports (7)†	Trade (8)	Trade (9)†
Suits' Index (S)	2005	- 0.52	- 0.49	- 0.60	- 0.58	- 0.43	- 0.43	- 0.46	- 0.43
Suits' Index (S)	1995	- 0.41	- 0.62	- 0.45	- 0.66	- 0.33	- 0.56	- 0.22	- 0.51

Note: (†) is used to identify industrial pollution-intensive sectors.

Table 2 presents the Suits' index, concentration of BOD emissions in terms of economic activity, for 'clean' and 'dirty' water polluting industries. All Suits' index values are negative indicating that the proportionality of economic activity and water pollution is regressive. Further, most of the regressivity of the emissions occurs in the lower half of the income spectrum indicating that the poorest nations are responsible for more emissions than would be expected for their level of economic activity (see Figs. 4-7). The largest disproportionality of emissions for the period 1995 (-0.66) occurs to 'dirty' BOD-IVA (see column 5) and the maximum regressive index for the period 2005 of -0.60 occurs to 'clean' industrial BOD-IVA (see column 4). This indicates some significant changes in pollution intensities in 'clean' and 'dirty' industrial sectors occurred over the period 1995-2005 (see columns 4 and 5).

BOD-Trade relationships display the greatest observed changes in the accumulated percent of emissions and economic activity relationship in both 'clean' and 'dirty' industrial sectors during the period 1995 to 2005 (see columns 8 and 9). As poorer countries expand their degree of openness to trade, the BOD emissions-trade relationship improves for 'dirty' industrial sectors, while the relationship with 'clean' industrial sectors seems to deteriorate.[20] Similar patterns are observed for countries on the fifth decile when exports are used as the measure of economic activity. Further, exports show promising tradeoffs between economic activity and environmental quality on pollution-intensive industries, but negative tradeoffs on 'clean' industrial sectors. These results may suggest that openness to trade is beneficial for the environment when the comparative advantage stems from differences in technology rather than labor cost.

Comparison of 'clean' and 'dirty' industrial emissions reveal changing patterns in their environmental performance. There are clear trends in the regressivity of 'clean' and 'dirty' sectors with regressivity rising in 'clean' industries and showing declining indices in 'dirty' sectors. When Suits' index values for 'clean' industrial sectors are compared between 1995 and 2005, all measures of economic activity display increasing levels of concentration among low-income countries (see columns 2, 4, 6, and 8). Here, trade-induced economic growth seems to have contributed to the expansion and widening of the cross-country pollution intensities. The opposite is true for 'dirty' industrial sectors with their index decreasing over the period of study

[20] Lucas et al., (1992); Wheeler et al., (1992) found lower polluting intensity of production for countries that pursue more open trade policies.

(see columns 3, 5, 7 and 9). In other words, when pollution intensity is defined as BOD emissions per economic activity, 'dirty' industrial sectors show decelerating pollution intensities and 'clean' sectors increasing pollution intensities, relative to the richer nations, during the period 1995-2005. Those findings hold regardless of the measure of economic activity used.

A possible inference of the latter result suggests that technology transfer and knowledge spillovers played a role in 'dirty' industries, with the poorest countries benefiting from past efforts on the part of industrial nations to curb BOD emissions.[21] With additional economic integration, increasing growth patterns of R&D expenditures in pollution-intensive sectors, and industrial nations specializing in capital-intensive 'dirty' industries, this trend is likely to continue.[22] It is important to notice that R&D is mainly performed by large companies and therefore directed to their range of activities (Gancia et al., 2008), hence the benefit from innovations generally is sector-specific (Jaffe et al., 1993).

Trade openness to world markets appears less beneficial to 'clean' sectors, for categories in which the industrialized nations have decreased their R&D investments. Trade openness altered the patterns of R&D expenditure (Albrecht J., 1998; Gancia et al., 2008) as scarce R&D resources tend to move away from sectors where imitation is easy, substitutability between goods is high, and protection for intellectual property rights is weaker (Gancia et al., 2008).[23] As the poorest countries become a larger part of the 'clean' sector's world market, the adverse effects of imitation on innovation will most likely become larger, thus reducing the incentives to invest in R&D in sectors in which those nations specialize. Using a panel of US industries over the period

[21] Rates of diffusion of new technology have being found to be positively correlated with measures of degree of trade openness (Wheeler et al., 1992; Coe et al., 1997; Sjöholm, 2000; Caselli and Coleman, 2001; Perkins, 2005).
[22] There is a general consensus that capital-intensive production processes generate more pollution per output than labor-intensive sectors (Examples include Antweiler et al., 2001; Cole et al., 2005)
[23] The geographical composition of R&D is fairly conservative: In 2005, 91 percent of the world R&D took place in the United States, Western Europe, and Japan (UNCTAD, 2005).

1972-1996, Gancia et al., (2008) found that inflows of import penetration from low-wage countries have been followed by a fall in U.S. R&D investment in those sets of products.

The effect of trade, as a channel for the rapid diffusion of newer and cleaner technologies, depends on foreign firm's technological advantage in relation to domestic firms. Lower levels of innovation in industrialized countries, as measured by R&D expenditure, may have decreased the potential quality of the technology transferred as innovation is vital for technical change. Results indicate the conventional mitigation technology transfer mechanism was not sufficient to curb emissions as BOD emissions from 'clean' industrial sectors, in the poorest nations, grew at a striking compounded average annual rate of 6.6 percent, during the period of study.[24] What is also certainly a potential explanation for the divergent BOD-Trade curve (See figure 7) in the poorest nations is that the rapid expansion of the 'clean' industries, and more importantly the 'cleanest' industrial categories (See figure 3), in those countries with laxer environmental regulations may have postponed or weakened their abatement efforts for lowering pollution emissions.

Table 3 disaggregates industrial 'clean' and 'dirty' water polluting categories from Table 1 into individual industrial sectors ISIC categories 31 to 39. 'Clean' industrial water polluting sectors ISIC 32, 33, 36, 38-39 and 'dirty' industrial sectors ISIC 31, 34, 35, and 37 pertain to Table 1 column 8 and 9, respectively. Table 3 shows varying degrees of BOD emissions concentrations across industries as they expand their levels of economic activity and liberalize their economies.

[24] In many fast growing middle-income countries pollution has risen due to the technique effect being overwhelmed by the technique effect in reducing emissions (Stern, 2005).

Table 3 – Concentration of Pollution from Industrial Sectors ISIC 31-39 (Accumulated %)

Decile (1)	BOD (31)†	BOD (32)	BOD (33)	BOD (34)†	BOD (35)†	BOD (36)	BOD (37)†	BOD (38-39)
Emissions 2005								
1	3.14	5.96	2.97	1.87	1.49	3.65	0.59	1.32
2	33.06	67.23	36.98	32.37	46.35	51.58	53.29	39.53
3	36.17	69.35	37.93	33.60	48.10	54.69	57.34	40.75
4	52.67	80.09	52.57	43.83	59.24	68.33	73.01	51.30
5	58.96	85.72	60.95	48.29	63.74	72.70	76.02	56.07
6	63.27	87.32	64.43	51.02	66.10	74.72	78.22	58.02
7	65.35	89.19	66.59	53.88	68.19	76.52	79.80	60.89
8	78.20	93.95	76.72	68.73	80.00	86.04	87.45	75.32
9	84.40	95.50	83.70	79.20	85.48	89.63	91.47	81.36
10	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Emissions 1995								
1	0.93	3.20	0.77	0.51	0.60	2.63	0.32	0.51
2	54.65	46.85	24.30	45.86	43.47	13.67	67.18	12.80
3	56.62	50.02	25.33	46.69	45.12	18.80	69.82	14.09
4	67.54	63.20	44.63	52.64	56.97	43.92	79.71	29.37
5	72.19	69.39	52.57	55.45	61.11	51.69	82.28	34.76
6	75.12	72.16	56.89	57.32	63.30	55.71	83.77	37.47
7	76.60	76.95	59.58	59.21	65.51	59.79	84.74	41.14
8	84.30	85.28	70.63	69.65	77.10	75.19	89.49	59.47
9	88.56	88.76	78.13	78.24	82.70	81.65	92.11	68.25
10	100.00	100.0	100.0	100.00	100.00	100.00	100.00	100.00

Note: BOD data on water polluting industrial sectors ISIC 31-39 was extracted from the World Development Indicators of the World Bank. Data on China's BOD emissions for 1995 was collected from the World Bank WDI 2002 CD-ROM. (†) is used to identify industrial pollution-intensive sectors.

Similar to Table 1, results in Table 3 indicate that during the period 1995-2005, the poorest nations expanded their share of BOD emissions from 'clean' industrial sectors and decreased their cumulated water polluting-intensive emissions from 'dirty' water polluting industrial sectors in all but industrial sector 35 (chemicals).[25] The largest upsurges in 'clean' sectors occurred in categories 32 (textiles and clothing), 36 (manufacture of non-metallic mineral products),[26] and 38-39 (fabricated metal products and professional goods). The largest decline in 'dirty' sectors occurred in categories 31 (Food industry) and 34 (Paper and Pulp Industry) (See figure 2).

[25] This could be the effect of import substitution in some developing countries (i.e. Jänicke et al., 1997). Several empirical papers offered explanations as to why more widespread evidence of Pollution Havens Hypothesis has not been found. For work along this line see Birdsall, et al., 1993; Mani, et al., 1998; Cole, 2004.

[26] Despite being an air pollution-intensive industry ISIC 36 doesn't classify as a water polluting 'dirty' sector (Mani et al., 1998).

Table 4 – Concentration of BOD Emissions in Terms of Industrial Sectors ISIC 31-39

Decile (1)	BOD (31)†	BOD (32)	BOD (33)	BOD (34)†	BOD (35)†	BOD (36)	BOD (37)†	BOD (38-39)
(S) – Exports 2005	- 0.40	- 0.40	- 0.26	- 0.31	- 0.47	- 0.54	- 0.56	- 0.37
(S) – Exports 1995	- 0.61	- 0.36	- 0.26	- 0.43	- 0.46	- 0.33	- 0.71	- 0.25
(S) – Trade 2005	- 0.42	- 0.60	- 0.42	- 0.31	- 0.47	- 0.59	- 0.56	- 0.37
(S) – Trade 1995	- 0.60	- 0.49	- 0.37	- 0.41	- 0.46	- 0.38	- 0.70	- 0.21
(S) – IVA 2005	- 0.47	- 0.73	- 0.47	- 0.37	- 0.51	- 0.60	- 0.62	- 0.43
(S) – IVA 1995	- 0.53	- 0.70	- 0.52	- 0.36	- 0.55	- 0.67	- 0.64	- 0.43
(S) – GDP 2005	- 0.56	- 0.80	- 0.55	- 0.45	- 0.59	- 0.68	- 0.70	- 0.52
(S) – GDP 1995	- 0.57	- 0.74	- 0.56	- 0.40	- 0.59	- 0.70	- 0.68	- 0.47

Note: (†) is used to identify industrial pollution-intensive sectors.

Table 4 presents the Suits' index for the economic activity-BOD relationships of individual industrial sectors ISIC 31 to 39. When IVA is used as a measure of economic activity, the Suits' coefficients for BOD-IVA activity relationships are overall consistent with Table 2. Relative to richer nations, BOD emissions from polluting intensive 'dirty' industries are becoming less concentrated among the lower income countries over time. BOD-IVA values for industrial sectors 33 (Wood industry) and 36 (Non-metallic Mineral Products) also exhibit decreasing rates, of 5 and 7 percentage points respectively, over the period of study.

On the other hand, 'clean' industrial sectors ISIC 32 (textiles and clothing) exhibit the largest increase in levels of BOD-IVA activity from -0.70 to -0.73. The scale effect seems to have outweighed the technique effect in the apparel industry.[27] As scarce R&D resources tend to be pushed towards sectors with higher prices and markets where patents generate more revenues (Acemoglu D., 1998, 2002; Pelli M., 2012) the garment sector's pursuit of rock-bottom prices may have failed to provide the proper economic incentives for innovation (UNIDO, 2006). The GDP-BOD relationship displays similar trends of regressivity as the IVA-BOD relationship.

[27] According to Mani et al. (1998), textiles migration reflected its continuing labor intensive specialization with its search for lower labor costs outweighing the benefits of technological change in richer nations.

Similar to Table 2, Suits' index values for BOD-Exports and BOD-Trade are negative and increasing for 'clean' industrial sectors and negative and decreasing for 'dirty' sectors. Results suggest emissions in the poorest countries became more regressive in 'clean' sectors and less regressive in 'dirty' industrial sectors relative to richer nations, during the period of 1995-2005. The exception is the chemical sector (ISIC 35) that slightly increased its values from -0.46 to -0.47. Decreasing BOD-Trade and BOD-Exports coefficients indicate lower income countries' emissions are becoming cleaner, relative to richer nations, as their degree of openness and level of exports increase.[28]

Since many developing nations approach technological innovation primarily through the adoption and adaptation of pre-existing, but new to-market, technologies (World Bank, 2008, 2010), a reduction in the level of innovation in industrialized nations will likely impact the potential environmental effects of the technology transferred to developing nations. With innovation moving away from the set of products in which the poorest nations specialize, it is imperative for the poorest countries to craft their domestic policies in order to spur innovation and to build R&D capacities in the activities in which they enjoy a comparative advantage (Lema et al., 2012).[29] More attention should be paid to the direction of innovation (Bell, 2009) as technological change is vital to improve firms' environmental performance. Policies to reshape the direction of technological development and to increase developing countries scientific and technological capacities will most likely have positive effects, curving 'clean' sectors' BOD emissions trajectories.

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[28] It is important to note, however, that within each ISIC industrial sector there is likely to be differences in the extent to which industries in the same categories (i.e. metal industries) have reduced their environmental impacts. Care must be taken to avoid generalizing the results presented here since BOD emissions come from the World Bank aggregated at a 2-digit level, preventing a more in detail analysis.

[29] Market forces cannot substitute for the role of governments in developing and promoting a proactive industrial policy (UNCTAD, 2005) as technological development is policy-driven by nature. This is well illustrated by Lall and Narula (2004) when exploring many Asian countries that have relied on a passive FDI-dependent strategy.

4. Conclusion

This study analyzes the economic activity-BOD relationships of the so-called 'clean' and 'dirty' water polluting industrial sectors, during the period 1995-2005. Results indicate the economic activity-environment trade-off of 'clean' and 'dirty' industrial sectors in the poorest nations has been altered during the period of study. The poorest countries, on average, improve their environmental performance from 'dirty' pollution-intensive industries. The opposite is true for 'clean' sectors, regardless of the measure of economic activity used. Here, the accumulated percentage of BOD emissions per level of economic activity in the poorest countries deteriorated relative to their richer counterparts.

More interestingly, 'dirty' industries in the poorest nations were found to benefit – in terms of BOD emissions – from extra exports and openness to trade, as indicated by the convergence of the Lorenz curves toward the line of equality. This suggests that average pollution intensities in the poorest countries became closer to the intensities of richer nations over the period of study. However, the opposite is true for 'clean' sectors where openness led to a divergence in pollution intensities. Here, the benefits of trade on the environment may have lessened as the level of innovation in industrialized nations decreased in those sectors in which the poorest countries enjoy a comparative advantage. Results indicate that 'clean' industrial sectors' technique effect was outweighed by the fast economic upsurge in reducing emissions. It's also possible that 'clean' industries, and most importantly, the 'cleanest' industrial categories may lag behind in their efforts to curb BOD emissions, becoming dirtier as they expand in countries with lax environmental regulations.

Rather than raising warnings against globalization, this study has identified a specific market failure under which trade can have undesirable effects. Given these market imperfections, the policy priority should be to promote investments in R&D to encourage technological innovation in activities in which the poorest nations have a comparative advantage, as technological progress is a key element to improve the economic activity-environment relationship. The optimal policy goal should involve ways to encourage domestic firms in the poorest nations to shift from technological imitation to local innovation.[30] More attention to the so-called 'clean' industrial categories and especially the ones identified as 'cleaner' sectors is needed for global improvement in emission reductions to occur.

[30] See UNIDO, 2006.

Appendix:

List of countries – Ordered by constant 2005 per capita GDP

Ethiopia, Eritrea, Nepal, Uganda, Kyrgyz Republic, Senegal, Vietnam, Indonesia, Bolivia, Azerbaijan, Philippines, Syrian Arab Republic, Paraguay, China, Morocco, Ecuador, Macedonia, Iran Islamic Republic, Kazakhstan, Tonga, Jordan, Bulgaria, Romania, Thailand, Russian Federation, Colombia, South Africa, Mauritius, Panama, Malaysia, Lithuania, Turkey, Latvia, Poland, Hungary, Chile, Croatia, Estonia, Czech Republic, Slovak Republic, Argentina, Trinidad and Tobago, Oman, Malta, Portugal, Slovenia, Greece, Korea Republic, New Zealand, Cyprus, New Zealand, Spain, Italy, Israel, France, Germany, Belgium, Netherlands, Austria, Canada, Finland, United Kingdom, Singapore, Ireland, Sweden, Denmark, Qatar, United States, Japan, Norway, Luxemburg.

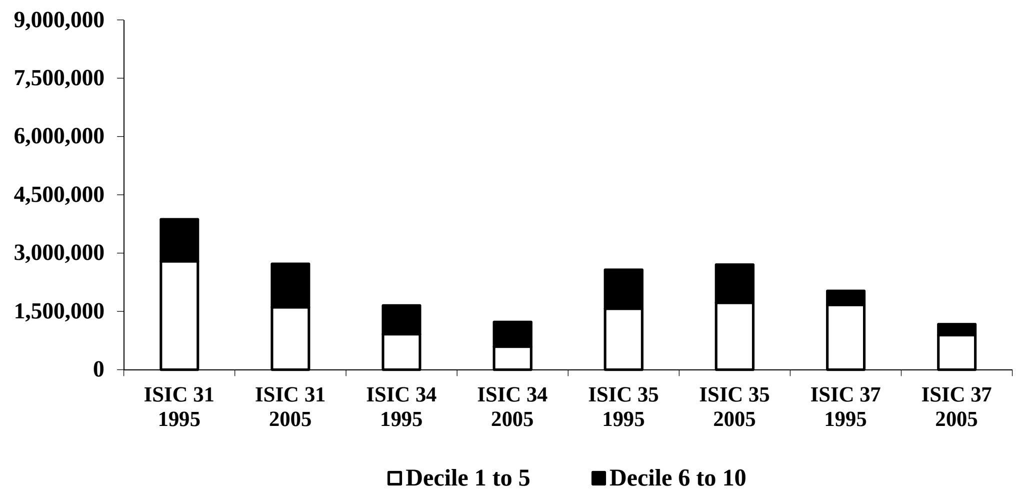

Figure 2
BOD emissions from pollution-intensive 'dirty' industrial categories (ISICs 31-34-35-37)
(In thousand kilograms per day)

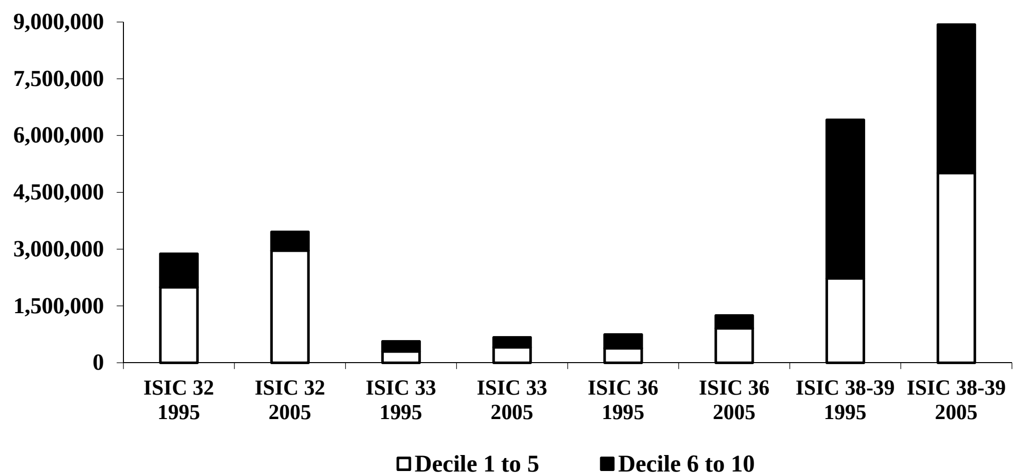

Figure 3
BOD emissions from 'clean' (ISICs 33-36) and the 'cleanest' industrial categories (ISICs 32-38-39)
(In thousand kilograms per day)

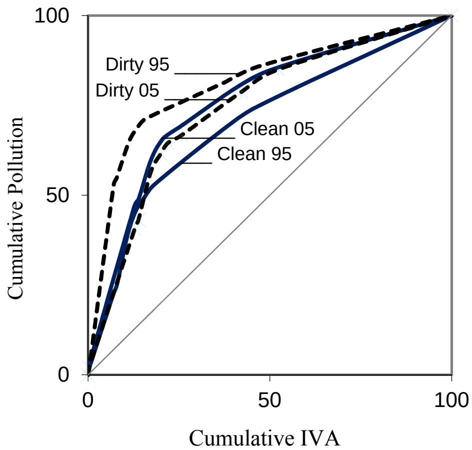

Figure 4
BOD and IVA, 1995-2005

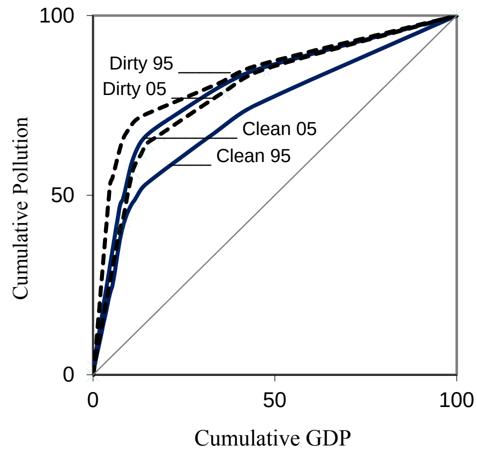

Figure 5
BOD and GDP, 1995-2005

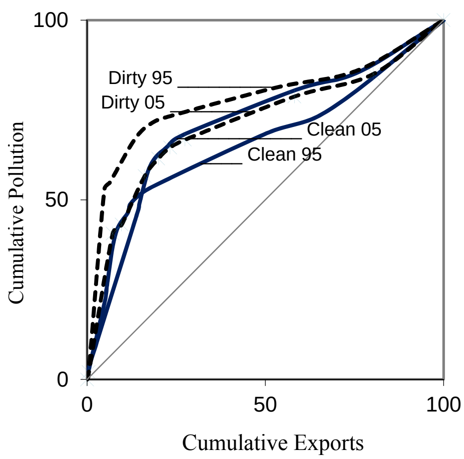

Figure 6
BOD and Exports, 1995-2005

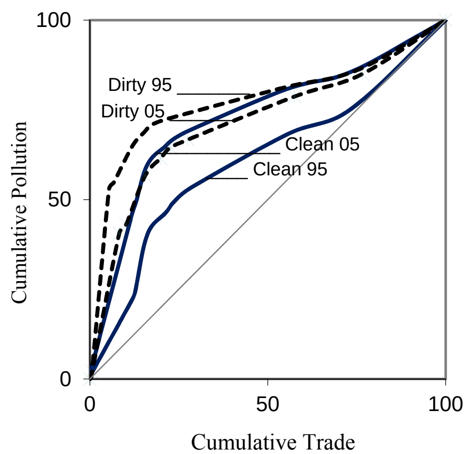

Figure 7
BOD and Trade, 1995-2005

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