Measuring the Pollution Terms of Trade with Technique Effects*

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Abstract

A unique database that includes temporal and cross-country variations of SO_2 emission intensities is used to perform an input-output analysis of trade-embodied emissions at the world-wide level (62 developed and developing countries) during the 1990-2000 period. This leads to a re-appraisal of the concept of the pollution terms of trade (PTT) introduced by Antweiler (1996). More variation in the data allows to control for two additional effects and to solve the original empirical paradox. The global pattern is one in which the major rich economies exhibit a small PTT index i.e. imports which have a higher pollution content than exports on average, the reverse being true for the major poor economies. Trade imbalances tend to exacerbate this asymmetry, allowing rich economies to offshore their pollution through trade. The implied net outflow or inflow of trade-embodied emissions for the three largest players is above 10% of the world total.

Keywords: international trade, environment, trade-embodied emissions, pollution terms of trade
JEL Classification: F1, O1, O3, Q4

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1. Introduction

By disconnecting production from consumption sources, international trade leads to a worldwide distribution of polluting emissions which does not reflect final demand. A common suspicion is that rich countries, with higher environmental standards, tend to offshore their pollution to poor countries, according to a “pollution-haven” effect (e.g. Levinson and Taylor (2008)). These concerns, along with a growing pressure to curb down global emissions, have led to a flurry of studies analyzing the emission-content of trade (e.g. Wiedmann (2009)). However, it is fair to say that most of these studies have been national or regional in scope, and that available evidence at the world-wide level is still scant. This lack of world-wide evidence is linked with important data requirements and limitations. First, input-output matrices are needed in order to capture the additional emissions generated by the derived demand for inputs (e.g. Levinson (2010)). Second, reliable trade and production data must be made available at a reasonable degree of disaggregation to identify the influence of the most polluting sectors. Third, country(and year)-specific emission coefficients are necessary to control for the fact that the emission content of a given amount of output varies across countries and over time, because of differences in both technologies and IO relationships. Taking the best out of available data for a specific pollutant, which is sulphur dioxide (SO_2), the first objective of this paper is to provide evidence of the pollution content of trade at the world-wide level, illustrating in particular the importance of capturing differences in (total) emission coefficients between partners and years.

The second objective of this paper is to propose a reconsideration of the concept of the pollution terms of trade (PTT) introduced fifteen years ago by Antweiler (1996). Most of the recent literature has produced results in terms of environmental trade balances, normally captured by the difference between export-embodied and import-embodied emissions, or Balance of Emissions Embodied in Trade (BEET) according to Muradian et al (2002). As noted by Straumann (2003), this measure is sensitive to trade imbalances, which may disappear or be reversed over time. By simply taking the ratio between the average pollution content per dollar of exports and the average pollution content per dollar of imports, the PTT index abstracts from this source of bias and appears more appropriate as a long run structural indicator. The original application reported by Antweiler (1996), based on a large range of pollutants (CO_2, SO_2, NO_2, lead, particulate matter, volatile organic compounds), came to the rather paradoxical conclusion that rich countries tended to exhibit a larger PTT index than poor ones. As already discussed by Antweiler himself, a possible reason for this result could come from data limitation. Indeed, he had to rely on US input-output adjusted emission intensities, and apply them universally, as if there were no technological differences across countries. Relying on his own words the original PTT was only capturing the "trade-composition" part of the PTT variation, not the "technological" part. Since then, although the calculation of input-output based embodied emissions has been burgeoning, there has been, to our knowledge, no systematic attempt to reconsider the issue of PTT estimates at the world-wide level.

This paper proposes to revisit PTT calculations by exploiting newly available data. The methodology is directly borrowed from Antweiler (1996), the basic difference being that, as we include time variation into the analysis, we present a decomposition of the PTT index into three components: a between-sector, a between-country, and a technique effect. The first effect corresponds to the "trade-composition" index measured by Antweiler, while the other two components are “technique” effects that reflect technological differences across countries and over time. Regarding empirics, the sample period is 1990-2000 with a good coverage (62 developed and developing economies), and a particular care has been given to capturing technological heterogeneity. Trade and country-specific input-output tables are taken from the Trade Production and Protection database of the World Bank (Nicita and Olarreaga, 2007), while country and time-specific polluting manufacturing emission intensities come from the recent database elaborated by Grether, Mathys and de Melo (2009). We also impose the consistency between trade and input-output data, and propose an original approach to control for reexports. As it turns out, the new empirical evidence reverses the paradoxical pattern observed by Antweiler (1996), and confirms the importance of including the newly computed correction terms.

The next section outlines the theoretical derivation of the PTT index and discusses its properties, making the link between the environmental trade balance, the trade ratio, and the PTT index. Section 3 shortly describes the data while section 4 reports the main results. Section 5 discusses data issues and alternative interpretations of the results, and the last section concludes.

2. Methodology

2.1 Between-country, between-sector and technical effects

Following Antweiler (1996), define I as the total number of industries. Then, for each country and year, the output vector, $Q_{[I\times 1]}$, is given by the usual expression, $Q = BQ + D = (\tilde{I} - B)^{-1} D$, where $B_{[I\times I]}$ is the intermediate input coefficient matrix, $D_{[I\times 1]}$ is final demand and $\tilde{I}_{[I\times I]}$ is the identity matrix. Total SO_2 emissions embodied in a given final demand vector are given by: $PQ = P(\tilde{I} - B)^{-1} D = AD$, where $P_{[1\times I]}$ is the vector of direct emission intensities (in kilos per US dollar) and $A_{[1\times I]} = P(\tilde{I} - B)^{-1}$ is the vector of total emission intensities including input-output relationships.

Using c as a country index and t as time index, the pollution content per dollar of exports is given by:

$$F_{ct}^{X} = \frac{A_{ct} X_{ct}}{j_I^{'} X_{ct}} \tag{1}$$

where $X_{ct[I\times 1]}$ is the export vector of country *c* at year *t* and $j^{'}_{I[1\times I]}$ is a unit vector $j_I^{'} = [1,1,...,1]$.

Similarly the pollution content per dollar of imports is given by:

$$F_{ct}^{M} = \frac{\sum_{j\neq c} (A_{jt} M_{cjt})}{j_I^{'} M_{ct}} \tag{2}$$

where $M_{jct[I\times 1]}$ is the vector of imports of country c from country j at time t.

The pollution terms of trade (PTT) index is then given by the ratio between the pollution content per dollar of exports and the pollution content per dollar of imports: [1]

$$\chi_{ct} = \frac{F_{ct}^{X}}{F_{ct}^{M}} \tag{3}$$

If the PTT is larger than one, this means that country c's exports are more pollution intensive than its imports. The reverse is true if the PTT index is smaller than one.

The PTT index captures three different effects. It reflects compositional effects in trade flows both between sectors and between countries, and it reflects technological changes over time. Hence, equation (3) can be decomposed in these three effects:

$$\chi_{ct} = \tilde{\chi}_{ct}\overline{\chi}_{ct}\hat{\chi}_{ct} \tag{4}$$

where $\tilde{\chi}_{ct} = \left[\frac{A_{US,90}X_{ct}}{j_I^{'}X_{ct}}\right] / \left[\frac{A_{US,90}M_{ct}}{j_I^{'}M_{ct}}\right]$ stands for the between sector effect,

$\overline{\chi}_{ct} = \left[\frac{A_{c,90}X_{ct}}{A_{US,90}X_{ct}}\right] / \left[\frac{\sum_{j\neq c}(A_{j,90}M_{cjt})}{A_{US,90}M_{ct}}\right]$ identifies the between country effect and

$\hat{\chi}_{ct} = \left[\frac{A_{ct}X_{ct}}{A_{c,90}X_{ct}}\right] / \left[\frac{\sum_{j\neq c}(A_{jt}M_{cjt})}{\sum_{j\neq c}(A_{j,90}M_{cjt})}\right]$ reflects the technical effect. One is left with the first part,

$\tilde{\chi}_{c}$, when country specific and time varying emission intensities are not available as this was the case in the Antweiler (1996) study.[2]

2.2 Environmental gains and losses from trade

At first sight, as χ_{ct} is defined as a ratio between two emission intensities, its name may seem slightly improper, as the concept of "terms of trade" usually refers to a ratio between two price indices. Note however that the traditional terms of trade can also be interpreted in terms

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[1] Antweiler (1996) has multiplied the index by 100 and was hence working with a benchmark of 100.

[2] Note that the product of the between country and the technical effects here corresponds to the technical effect in the Antweiler (1996) paper.

of a ratio between two quantities, i.e. the amount of import units per dollar over the amount of export units per dollar. This is precisely how the PTT index is defined, although one should beware of three differences: (i) the physical quantities involved are kilos of emissions, not units of goods, (ii) imports of goods correspond to export of emissions (which occur at home rather than abroad) and (ii) contrary to goods, emissions are not desirable. This implies in particular that everything else equal, an increase in PTT decreases the environmental position of the country, as for each emission unit sent abroad (through imports of goods), the domestic increase in emissions (through exports of goods) becomes larger.

Following this line of reasoning, Antweiler noted that trade may become an instrument to redistribute environmental damage across countries, instead of eliminating it. In this zero-sum game, the gains for a given country (the emissions sent abroad through imports of goods) correspond to losses for the rest of the world (due to emissions embodied in the partners's exports). To illustrate the relationship with the concept of PTT, let us define the *net environmental gain* for country *c*, NEG_{ct}, by the difference between import-embodied emissions and export-embodied ones. Using equations (1) and (2) one obtains:

$$NEG_{ct} \equiv \left(\sum_{j \neq c} A_{jt} M_{jct} \right) - \left(A_{ct} X_{ct} \right) = F_{ct}^{M} \left(j_I^{'} M_{ct} \right) - F_{ct}^{X} \left(j_I^{'} X_{ct} \right) \quad (5)$$

Next, let us define *world trade-embodied emissions* as WEE_t, noting that it can be obtained as either the sum of export-embodied ($\sum_{c} A_{ct} X_{ct}$) or the sum of import-embodied ($\sum_{c} \sum_{j \neq c} A_{jt} M_{jct}$) emissions. Using equation (3), it is straightforward to show that the net environmental gain for country *c* expressed as a percentage of world trade-embodied emissions is given by:

$$\frac{NEG_{ct}}{WEE_t} \equiv \theta_{ct}^{M} \left[1 - \chi_{ct} \rho_{ct} \right] = \theta_{ct}^{X} \left[\frac{1}{\chi_{ct} \rho_{ct}} - 1 \right] \quad (6)$$

where θ_{ct}^{M} (θ_{ct}^{X}) is the share of country c in import (export) embodied emissions ($\theta_{ct}^{M} \equiv \left(\sum_{j\neq c} A_{jt} M_{jct}\right) / \left(WEE_t\right), \theta_{ct}^{X} \equiv \left(A_{ct} X_{ct}\right) / \left(WEE_t\right)$) and ρ_{ct} is the export-import ratio ($\rho_{ct} \equiv \left(j_I^{'} X_{ct}\right) / \left(j_I^{'} M_{ct}\right)$).[3]

Equation (6) illustrates the inverse relationship between the PTT index and the net environmental gains from trade. In a long-run situation where trade is balanced ($\rho_{ct}=1$), PTT=1 is the threshold above (below) which the country becomes an environmental loser (winner). The larger the deviation from the threshold, the larger the associated gain or loss, with extreme gains or losses bounded by the import or export shares (θ_{ct}^{M} or θ_{ct}^{X}). If trade is unbalanced ($\rho_{ct} \neq 1$), the same reasoning applies, except that a country may now gain because its imports have a larger value than its exports. Consequently the threshold for PTT becomes $1/\rho_{ct}$.

Although the above relationship provides a useful basis to interprete results (see the discussion in section 5), it also deserves some words of caution. First, as technology differs across countries, the domestic emissions that would be generated in case imported goods were produced locally would be different from those generated abroad. This suggests that in practice, redistributing world emissions through trade is not a zero-sum game, in line with the concerns of environmentalists. Second, as long shown by economists, trade itself is not a zero-sum game either: welfare does not only depend on emissions, so that the environmental net gains mentioned above only reflect a partial effect from trade. Third, a thorough analysis of the causes and consequences of PTT variations across countries would require a complete general equilibrium framework, although this is beyond the scope of the present paper.

3. Data Preparation

To be able to identify the three distinct components of the PTT index shown in equation (3), a first condition is that environmental data must contain a specific pollution coefficient for each

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[3] Of course the simplest expression for (NEG_{ct}/WEE_{ct}) is $\theta_{ct}^{M} - \theta_{ct}^{X}$, which is equivalent to (6) as $\chi_{ct}\rho_{ct} = \theta_{ct}^{X} / \theta_{ct}^{M}$. Although this alternative expression does not illustrate the link with PTT, it confirms that the sum of the relative net gains across all countries is zero.

sector in each country and over time. This type of data has been recently made available for direct SO_2 emissions (the P vector) by Grether, Mathys and de Melo (2009), combining information from various sources (Hettige et al (1995), Olivier and Berdowski (2001) and Stern (2006)).

A second condition is to rely on input-output figures that are both country-specific and consistent with trade data for a large sample of countries. The Trade, Production and Protection (TPP) database of the World Bank (Nicita and Olarreaga, 2007) is the most recent one satisfying these criteria. A number of adjustments were necessary to prepare the data for the empirical analysis. First, original input-output shares (of intermediate sales into total production) have been converted into input-output coefficients using the relevant output figures (these IO coefficients are needed to compute the A vector of total emission intensities). Second, trade data have been aggregated from the 28 ISIC-3 digit categories into the 17 input-output sectors reported in the TPP database (see the correspondence in table A1 in the Appendix). Third, simple ad hoc conventions were adopted to check material balances and to make sure that trade, production and input-output data are consistent with each other (e.g. no negative value added nor negative final demand for domestic or foreign goods). Most of these adjustments took the form of a reduction in input-output coefficients, so that the total emission intensities used in the present paper may be considered as a lower bound (see the Appendix for the details).

A third condition to identify reliable PTT indices is to trace imports back to their original production site. Failing to do so may generate important biases in PTT calculations as reexports represent a substantial share of trade flows for certain countries and pollution intensities differ markedly from one country to another.[4] Although COMTRADE data on reexports are only available a quarter of the TPP countries, we rely on this subsample to calibrate a simple and original allocation methodology that allows to control trade flows for reexports (see the Appendix on data preparation for the details).

[4] This was not a source of concern for Antweiler (1996) as he had to impose the same pollution intensities to every country because of lack of available data on pollution intensities.

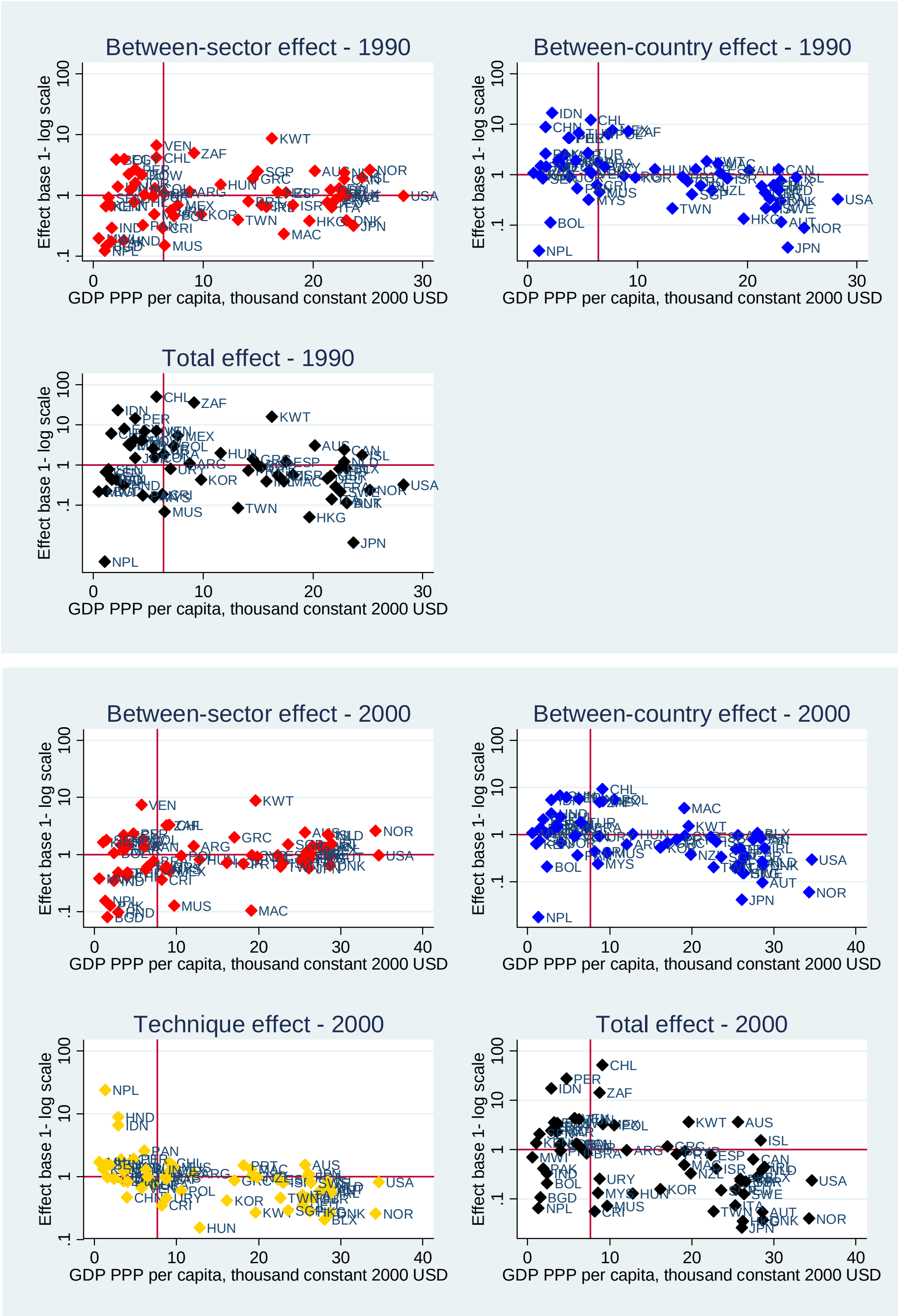
Following these adjustments, a consistent data set is made available on trade, pollution and production variables, covering 62 countries, 3 years (1990, 1995, 2000) and 17 manufacturing sectors.

4. Empirical Findings

The PTT index has been computed for each one of our 62 countries, for 1990 and 2000. Moreover, following equation (4), the different indices based on limited information have also been computed, providing a complete decomposition of the PTT index into three components. Detailed results are reported in Appendix Table A2. To ease interpretation and relate our results with the pollution-haven debate, we present our results with figures that plot the index against GDP per capita, as richer countries tend to adopt more stringent environmental policies (see e.g. Copeland and Taylor (2003)). Each panel is split into four quadrants by a horizontal line at the PTT=1 reference level and a vertical line representing average GDP per capita at the world-wide level. A distribution of points in the upper-left and bottom-right quadrants would be consistent with the pollution-haven view.

Figure 1 reports the results at the country level. We start with the left upper panel, which represents the between-sector effect in 1990, i.e. the PTT index based on the assumption made by Antweiler, namely that US emission intensities for different industries are applicable to all other countries. This leads to a distribution of points that has no obvious orientation. If any, the relationship with GDP per capita appears to be slightly positive, restating the paradox that has been found by Antweiler, namely that rich countries have relatively dirty average exports compared to low income countries. When shifting to the right-hand side panel, representing the between-country effect, the opposite pattern emerges. Apart from Bolivia and Nepal, the large majority of poor countries locate above the horizontal line, and a substantial number of rich countries are below the same line. This suggests that compared to US figures, large emission intensities seem to be biased towards exports in poor countries and towards imports in rich countries, a pattern that is more akin to the pollution-haven view. The total effect in 1990 results from the combination of the two previous effects (there is no technique effect as this is the base year). Broadly speaking, the overall pattern looks closer to the between-country effect, suggesting an inverse relationship between PTT indices and GDP per capita.

Figure 1: PTT against GDP per capita by country, 1990 and 2000



Notes: cf. equation (4) in text for a definition of each effect / GDP per capita figures are taken from the World Bank Development Indicators, 2007.

The evidence for 2000 is reported in the lower part of the figure. The between-sector and between-country effects look quite similar to what was observed for 1990. The novelty comes from the technique effect, which exhibits a clear inverse relationship with GDP per capita. This suggests that technological changes over time reinforce the pollution-haven effect, leading to more export rather than import-embodied emissions in poor countries and the reverse in rich countries. This strengthens the average pollution-haven pattern of the total effect, which appears in the bottom-right panel of the figure.

Taking logs of equation (4), we also computed a simple variance decomposition of PTT indices. Whatever the year, the between-country effect represents a rough two-third of the total variance, while the technique and between-sector effects share the remaining third in roughly equal parts in 2000. Simple OLS regressions have been performed for each year. As reported in the first two lines of Table 1, when regressing ln(PTT) over the natural logarithm of GDP per capita, and whatever the year, the elasticity coefficient is always significant, positive for the between-sector effect, and negative for the between-country and technique effects. For the total effect, it is negative, but only significant in 2000. When data are pooled together and fixed effects are introduced for each year and country, the coefficients keep the same sign but they are not significant anymore (see last line of Table 1). This suggests that the pollution-haven pattern is only robust across countries, but not over time once country and year-specific effects have been controlled for.

Overall, although the dispersion of results is quite large, country-level estimates suggest that if one is limited by US technology coefficients, PTT indices seem either unrelated or slightly positively related with GDP per capita. However, the evidence also suggests that the two effects that control for technological differences (the between-country and the technique effect) exhibit a negative relationship with per capita GDP, and that those effects prevail over the previous one in shaping a total pattern that is consistent with the pollution-haven argument, and significantly so regarding cross-country variation.

Table 1: Estimated elasticities between PTT and GDP per capita (t-stat between parenthesis) [a)]

Regression method	Between-sector effect	Between-country effect	Technique effect	Total effect
	Dependent variable (see equation (4))			
OLS [a)]				
1990	0.25*** (2.10)	-0.43*** (-2.84)	n.a.	-0.19 (-0.85)
2000	0.27** (2.41)	-0.39*** (-2.68)	-0.45*** (-5.35)	-0.58*** (-2.98)
Panel [b)]				
1990-2000	0.29 (1.12)	-0.25 (-1.61)	-0.77* (-1.74)	-0.74 (-1.46)

[a)] results from OLS regressions of ln(PTT) on a constant plus the natural logarithm of GDP per capita (63 observations: 62 countries plus the rest of the world)
[b)] results from panel regressions of ln(PTT) on the natural logarithm of GDP plus year and country dummies (63 observations times 3 years: 1990, 1995, 2000)
(***/**/*) significant at the 99%/95%/90% level / n.a.: not applicable

5. Discussion of Results

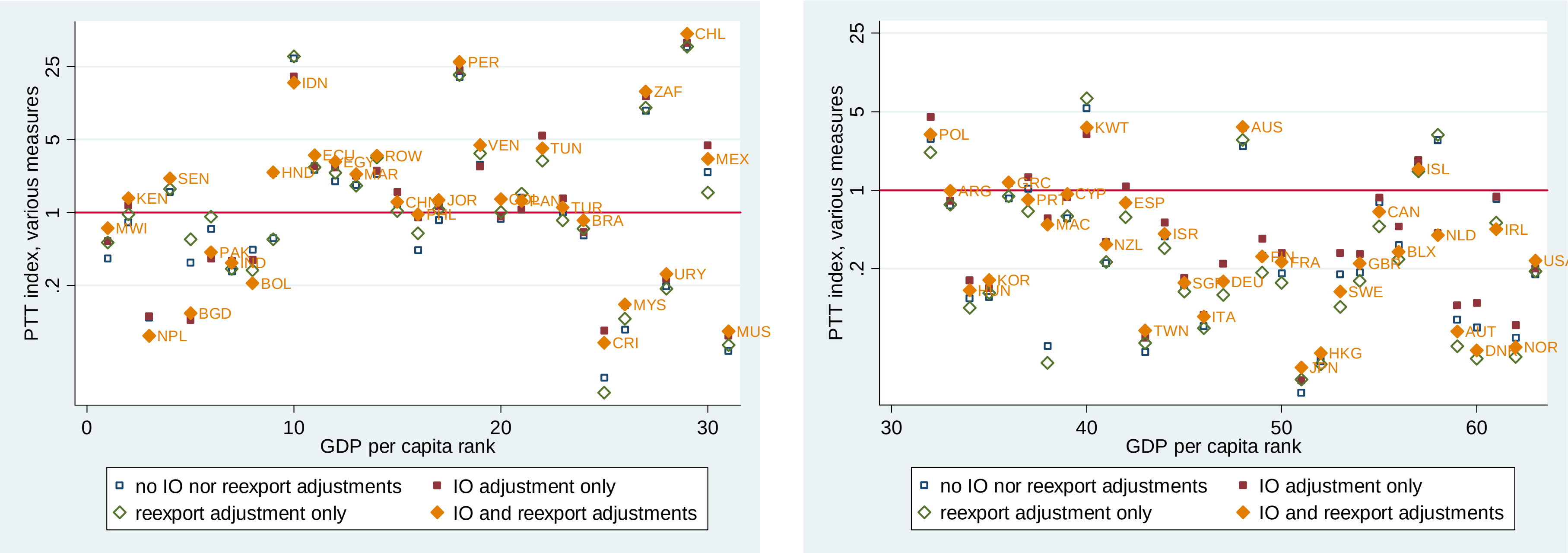
5.1 Alternative measurements

As mentioned in section 3 and presented in details in the Appendix, the results presented in section 4 rely on a double correction of (i) input-output (IO) coefficients (to insure consistency with trade data) and (ii) trade flows (to abstract from reexports). Both corrections are duly motivated but, as a robustness exercise, we report below the PTT indices that are obtained in the three alternative cases where either one or both corrections are omitted.

In Figure 2, to improve readability, countries are reported by rank of GDP per capita rather than levels. For each country, the IO adjustment is represented by a switch from a hollow to a color-filled symbol, while the reexport adjustment is represented by a switch from a small square to a large diamond. Although most of the country dots are fairly close to one another, some countries experience large changes in PTT estimates. Most of these large changes (for Honduras, Costa Rica, Macao and Bengladesh) are found in the group of relatively poor countries and due to adjustments in IO coefficients, which is related to the poor quality of production data. For a limited number of relatively rich countries (Austria, Danemark and

Figure 2: PTT intervals according to different adjustment procedures, 2000

(a) 31 poorest countries **b) 31 richest countries**



Note: IO and reexport adjustments are described in the Appendix

Sweden), the trade data adjustment leads to lower estimated PTTs, which suggests that the goods that they reexport have a larger PTT index than those that have reached their final destination.

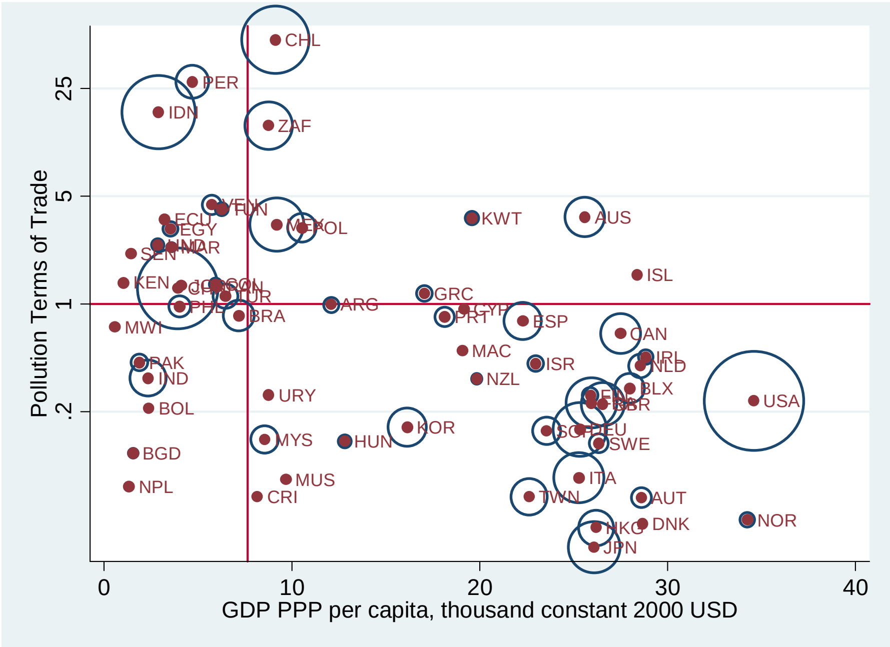
Overall, the two panels of Figure 2 confirm the regularity identified in section 4, namely that poor (rich) countries tend to exhibit a PTT index which is larger (smaller) than 1. When regressions are performed on the three alternative sets of PTT indices, the signs and significance of results are also very similar to those reported in Table 1. In short, the pattern identified in section 4 can be considered as reasonably robust.

5.2 Alternative representations

What happens when country size is taken into account? In Figure 3, which reports 2000 results for the total effect (as in the right-bottom panel of Figure 1), the size of each dot is proportional to the share of each country in world trade-embodied emissions. The pattern that emerges is now even clearer, with large poor countries such as Indonesia, China and Chile, exhibiting large PTT indices, while large rich countries like the USA, Germany and Japan are characterized by PTT indices which are lower than one. Weighing observations also translates into a stronger relationship in terms of OLS regression for 2000 (with respect to Table 1, the estimated elasticity is now -1.40 , rather than -0.58, while the absolute value of the t-stat increases 2.98 from to 6.83), although results from the panel analysis remain non significant (but for the technique effect, which becomes significant at the 99% level).

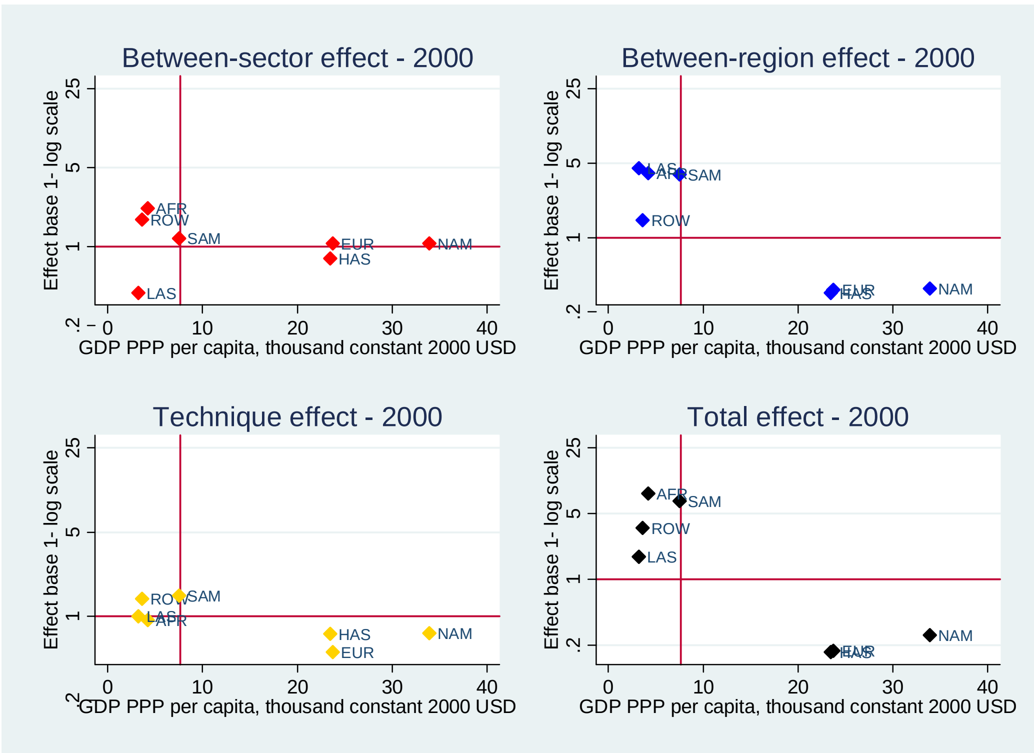
As an alternative way to abstract from the large number of countries, Figure 4 plots the same kind of graphs for 6 broad regions (see Appendix Table A3 for the country groupings). Here again, the picture that emerges is even clearer than in Figure 1. The between-sector evidence is inconclusive as regional dots are located in the four panels of the figure. For each other effect (including the total effect), the pattern is totally consistent with the pollution-haven view, as all points are located in the upper-left and the bottom-right panel of each figure.

Figure 3: Emission-weighted Total Effect, 2000



Note: Rest of the world countries are not considered in determining weights.

Figure 4: PTT against GDP per capita by region, 2000



Notes: cf. equation (4) in text for a definition of each effect. Regional definition: AFR: Africa, EUR: Europe, HAS: High Income Asia, LAS: Low Income Asia, NAM: North America, ROW: Rest of the World, SAM: South America / For a detailed country list by region see Appendix table A2.

5.3 Alternative interpretations

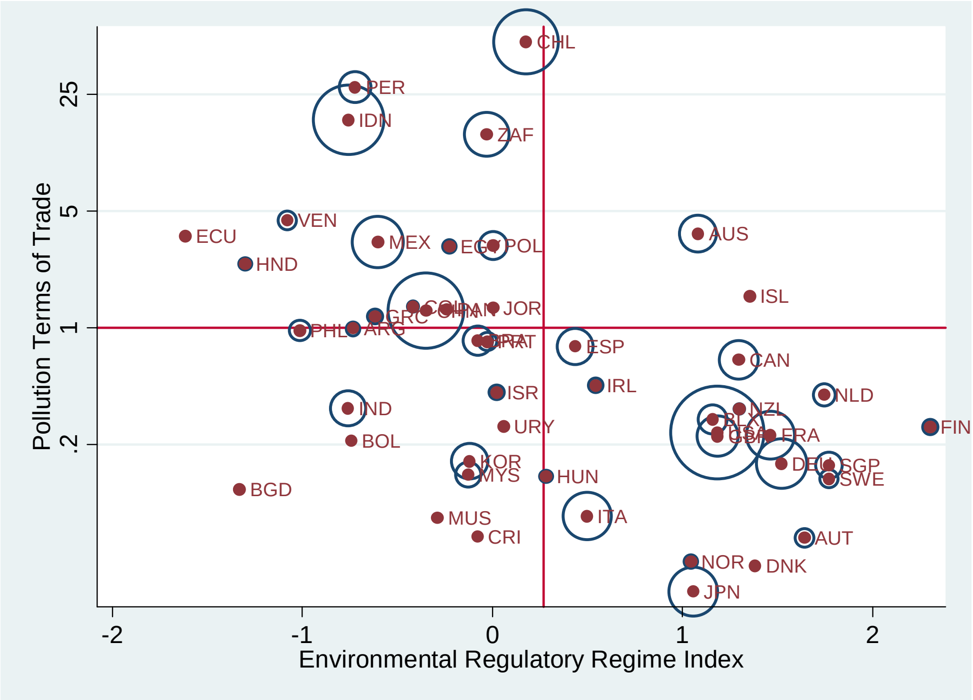
What can be inferred from the robust pattern identified so far? One possible interpretation, which is concerned with the causes of the phenomenon, is the pollution-haven hypothesis. According to this view, in a decade of trade liberalization like the 90s, “dirty” industries tend to locate preferentially in poor countries, because the latter adopt less stringent environmental policies than their richer partners, and this difference is stronger than all other determinants of comparative advantage in polluting products. A simple way to test this argument is to replace GDP per capita, which appears on the horizontal axis of Figure 2, by a more direct proxy of the stringency of environmental policy.

This is done in Figure 5(a), where 2000 PTT values are plotted against the value of the Environmental Regulatory Regime Index developed by Esty and Porter (2001). The downward-sloping pattern is clearly confirmed, with a highly (99%) significant elasticity coefficient of -3.2 (-1-4) for the weighted (unweighted) regression.[5] However, a more appropriate test of the pollution haven hypothesis should be based on temporal variation. As illustrated by Figure 5(b), when 2000 levels are replaced by differences in the log values of PTT over the 1990-2000 period, the relationship tends to break down. The unweighted regression coefficient is smaller (-0.5) and only significant at the 95% level, while the weighted regression coefficient becomes positive and non significant [6] This is in line with the results reported in Table 1, and with previous studies on SO_2 emissions that identified pollution-haven patterns in cross sections but not in time-series variations (e.g. Grether et al (2010)).

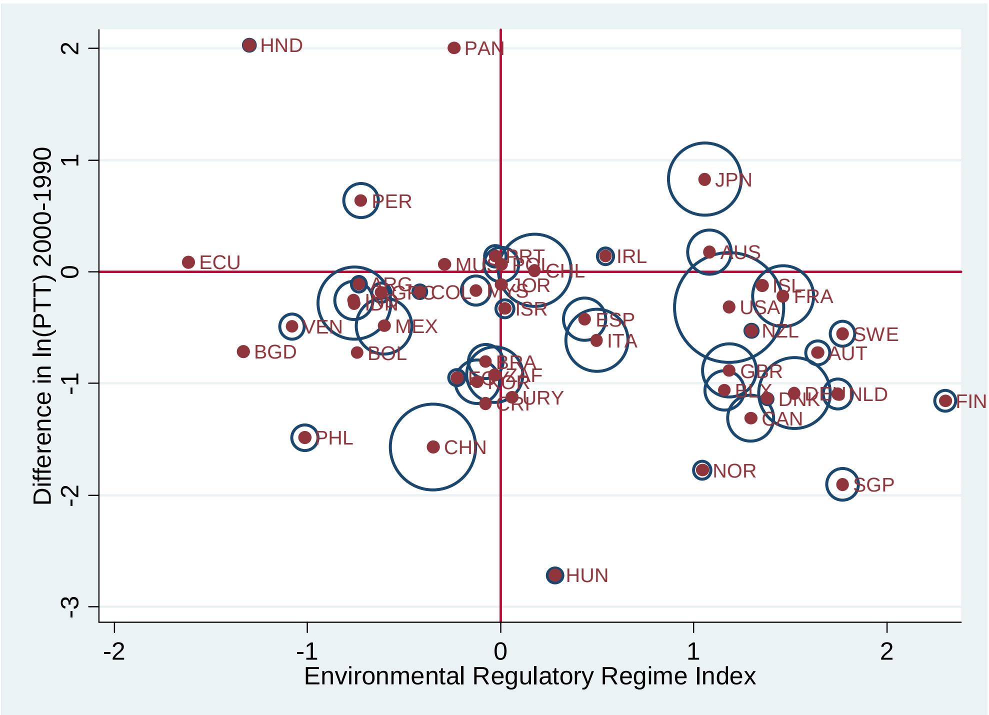
[5] Regressions are based on a sample of 49 countries for which index figures are available, and we add 2 to the value of the environmental index to avoid taking logs of a negative value.
[6] These results are robust to the use of alternative measures of environmental stringency indicators, like the Environmental Sustainability Index (Esty et al (2005)) or the survey index of the World Economic Forum (Cornelius and Schwab (2003)).

Figure 5: Pollution-haven Patterns

(a) Levels in 2000 (with trade-embodied emissions as weights)



(b) Differences 2000-1990 (weights: trade-embodied emissions)

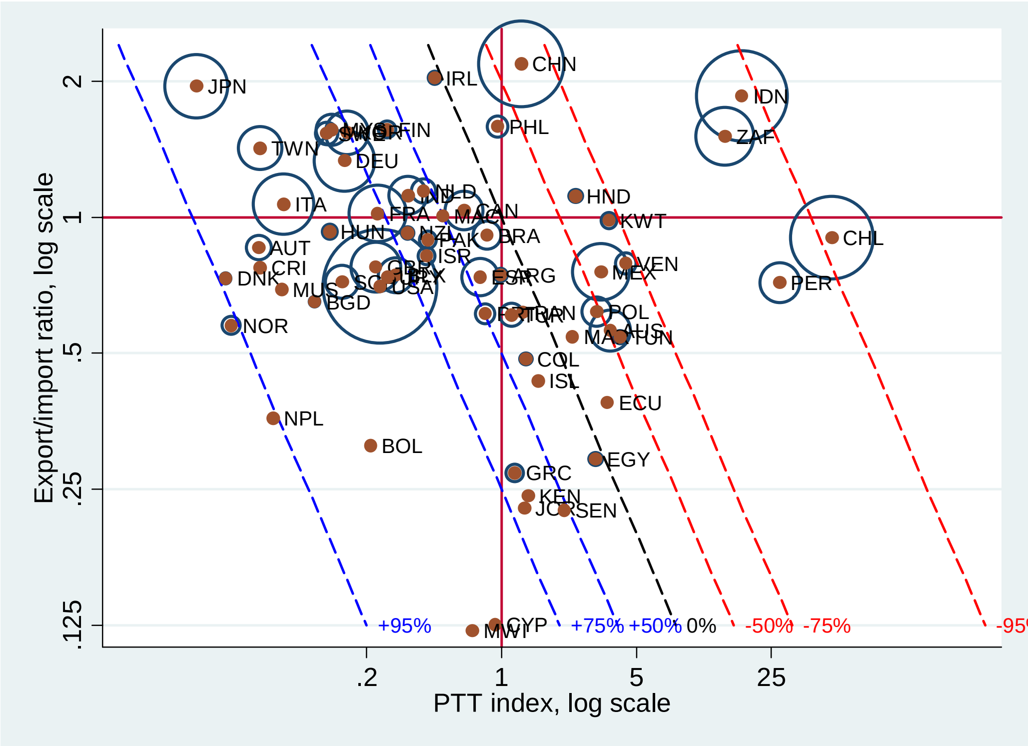


A second interpretation, which relates to the consequences of the observed pattern, is to rely on the zero-sum game described in subsection 2.2. According to this view, which is, as stated above, only an approximation of the welfare effects of trade in polluting products, a country experiments an environmental net gain if the emissions embodied in its imports are larger than those embodied in its exports. As shown by equation (6), this condition is fulfilled when the product between the PTT index (χ_{ct}) and the export over import ratio (ρ_{ct}) is smaller than 1. In Figure 6(a), as log scales are used on the axis, this is so for all countries which locate below the dashed downward-sloping diagonal ($\ln(\rho_{ct}) + \ln(\chi_{ct}) = 0$). The larger the dot (which is proportional to the share of the country in world import or export-embodied emissions depending whether the country is an environmental winner or loser), and the more it is distant from the diagonal, the larger the net environmental net gain or loss of the country (iso-curves for 50%, 75% or 95% of the maximum gain or loss -- which corresponds to the emission share -- are also reported on the diagram). Whatever the year (1990 not reported to save space), it turns out that half of the countries locate in the bottom left (winners) and top right quadrants (losers), i.e. where the PTT index and the export over import ratio reinforce each other. In the other quadrants, χ_{ct} and ρ_{ct} come at cross-purposes, but in two-third of the cases, and for all large countries in terms of world emission shares, it is the PTT which is the driving force. As a result, the general pattern is one in which, apart from India and Malaysia, most of the large environmental winners are large rich countries, while most of the large environmental losers are large poor countries (apart from Australia and Canada). From 1990 to 2000, these basic patterns are unaltered, although three large emerging economies, Indonesia, Peru and Chile, see their PTT index increase strongly.

Although Figure 6(a) is useful to disentangle the influence of χ_{ct} and ρ_{ct}, it does not represent the environmental gain or loss directly. This is done in Figure 6(b), which reports the export-embodied (θ_{ct}^{X} , negative, left-hand side) and the import-embodied (θ_{ct}^{M} , positive, right-hand side) emission shares of the major countries in the sample (i.e. those countries for which at least one of either θ_{ct}^{X} or θ_{ct}^{M} is larger than 1%). Countries are ranked by decreasing order of the *effective* net environmental gain ($\theta_{ct}^{M} - \theta_{ct}^{X}$), represented by the red diamond, while the *potential* net environmental gain that would result in case of balanced trade (ρ_{ct} set equal to 1 in equation (6)) is represented by the blue hollow circle. The largest winner, by far, appears to be the US, with a net gain larger than 15% of world trade-embodied emissions.

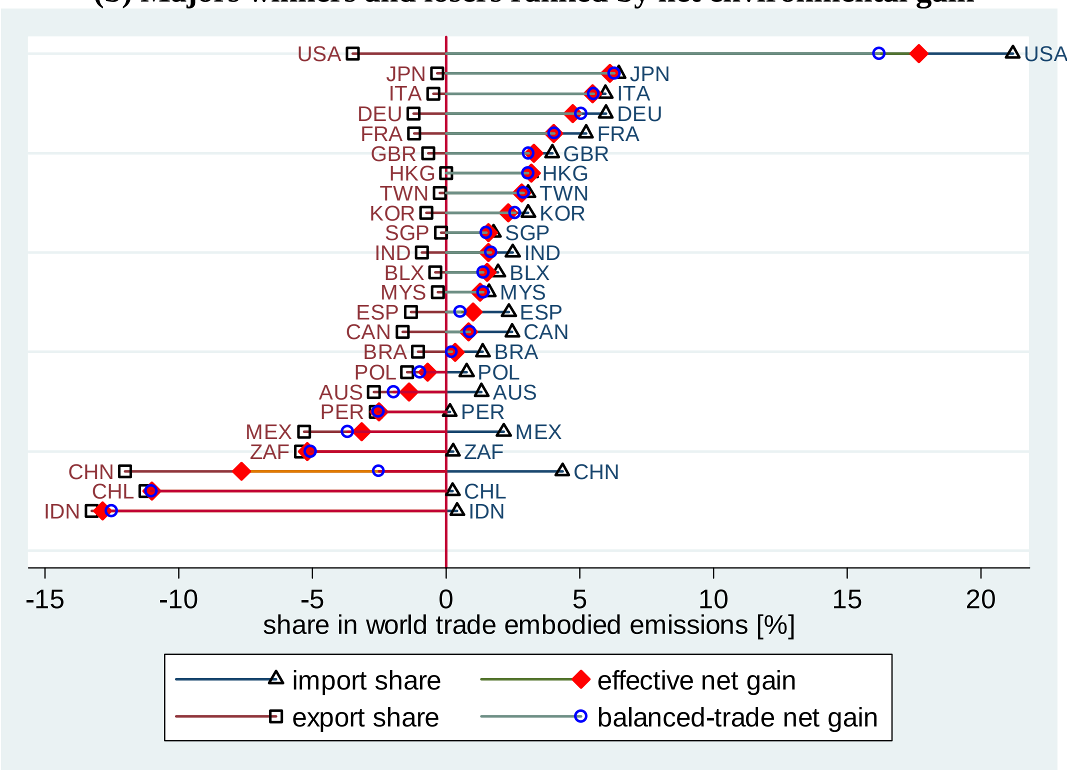
Figure 6: Environmental Winners and Losers, 2000

(a) Iso-curves for net environmental gains



Note: the number associated with each dashed line is the effective percentage of the potential loss or gain, the latter being proportional to the surface of each circle. Hong Kong and the Rest of the World excluded from the diagram for readibility.

(b) Majors winners and losers ranked by net environmental gain



Note: Excluding ROW and all countries with a share in export and import embodied emissions smaller than 1%. The effective net gain corresponds to the difference between the import and the export share. The balanced-trade potential net gain is obtained by imposing an export/import ratio equal to 1 in equation (6).

The largest losers in 2000 are Indonesia, Chile and China. The Chinese case is particular on two counts. First, it is the only large developing country which has also a substantial share in import-embodied emissions, a novelty with respect to 1990 (not represented). Second, the magnitude of its environmental loss is linked to its trade surplus: it would drop from 8% to 2.5% if it was only determined by its PTT index.

6. Conclusions

In a world in which exports and imports would be perfectly balanced for each country and where every good would generate the same amount of emissions per dollar of production, international trade would be inconsequential in terms of the distribution of pollution across countries. Neither of these two conditions being satisfied in practice, this paper provides a simple framework to analyze the practical importance of these two sources of trade-induced reallocation of world-wide emissions. Starting with trade imbalances, even if embodied emissions per dollar are identical for all goods, a country running a trade deficit is able to shift emissions abroad as those emissions contained in its imports are larger than those included in its exports. And regarding emission intensities, even if trade is balanced, the same emission offshoring applies if the Pollution Terms of Trade (PTT) index is smaller than one, i.e. if the average emission content of imports is larger than the average emission content of exports.

Relying on a recent and rich database for SO_2 emissions intensities, and controlling for input-output relationships and reexport activities, our analysis shows that both sources of emission reallocation have been important during the nineties. For half of the sample countries, they tend to reinforce each other, as illustrated by the two polar cases of the US (a low PTT index combined with a trade deficit) and China (a high PTT index combined with a trade surplus). When they work at cross-purposes, PTT is normally the driving force, as there are twice more cases where PTT rather than trade imbalance drives the net outcome. Across countries, and overcoming the original paradox reported by Antweiler (1996), the value of the PTT index is negatively associated with GDP per capita, and significantly so in 2000, with an estimated elasticity between -0.6 (unweighted) and -1.4 (emission-weighted). Overall, the general pattern is one under which most large environmental winners are large rich countries (except for India and Malaysia) and where large environmental losers are large emerging economies (except for Canada and Australia). The order of magnitude of these gains or losses is large, between 10% and 15% of world embodied emissions for the two countries located at the bottom of the distribution (Indonesia and Chile), and more than 15% for the country located at the top (the US). These results underline both the importance of the emission offshoring issue and the relevance of the PTT index to address it.

One may regret that the reported evidence is limited to SO_2, which is only of secondary interest regarding the major challenge of global warming. Again, this was due to data limitation, and similar estimates for CO_2 are clearly desirable in the future. Moreover, it turns out that, as those gases are both related to energy use, the industries concerned are very similar. Indeed, for the average emissions reported by Cole and Elliott (2003) across UK industries, the correlation between sulphur dioxide and carbon dioxide is larger than 0.9 during the nineties. Thus, similar trends may be expected in terms of composition effects.

It should be clearly stated that the zero-sum game indicator of net environmental gain used in this paper (and many others) is only an accounting measure of trade-embodied emissions, which lies far away from a proper general equilibrium analysis of the impact of trade on the environment (see Antweiler et al (2001) for a thorough analysis of the SO_2 case). However, it deserves interest for at least two reasons. First, when the impact of pollution is mainly local, it is indeed a measure of the environmental damage which is transferred abroad through trade. Second, even when the impact of pollution is regional (SO_2) or global (CO_2), it is a measure of the additional burden that domestic consumption imposes on the community of trading partners, a critical dimension to design appropriate international environmental agreements.

Two final caveats are in order. First, even if we tried to take the best out of available data, caution is required in analyzing results given the adjustment procedures that had to be followed, in particular to estimate input-output coefficients or re-export flows. Better quality data are certainly needed in the future, and may alter certain PTT estimates, although our own sensitivity analysis suggests that it is unlikely that they would affect the overall pattern. Second, given the greening of production technologies, one may argue that the severity of the problem may vanish over time. However this technique effect has to be balanced with the scale effect arising from the continuous increase in trade flows. In the case of SO_2 during the nineties, although emission coefficients decreased in most countries, exports and imports flows increased to such an extent that the total amount of emissions embodied in world trade increased by 46%. Whether these trends will continue or be reversed in the future is still an open question.

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Appendix on data preparation

Import data being considered as more reliable than export data, all exports in this closed sample are estimated by mirror imports. Missing output data were extrapolated on the basis of simple rules already described in Grether et al (2009). All trade and output figures used in this paper correspond to 3-year moving averages around each "base" year (1990,1995,2000). This appendix describes first how input-output coefficients and/or production data were adjusted to make them consistent with trade data and second how all the available information was exploited to generate estimates of reexport flows and distribution across countries.

a) Adjusting input-output coefficients

Regarding input-output matrices, there are four inconsistencies in the original data leading to negative values of key variables for certain sectors:[7]

(i) negative total absorption, obtained as the difference between output and net exports;
(ii) negative expenses on imported intermediate inputs, obtained as the difference between expenses on intermediate inputs (from the input matrix) and expenses on domestic intermediate inputs (from the output matrix);
(iii) negative sum of final demand on imported products plus reexports, obtained from the imports material balance (equation [A2] below);
(iv) negative value added, obtained as the difference between production and intermediate expenses (from the output matrix[8]);
(v) negative global final demand, obtained from the aggregate material balance (equation [A3] below);

These inconsistencies are eliminated by adjusting input-output coefficients (always in the same proportion for a given line or column) or the output level of the corresponding sector in a conservative fashion, i.e. by limiting the adjustment to what is just necessary to convert the negative key variable from negative to zero. Trade data are kept unchanged, as they are considered as more reliable.

The adjustment procedure runs as follows: A first output upward adjustment is performed for each case (i). Then cases (ii) and (iii) are treated by adjusting downwards the corresponding output (respectively input) matrix coefficient. For cases (iv) and (v), the "adjustment burden" is shared between an output increase or a decrease of the relevant input-output coefficient in an equal way. As those steps are interdependent, the procedure is repeated until all negative occurrences disappear.

The adjustment procedure converges after 6 iterations. For coefficients of the output matrix, the average decrease is less than 20% in more than 90% of the cases (the largest decrease being for Macao in 1995, with -24%). For coefficients of the input matrix, the average decrease is less than 27% in more than 90% of the cases (the largest adjustment is for the

[7] Case (i) affects 3% of the observations, case (ii) 25%, cases (iii) and (v) around 20%, and case (iv) roughly 6%. Note that for 8 countries, the IO matrices were not available and had to be borrowed from a neighbouring similar country (Netherlands for Benelux, Greece for Hungary, Mexico for Brazil, Norway for Iceland, Turkey for Israel, Philippines for Mauritius, Cameroon for Senegal and Morocco for Tunes). On average, these 8 countries do not present a higher occurrence of inconsistencies than the rest of the sample.

[8] There are no cases of negative value added based on the input matrix, apart from Argentina, where all input coefficients had to be decreased by 21%.

Philippines in 2000, with -48%). Regarding output figures, for more than 90% of the cases, the average increase in national production is smaller than 13% (the maximum is Honduras in 2000: plus 94%, then it drops to 73% and 64%, i.e. Panama in 1990 and 1995 respectively).

b) Estimating reexports

The objective here is to "clean" trade data from reexports, keeping only direct trade relationships between the originally producing country and the finally consuming country. For this purpose we have to solve two questions for each country and sector: how much of gross exports correspond to reexports? and where do these reexports come from and go to?

The first question is answered on the basis of material balances and some assumption on final demand structure. Making the distinction between domestic and foreign (i.e. imported) production, the following three material balance relationships must apply to any sector *i*:

$$q_i = v^d_i + f^d_i + x^d_i \quad \text{[A1]}$$
$$m_i = v^m_i + f^m_i + x^m_i \quad \text{[A2]}$$
$$q_i + m_i = v_i + f_i + x_i \quad \text{[A3] = [A1]+[A2]}$$

where q stands for domestic output, m for imports, x for exports, v for intermediate sales, f for final demand and a d (m) superscript indicates domestic (imported) production. Equations [A1] and [A2] look like a two-equation four-unknowns ($f^d_i, f^m_i, x^d_i, x^m_i$) system. As we know total exports and total final demand in each country, $x^d_i + f^d_i$ can be replaced by $x_i + f_i - (x^m_i + f^m_i)$ in [A1], so that we are left with two unknowns (x^m_i and f^m_i). However at this stage there is over-determination as both equations include the same sum of the two unknowns. We need to keep only [A1] or [A2], and impose some additional restriction. Our assumption is simply that reexports are a given share, noted ε, of final demand on imported goods (i.e. $x^{m*}_i = \varepsilon (m_i - v^m_i)$, subject to the constraints: $x^{m*}_i \leq x_i$, $f^{m*}_i \leq f_i$).[9]

We calibrated the value of ε relying on additional COMTRADE data, which were available for a subset of our sample countries (17 out of 62, see the note of table A3). These data suggest that the average share of reexport in gross exports is substantial and rising over time. Moreover, it differs markedly between "entrepôt" countries like Hong-Kong (where it rises on average from 66% in 1990 to 88% in 2000) and other countries (where the corresponding figures are 4% and 7.5%). Obtained by grid search, the values of ε that minimize the root mean squared error on the subset of reporting countries are 5% for non-entrepôt and 50% for entrepôt countries. For some countries, like Danemark or Benelux, this leads to a relatively high share of reexports in exports or imports (around 70%). The overall average reexport share at the world level, 11%, is perfectly in line with the orders of magnitude obtained from the subset of reporting countries.

This leaves us with the second question, namely, how to allocate national reexports across origin and destination countries. The best way to visualize the problem is to think about a 62x62 export matrix where each line (column) represents a country's exports (imports). Consider the ideal case where A exports 100 to B which are then further reexported to C. If perfect information were available, reexport correction would consist in adjusting three cells

[9] We also made the alternative and common conjecture that the share of intermediate sales in domestic expenses is the same for the national and the foreign good (i.e. $f^d_i / v^d_i = f^m_i / v^m_i = f_i / v_i$). However this led to unrealistically high estimates of total exports in gross exports (more than 40% on average).

in the export matrix: (i) reduce B's exports to C by 100, (ii) reduce A's exports to B by 100, and (ii) increase A's exports to C by 100. As this information is not available, we proceed by allocating these reductions and increases of trade flows proportionately columns or lines of the export matrix. This leads to the following seven-step procedure:

(i) for every country (apart from the subset of reporting countries, where detailed info by CCOD is available), calculate the *potential* reduction of export flows, by allocating the original estimated amount of reexports proportionately along each line;
(ii) for every country, calculate the *potential* reduction of import flows, by allocating the original estimated amount of reexports proportionately along each column;
(iii) calculate, for each cell of the export matrix, the *individual average* reduction of the trade flow, which is the simple average between the potential reduction of exports and the potential reduction of imports.
(iv) for every country, calculate the reduction of total exports and the reduction of total imports implied by point (iii), bounding these figures by the original estimated amount of reexports. Calculate the average between these two figures, which is called the *national average* reduction in total trade.
(v) calculate reexport correction terms, i.e. allocate the national average reduction in total trade proportionately across all trading partners of a given country, the weight given to each cell being the product between the export and the import shares of the corresponding country (adjusted so that all diagonal elements are zero). This generates *n* correction terms per cell (*n* being the number of countries), which are summed up and added to obtain the *reexport re-allocation term* for each cell.
(vi) proceed to the effective correction of each cell, by substracting from the original figure the *individual average* reduction of trade flow (calculated in point (iii)) and adding to the results the *reexport re-allocation term* (calculated in point (v)).
(vii) for every country, calculate the effective reduction of total exports and the effective reduction of total imports implied by point (vi). Taking the difference with the original estimated amount of reexports leads to the residual amount of reexports on the export side, or *export residual*, and to the residual amount of reexports on the import side, or *import residual*.

Start again with points (i)-(vii) in a new loop where the original estimated amount of reexports is replaced by the export residual in point (i) and by the import residual in point (ii) while in point (iv) the reduction of total exports or imports is bounded by the export or import residual (if the latter is negative, the corresponding reduction is set to zero). The procedure stops when the sum of the absolute value of the export and import residuals across all countries stops decreasing (or does it by less than 1 dollar per loop). This is usually achieved after less than 400 iterations (the maximum is 593 iterations for in 1990).

This procedure creates new trade routes (the share of positive cells in the export matrix rises from 70% to 93% on average), which is to be expected when re-export flows are disentangled. Moreover, it makes sure that in the end and for each country, exports and imports are reduced by the amount of reexports estimated when answering the first question raised above.

Table A1: Correspondence table between input-output and ISIC sectors

Input-output sector	ISIC 3-digit	Description
1	311/312	Food products
2	353/354	Petroleum
3	313/314	Beverages & Tobacco
4	321	Textiles
5	322	Wearing Apparel
6	323/324	Leather & Footwear
7	331/332	Wood & Furniture
8	341/342	Paper & Printing
9	351/352/355/356	Chemicals & Plastic
10	361/362/369	Non-metal minerals
11	371	Iron & Steel
12	372	Non-ferrous metals
13	381	Metal products
14	384	Transport equipment
15	382	Non-elect. machinery
16	383/385	Machinery & Professional equipment.
17	390	Other manufacturing products

Table A2: PTT indices for SO_2 emissions, 1990 / 2000

Country	1990				2000			
	Between-sector effect	Between-country effect	Technique effect	Total effect	Between-sector effect	Between-country effect	Technique effect	Total effect
	(1)	(2)	(3)	(4)=(1)*(2)*(3)	(1)	(2)	(3)	(4)=(1)*(2)*(3)
Share of Variance	**0.37**	**0.63**	**0**	**1**	**0.20**	**0.59**	**0.21**	**1**
ARG	1.15	1.19	1.00	1.37	1.42	0.74	1.24	1.30
AUS	2.53	1.63	1.00	4.11	2.45	1.23	1.65	4.97
AUT	0.97	0.15	1.00	0.15	0.90	0.12	0.69	0.08
BGD	0.15	2.10	1.00	0.31	0.08	1.79	1.09	0.16
BLX	1.07	1.06	1.00	1.13	1.27	1.42	0.23	0.41
BOL	3.87	0.12	1.00	0.48	1.06	0.23	0.99	0.25
BRA	1.10	2.10	1.00	2.30	0.77	2.16	0.85	1.42
CAN	1.85	1.49	1.00	2.76	1.38	0.91	0.63	0.79
CHL	4.19	14.11	1.00	59.07	3.33	11.34	1.81	68.39
CHN	0.68	11.58	1.00	7.90	0.41	9.01	0.47	1.74
COL	1.31	1.72	1.00	2.24	1.83	1.15	0.78	1.64
CRI	0.29	0.71	1.00	0.21	0.36	0.53	0.38	0.07
CYP	0.69	2.07	1.00	1.42	0.96	1.40	1.19	1.60
DEU	0.76	0.81	1.00	0.62	0.87	0.64	0.39	0.22
DNK	0.39	0.40	1.00	0.15	0.64	0.31	0.29	0.06
ECU	2.24	1.80	1.00	4.03	1.46	1.52	2.01	4.45
EGY	3.97	2.75	1.00	10.92	2.19	2.65	0.98	5.70
ESP	1.11	1.44	1.00	1.60	0.97	1.17	0.98	1.11
FIN	1.30	1.01	1.00	1.31	1.12	0.70	0.51	0.40
FRA	0.85	0.45	1.00	0.38	0.92	0.32	1.09	0.32
GBR	1.22	0.60	1.00	0.74	1.42	0.44	0.51	0.31
GRC	1.88	1.09	1.00	2.05	2.01	0.96	0.95	1.84
HKG	0.38	0.15	1.00	0.06	0.83	0.18	0.30	0.04
HND	0.18	3.18	1.00	0.58	0.10	4.75	10.54	4.94
HUN	1.52	1.86	1.00	2.83	0.81	1.40	0.17	0.19
IDN	1.38	19.72	1.00	27.27	0.48	7.04	8.83	30.02
IND	0.29	3.83	1.00	1.13	0.34	1.56	0.94	0.51
IRL	0.64	0.76	1.00	0.49	1.55	0.64	0.61	0.61
ISL	1.99	2.10	1.00	4.18	2.25	1.32	1.08	3.20
ISR	0.69	1.37	1.00	0.94	0.71	1.19	0.92	0.78
ITA	0.63	0.32	1.00	0.20	0.74	0.26	0.54	0.11
JOR	1.61	1.48	1.00	2.38	1.44	1.08	1.56	2.42
JPN	0.32	0.05	1.00	0.01	0.58	0.05	1.18	0.04
KEN	0.67	3.37	1.00	2.26	1.66	1.24	1.60	3.29
KOR	0.49	1.09	1.00	0.53	0.71	0.68	0.44	0.21
KWT	8.65	3.00	1.00	25.96	8.91	1.94	0.28	4.88
MAC	0.23	1.81	1.00	0.42	0.10	4.06	1.47	0.62
MAR	1.23	3.05	1.00	3.76	1.21	2.06	1.36	3.38
MEX	0.69	8.97	1.00	6.17	0.51	6.17	1.30	4.10
MUS	0.15	0.79	1.00	0.12	0.13	0.66	1.69	0.14
MWI	0.20	1.24	1.00	0.25	0.38	1.38	1.93	1.02
MYS	0.49	0.40	1.00	0.20	0.56	0.31	1.02	0.18
NLD	2.39	0.61	1.00	1.46	2.17	0.31	0.76	0.51
NOR	2.64	0.12	1.00	0.31	2.58	0.08	0.27	0.05
NPL	0.12	0.04	1.00	0.00	0.15	0.03	26.82	0.11
NZL	1.12	0.60	1.00	0.67	0.91	0.45	1.04	0.42
PAK	0.17	3.82	1.00	0.66	0.13	3.15	2.09	0.84
PAN	0.33	0.81	1.00	0.26	1.37	0.48	2.84	1.86
PER	2.68	6.07	1.00	16.29	2.35	7.17	2.07	34.80
PHL	0.78	6.43	1.00	5.04	0.49	2.86	0.88	1.22
POL	0.46	16.14	1.00	7.42	0.94	7.45	0.66	4.62
PRT	0.80	1.18	1.00	0.94	0.69	1.02	1.65	1.16
ROW	2.17	1.89	1.00	4.10	1.72	1.46	1.39	3.50
SEN	0.92	2.28	1.00	2.09	1.77	1.01	1.79	3.19
SGP	2.48	0.53	1.00	1.30	1.52	0.48	0.32	0.23
SWE	0.97	0.29	1.00	0.28	1.02	0.19	0.88	0.17
TUN	1.02	8.90	1.00	9.09	0.55	8.12	1.45	6.49
TUR	0.96	3.78	1.00	3.61	0.61	2.57	1.08	1.70
TWN	0.39	0.27	1.00	0.11	0.61	0.26	0.48	0.07
URY	0.56	1.86	1.00	1.04	0.61	1.17	0.51	0.36
USA	0.99	0.41	1.00	0.41	0.97	0.37	0.86	0.31
VEN	6.69	1.23	1.00	8.23	7.38	1.04	0.68	5.27
ZAF	5.03	8.81	1.00	44.27	3.21	5.99	1.04	19.92

Notes: cf. equation (4) in text for the definition of each effect.

Table A3: Regional grouping of countries

N. America, NAM (2)	**High Income Asia , HAS(10)**	**Europe, EUR (19)**	**Africa, AFR (8)**	**Low Income Asia, LAS (10)**
Canada (CAN)	*Australia* (AUS)	Austria (AUT)	Egypt (EGY)	Bangladesh (BGD)
USA (USA)	*Hong Kong* (HKG)	Belgium & L. (BLX)	*Kenya* (KEN)	China (CHN)
	Israel (ISR)	*Cyprus* (CYP)	Morocco (MAR)	*India* (IND)
S. America, SAM (13)	Japan (JPN)	Denmark (DNK)	Mauritius (MAS)	Indonesia (IDN)
Argentina (ARG)	Korea (KOR)	Finland (FIN)	*Malawi* (MWI)	*Jordan* (JOR)
Bolivia (BOL)	*Kuwait* (KWT)	France (FRA)	Senegal (SEN)	Malaysia (MYS)
Brazil (BRA)	*Macau* (MAC)	Germany (DEU)	S. Africa (ZAF)	Nepal (NPL)
Chile (CHL)	*New Zealand* (NZL)	Great Britain (GBR)	Tunisia (TUN)	*Pakistan* (PAK)
Colombia (COL)	Singapore (SGP)	Greece (GRC)		*Philippines* (PHL)
Costa Rica (CRI)	*Taiwan* (TWN)	Hungary (HUN)		Turkey (TUR)
Ecuador (ECU)		Ireland (IRL)		
Honduras (HND)		Island (ISL)		
Mexico (MEX)		Italy (ITA)		
Panama (PAN)		Netherlands (NLD)		
Peru (PER)		Norway (NOR)		
Venezuela (VEN)		Poland (POL)		
Uruguay (URY)		Portugal (POR)		
		Spain (ESP)		
		Sweden (SWE)		

Note: Countries in italic are those reporting reexport data in the COMTRADE database.