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The pollution terms of trade and its five components ☆

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ABSTRACT

Based on two extensions, this paper proposes a re-appraisal of the concept of the pollution terms of trade (PTT) introduced by Antweiler (1996). First, detailed data allows capturing the effect of differences in emission intensities across countries and over time. Second, relying on Johnson and Noguera (2012), the revised PTT index controls for trade in intermediate goods and is based on value-added rather than gross output figures. Applied to a database for SO_2 emission intensities for 62 developed and developing countries over the 1990–2000 period, it turns out that the first extension has a larger empirical importance than the second one. The global pattern is one in which the major rich economies exhibit a PTT index below one (higher pollution intensity in imports than in exports). Trade imbalances tend to exacerbate this asymmetry, allowing rich economies to further offshore their pollution through trade.

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, limited to one year, 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, data on imported input requirements by trade partner are necessary to attribute intermediate imports to their final destination (Johnson and Noguera, 2012). Third, reliable trade and production data must be made available and compatible at a reasonable degree of disaggregation to identify the influence of the most polluting sectors. Fourth, 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 input–output relationships. Taking the best out of available data for a specific pollutant, which is sulfur 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 countries and years and taking properly into account trade in intermediate goods.

SO_2 is a particularly useful pollutant to investigate because it is primarily anthropogenic, primarily industry-driven (rather than generated by transportation or household activity), and primarily a local (rather than a trans-boundary or global) pollutant.[1] In previous work Grether et al. (2009) have decomposed world-wide SO_2 manufacturing emissions over 1990–2000 into the well-known scale, technique and composition effects. It has been shown that despite the considerable increase of manufacturing activity by 10% (scale effect) total emissions have fallen by roughly 10% thanks to the adoption of cleaner techniques (technique effect) and a small shift towards cleaner industries. When

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using output as the scale measure, there is however an important shift towards “dirty” countries. These results confirm the importance of analyzing in more detail the SO_2 pollution content of trade.

The second objective of this paper is to propose a reconsideration of the concept of the pollution terms of trade (PTT) introduced more than 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 import-embodied and export-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 is all the more regrettable that recent contributions point towards the importance of trade in intermediate goods in shaping the factor content or the value-added content of trade (e.g. Johnson and Noguera, 2012 and Trefler and Zhu, 2010). In the presence of intermediate trade, the relationship between demand and polluting emissions becomes more complex. This is so because imports may correspond to inputs which are used to produce other goods which are further exported to another destination country. This affects the measurement of import or export-embodied emissions (and thus also PTT calculations) in a non-trivial way. The new methodology developed recently makes it possible to control for these effects, by uncovering the implicit trade flows that relate the original producer (and the corresponding emissions) to the final consumer (in the destination country that does manage to offshore pollution).

This paper proposes to revisit PTT calculations by exploiting newly available data and recent methodological advances in the analysis of intermediate trade. The approach is directly borrowed from Antweiler (1996), the basic difference being that we include time and country variations into the analysis, as well as trade in intermediate goods, which allows for an original decomposition of the PTT index into five components: a between-sector, a between-country, a technique, an intermediate trade and a value added effect. The first effect corresponds to the “trade-composition” index measured by Antweiler (1996), the second (third) effect captures the influence of different emission intensities across countries (over time), the fourth effect reflects the impact of using implicit (i.e. final demand driven) rather than reported trade flows, and the fifth the impact of considering value added rather than output trade flows. Regarding empirics, the sample period is 1990–2000 with a good coverage (63 developed and developing economies), and a particular care 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 et al. (2009). We also impose the consistency between trade and input–output data, control for reexports and apply the proportionality assumption to spread intermediate input requirements across trade partners (see Johnson and Noguera, 2012). 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 reviews the empirical evidence regarding pollution content of trade calculations. Section 3 outlines the theoretical derivation of the PTT index when trade in intermediate goods is taken into account and makes the link between the environmental trade balance, the trade ratio, and the PTT index. Section 4 shortly describes the data, Section 5 reports and discusses the main results and the last section concludes.

2. Literature review

Serious concern has been raised that in an era of globalization and differences in environmental stringency, trade liberalization will lead to a delocalization of polluting industries to countries with lower standards, i.e. the so called “pollution havens” (see Copeland and Taylor, 2004).[2] The possibility of delocalizing economic activities implies that international evidence is called for. Yet most evidence is from the US (Ederington et al., 2005; Levinson and Taylor, 2008; Levinson, 2010). The seminal paper by Antweiler et al. (2001) investigated the effect of trade on SO_2 concentrations using data from a large international sample of measurement installations. With increased trade liberalization they find that the concentration-decreasing technique effect is more than over-compensating the concentration-increasing scale and composition effects. Using the same framework but SO_2 emission data (instead of concentration data) Cole and Elliott (2003) could only partly confirm that trade is good for the environment. This discrepancy illustrates the challenges faced by studies investigating the causal link between trade and the environment in terms of estimation techniques and data needs, especially when it comes to proxies for environmental regulation and pollution measures. So far, studies working with a panel of countries had to rely on global measures of environmental quality (e.g. total country-emissions) and had to use proxies to identify scale, composition and technique effects (e.g. GDP, GDP/capita, etc.).

Several other arguments have been put forward to explain why it might be difficult to identify the pollution haven effect empirically. Ederington and Minier (2003) argue that environmental regulation might act as a secondary trade barrier and Frankel and Rose (2005) take specifically into account the endogeneity of trade and estimate the effect of trade on a country's environment for a given level of GDP for a sample of 40 countries. They find that trade has a beneficial effect on SO_2 concentration levels. Further Ederington et al. (2005) argue that for most industries, pollution abatement costs are a small component of total costs, and that those industries with the largest pollution abatement costs also happen to be the least geographically mobile. Finally it has been put forward, that the “factor endowment effect”; i.e. the fact that dirty industries are relatively capital intensive and would be attracted by capital abundant countries, would go in opposite direction of the pollution haven effect, as capital abundant countries also turn out to adopt stricter environmental regulations. Grether et al. (2012) have disentangled the two effects for a large number of pollutants and almost fifty countries. They find significant pollution haven and factor endowment effects going in the expected direction for trade between low and high income countries. On a global scale however, because the bulk of trade is intra-regional with a high share between high income countries, these effects are small relative to other determinants of the worldwide pollution content of imports (here computed without taking input–output linkages into account).

Another strand of the literature has put the emphasis on the link between emissions and sectoral economic activity, using detailed environmental data but restricting itself to reporting emissions embodied in trade flows. Following Muradian et al. (2002) several papers have computed the balance of emissions embodied in trade (BEET). The

[2] We restrict here our discussion to the analysis of trade flows. A large number of studies investigated also the effect of differences in environmental regulation on FDI flows. See for example Eskeland and Harrison (2003) or Javorcik and Wei (2004).

difference between imported and exported pollution emissions allows identifying each country's environmental responsibility in terms of consumption as opposed to production. These computations, which have been flourishing for CO_2 emissions, do however take a rather short term perspective, since the BEET is strongly affected by any temporal trade balance disequilibria. On the contrary, the measure proposed by Antweiler (1996), the pollution terms of trade (PTT), is not affected by the trade balance. Taking a long term perspective is in line with the literature on pollution havens discussed above, since the Heckscher–Ohlin–Vanek framework also reflects a long run view. The PTT represents the physical units of pollution exported per dollar of exports divided by the units of pollution imported per dollar of imports. It is not a measure of total pollution displaced but a measure of relative pollution intensity. Therefore the PTT has in addition to the long term perspective two other advantages over the BEET. First it abstracts from any scale effects and makes PTT comparable across countries of different size. Second, it has the interpretation of an international exchange rate of emissions, telling how countries can convert exported emissions into imported emissions.

The methodology and the data used to compute the pollution embodied in trade have also received considerable attention in the literature. Turner et al. (2007) have put forward that theoretically an inter-regional world input–output table that is disaggregated nationally and sectorally in a consistent way would be needed to determine how activity in one region drives activity in other regions. They acknowledge however that three problems have so far prevented the application in the literature: data availability, reconciliation of data from different sources and countries and the computability in terms of balancing conflicting data. Johnson and Noguera (2012) and Trefler and Zhu (2010) have recently developed the modeling framework to address two related problems. The problem of factor content estimations with trade in intermediate goods is addressed in Trefler and Zhu (2010). They present the methodological framework to construct a world-wide input–output matrix and the way production values can be consistently converted in factor contents embodied in observed trade flows.[3] With increased world-wide production sharing, the problem of double-counting in the value of trade flows is becoming serious. Johnson and Noguera (2012) have addressed this concern by computing the value added content of trade.

This paper adds to the existing literature on three axes. First, it uses country-, year- and sector-specific emission intensities data that have been carefully constructed. This allows linking emissions directly to economic activity and identifying between-sector, between-country and technique effects without having to rely on indirect proxies. Second, it relies on the PTT, having therefore a measure at hand that is independent of scale and comparable across countries. Moreover this measure is not influenced by temporal disequilibria in trade balances and allows therefore taking a longer term perspective. Third, it establishes the formal link between PTT measurements and the most recent work on the computation of embodied factor contents and the value added content of trade. This allows incorporating trade in intermediate goods in a coherent and up-to date way, relating pollution emissions to the final consumer, and leading to a novel decomposition of the PTT index into five components.

3. Methodology

In order to include trade in intermediate goods in the calculations of the PTT index we proceed in four steps. First, following the approach of Trefler and Zhu (2010) and most of their notation, we characterize the links between output, trade and input requirements at the global level, when all countries are linked together in a world input–output table. Second, in line with the argument developed by Johnson and Noguera (2012), we uncover the *implicit* trade flows that appear when each production activity is associated with the final demand it is aimed to satisfy. This provides the background for a final demand-driven attribution of production emissions across countries and sectors, which is used to calculate the value added based PTT index in a third subsection.[4] A final subsection relates the PTT index to a partial measure of net environmental gains from trade.

3.1. Input requirements and reported trade

Let us consider a world where there are N countries, indexed by i (or j) and S sectors indexed by s. Total production and total exports of country i are represented by the $S\times 1$ vectors Q_i and X_i respectively. Final demand of country j of goods produced in country i is given by the $S\times 1$ vector C_{ij}, total imports of country j of goods produced in country i are given by the $S\times 1$ vector M_{ij}, and input requirements of country j sectors of intermediate inputs produced by country i's sectors are given by the $S\times S$ matrix B_{ij}. Material balances imply that:

$$X_i = Q_i - B_{ii}Q_i - C_{ii} \tag{1a}$$

$$M_{ij} = B_{ij}Q_j + C_{ij}. \tag{1b}$$

Both trade vectors include final and intermediate goods. The first equation obtains total exports as the difference between total production and domestic demand while the second splits imports into intermediate and final use.

To condense both relationships into a single equation we need to introduce some additional matrix notation. Let Q be the $NS\times N$ bloc-diagonal matrix of national production (each column representing national production on the diagonal and zero otherwise), C the $NS\times N$ partitioned matrix of global final demand (each column representing final demand of the corresponding country towards all final goods in the world), B the $NS\times NS$ world input–output matrix (each column representing the input requirements of the corresponding sector and country towards all intermediate goods in the world) and T the $NS\times N$ world trade matrix (each column representing, for the corresponding country, exports as positive elements on the diagonal and imports as negative off-diagonal elements). That is,

$$Q = \begin{pmatrix} Q_i & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & Q_N \end{pmatrix}, \quad C = \begin{pmatrix} C_{11} & \cdots & C_{1N} \\ \vdots & & \vdots \\ C_{N1} & \cdots & C_{NN} \end{pmatrix},$$
$$B = \begin{pmatrix} B_{11} & \cdots & B_{1N} \\ \vdots & & \vdots \\ B_{N1} & \cdots & B_{NN} \end{pmatrix}, \quad \text{and } T = \begin{pmatrix} X_1 & \ldots & -M_{1N} \\ \vdots & & \vdots \\ -M_{N1} & \cdots & X_N \end{pmatrix}. \tag{2}$$

Combining Eqs. (1a), (1b) and (2) leads to:

$$T = Q - [BQ + C] = Q - Q_D \tag{3}$$

where $Q_D \equiv BQ + C$ represents demand on domestic goods, both intermediate and final. Eq. (3) simply states that, at every bilateral country and sector level, net exports are just equal to the difference between national production and national demand. It also implies the well-known Leontief relationship between "net" and "gross" outputs, i.e. $Q = (I-B)^{-1}(C+T)$.

The usual next step in factor content studies is to multiply each column of matrix T by a vector of total factor requirements (i.e. direct factor requirements multiplied by the inverse Leontief matrix) to calculate the factor content (in our case the emission content) of trade. However we refrain to do so at this stage in order to illustrate the consequences of controlling for trade in intermediate goods, as illustrated in the next section.

[3] See Aichele and Felbermayr (2012) for an application of the methodology by Trefler and Zhu (2010) to the CO_2 content of trade.

[4] All relationships are established for a single pollutant (SO_2 in our context), but are easily generalized for the case of multiple pollutants.

3.2. Emissions embodied in final demand-driven trade

As argued by Johnson and Noguera (2012), when the production chain spreads across several countries, observed intermediate trade flows may be difficult to interpret. A first problem is double counting, which leads these authors to propose a measure of the value-added content of trade. A second problem is that observed trade flows attribute intermediate exports to the immediate buyer rather than to the final consumer. As will be shown below, regarding the measurement of the pollution terms of trade, the former problem is relatively innocuous, but the latter requires more development.

Let us come back to Eq. (3) with a seemingly absurd proposal: why not use it as a basis to calculate the emission content of trade by applying direct (instead of inverse-Leontief augmented) emission intensities to the two terms on the right-hand side, i.e. supply (Q) and demand (Q_D) of domestic goods? The answer is no, because the second term (Q_D), does not reflect what would be required for that purpose, namely total production (of all goods, in all countries) generated by the final demand of a particular country. However we do know how to construct that hypothetical term, which is simply given by:

$$\tilde{Q}_D = (I-B)^{-1}C. \tag{4}$$

We will call $\tilde{Q}_D$ the *implicit* demand matrix. Each column of that $NS\times N$ matrix reflects total demand (for both intermediate and final uses) on all goods generated by the vector of final demand of a particular country. Note that, by construction, Q_D and $\tilde{Q}_D$ correspond to two alternative ways to decompose the same world totals in the sense that the sum of the elements along a given line of each matrix is identical (it corresponds to total production of a given good in a given country). What is in fact different, and matters, is that the off-bloc-diagonal elements of a column of $\tilde{Q}_D$ do not correspond to observed imports, but to those total imports which are implied, both directly and indirectly, by the final demand of that country (and conversely for the on-bloc-diagonal elements, which represent domestic production).

This alternative methodology, which is proposed by Johnson and Noguera (2012) to calculate the value-added content of trade (their Eq. (4) is our Eq. (4) but for the difference in notation), reshapes trade routes so that any good destination's is where final demand locates. In the case of PTT calculations, where one of the objectives is precisely to use trade data such as to attribute the responsibility of emissions to the country where final demand is located, we believe this is the appropriate approach.

By replacing Q_D by $\tilde{Q}_D$ in Eq. (3) we obtain the matrix of *implicit* (or final demand driven) trade:

$$\tilde{T} = Q-\tilde{Q}_D = \begin{pmatrix} \tilde{X}_1 & \cdots & -\tilde{M}_{1N} \\ \vdots & & \vdots \\ -\tilde{M}_{N1} & \cdots & \tilde{X}_N \end{pmatrix}. \tag{5}$$

Furthermore, by combining Eqs. (3) and (5) one obtains:

$$\tilde{T} = (I-B)^{-1}T. \tag{6}$$

Recall that the differences in trade patterns between implicit ($\tilde{T}$) and reported (T) trades are due to the reattribution of intermediate trade flows (final trade flows are identical under the two approaches).[5]

[5] The difference between implicit and reported total exports for a given country is a priori ambiguous. On the one hand, implicit trade adds as new exports all domestic sales of intermediate goods which are produced to satisfy foreign demand. On the other hand, it substracts from reported exports all foreign purchases of domestic intermediate goods which are used to satisfy domestic demand. In the case of our sample, implicit exports turn out to be larger than reported exports for all countries, i.e. at the national level, "the foreign demand" effect always dominates the "domestic demand" effect. Algebraically, if $\tilde{Q}_{D,ij}$ is the $S\times 1$ vector representing production of country i induced by final demand of country j, implicit exports of i are larger than reported exports if $B_{ii}\left[Q_i-\tilde{Q}_{D,ii}\right] > \sum_{j\neq i} B_{ij}\tilde{Q}_{D,ji}$, with the left(right) hand side element of the inequality representing the foreign (domestic) demand effect.

Following the responsibility principle, our calculations of bilateral embodied emissions are based on final demand-driven trade flows. The $N\times N$ matrix of trade-embodied emissions, E, is obtained from $\tilde{T}$ by applying to every "constructed" bilateral trade vector $\tilde{T}_{ij}$ the corresponding $1\times S$ vector of direct emission intensities $D_i{}'$, that is:

$$E = \begin{pmatrix} e_1^X & \cdots & -e_{1N}^M \\ \vdots & & \vdots \\ -e_{N1}^M & \cdots & e_N^X \end{pmatrix} = \begin{pmatrix} D_1{}'\tilde{X}_1 & \cdots & -D_1{}'\tilde{M}_{1N} \\ \vdots & & \vdots \\ -D_N{}'\tilde{M}_{N1} & \cdots & D_N{}'\tilde{X}_N \end{pmatrix}. \tag{7}$$

Two comments are in order regarding Eq. (7). First, if our objective was only to calculate the net emission (or factor) content of trade, we would be simply adding up all elements of each column obtaining as a result the $1\times N$ vector $D'\tilde{T}$, with D the $NS\times 1$ world vector of emission intensities. In this case, as shown by Eq. (6), it would be strictly equivalent to apply the vector of direct emission intensities (D') to corrected flows ($\tilde{T}$) or to apply the vector of total emission intensities ($D'(I-B)^{-1}$) to reported flows (T). However, this equivalence breaks down if one is interested in the emission content of bilateral flows (as opposed to net trade flows), as is the case for PTT calculations, which is why we rely on corrected trade flows below. Second, in the particular case where all trade is in final goods (which was Antweiler's implicit original assumption), B and the inverse Leontief become block-diagonal, which re-establishes the above-mentioned equivalence and justifies the use of (national input–output data only and) total emission intensities applied to reported flows.

Results can also be interpreted in terms of value-added trade. Using the input requirements of the B matrix, it is straightforward to convert the gross output figures that appear in Eq. (5) into corresponding value-added figures. This affects of course the magnitude of trade flows and also allows analyzing the distribution of income generated by national final expenditures in an integrated world. However, regarding the distribution of emissions, this conversion is without consequence, because emission intensities are increased by the same proportional amount as value flows are decreased, so that the matrix of traded emissions, E, remains unchanged. To avoid introducing unnecessary additional notation, we will just keep that in mind, remembering that trade flows in Eq. (7) can be interpreted indifferently as output or value-added trade.

3.3. Calculating the pollution terms of trade

Using the same notation as above, the average content of emissions per dollar of exports (F_j^X) or imports (F_j^M) by country j is given by the following expressions:

$$F_j^X = \frac{e_j^X}{U'\tilde{X}_j} \tag{8a}$$

$$F_j^M = \frac{\sum_{i\neq j} e_{ij}^M}{\sum_{i\neq j} U'\tilde{M}_{ij}} \tag{8b}$$

where U is a $S\times 1$ vector of ones and we recall that implicit trade flows ($\tilde{X}_j$,$\tilde{M}_{ij}$) can be interpreted either as output or as value-added trade flows. Finally, abstracting from the temporal dimension for the moment, we can define the pollution terms of trade of country j as:

$$\mathcal{X}_j = \frac{F_j^X}{F_j^M} \tag{9}$$

Note that the precision with which $\mathcal{X}_j$ is estimated depends critically on data availability regarding emission intensities (D) and input–output coefficients (B_{ij}). This is illustrated sequentially in Table 1, where the first line corresponds to the original study by Antweiler (1996) where US data were applied to all countries and periods, and the last one to

Table 1
Progressive refinements of PTT calculations.

Case	Trade flows	Emission intensities	Domestic input–output matrix	Bilateral input–output matrix	Effects captured
I (Antweiler)	Reported trade flows	US, 1990	US	Not used	Between sector effect
II	Reported trade flows	Country specific, 1990	Country specific	Not used	I + between country effect
III	Reported trade flows	Country specific, time varying	Country specific	Not used	II + technique effect
IV	Final-demand driven trade flows	Country specific, time varying	Country specific	Used	III + intermediate trade effect
V (this paper)	Final-demand driven value-added trade flows	Country specific, time varying	Country specific	Used	IV + value-added effect

the present paper, which relies on period- and country-specific information and controls for trade in intermediate inputs.

Introducing now a time subscript (t) and following Antweiler, one can decompose the pollution terms of trade index into the following multiplicative elements:

$$\mathcal{X}_{jt} = \mathcal{X}^{I}_{jt}\,\bar{\mathcal{X}}_{jt}\hat{\mathcal{X}}_{jt}\tilde{\mathcal{X}}_{jt}\breve{\mathcal{X}}_{jt} \tag{10}$$

where $\bar{\mathcal{X}}_{jt} = \frac{\mathcal{X}^{II}_{jt}}{\mathcal{X}^{I}_{jt}}$, $\hat{\mathcal{X}}_{jt} = \frac{\mathcal{X}^{III}_{jt}}{\mathcal{X}^{II}_{jt}}$, $\tilde{\mathcal{X}}_{jt} = \frac{\mathcal{X}^{IV}_{jt}}{\mathcal{X}^{III}_{jt}}$, $\breve{\mathcal{X}}_{jt} = \frac{\mathcal{X}^{V}_{jt}}{\mathcal{X}^{IV}_{jt}}$ and the *I*, *II*, *III*, *IV*, *V* superscripts correspond to the different cases listed in Table 1. $\mathcal{X}^{I}_{jt}$ stands for the between-sector effect, $\bar{\mathcal{X}}_{jt}$ for the between-country effect, $\hat{\mathcal{X}}_{jt}$ for the technique effect, $\tilde{\mathcal{X}}_{jt}$ for the intermediate trade effect and $\breve{\mathcal{X}}_{jt}$ for the value-added effect. The progressive introduction of these effects will be commented in the empirical section (Section 5). Note that the different sources of change are emission intensities for cases *I–III*, and input–output coefficients and effective trade flows for cases *IV* and *V*. In the particular case of the value-added effect, as shown in the previous section, emissions embodied in trade are unchanged. The only change from case *IV* to case *V* is trade figures, which become lower as output is replaced by value-added. This means that the PTT index is multiplied by the *relative value-added content of imports*, i.e. the ratio between the value-added content of imports and the value-added content of exports, and this multiplicative term is, according to our definition, just equal to the value-added effect.

3.4. Environmental gains and losses from trade

At first sight, as $\mathcal{X}_{jt}$ 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 as a ratio between two quantities, i.e. the amount of import units per dollar divided by the amount of export units per dollar. This is precisely how the PTT index is defined, although one should be aware 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 abroad rather than at home) 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 (1996) 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' exports). To illustrate the relationship with the concept of PTT, let us define the *net environmental gain* for country *j*, NEG_{jt}, by the difference between import-embodied emissions and export-embodied ones (i.e. NEG_{jt} is equal to the balance of emissions embodied in trade, or BEET, as defined by Muradian et al., 2002). Using the same notation, one obtains:

$$NEG_{jt} = \sum\nolimits_{i \neq j} e^{M}_{ijt} - e^{X}_{jt}. \tag{11}$$

Next, let us define *world trade-embodied emissions* as WEE_t, noting that it can be obtained as either the sum of export-embodied (e^{X}_{jt}) or the sum of import-embodied ($\sum_{i \neq j} e^{M}_{ijt}$) emissions. Using Eq. (11), it is straightforward to show that the net environmental gain for country *j* expressed as a percentage of world trade-embodied emissions is given by:

$$\frac{NEG_{jt}}{WEE_t} \equiv \theta^{M}_{jt}\left[1 - \mathcal{X}_{jt}\rho_{jt}\right] = \theta^{X}_{jt}\left[\frac{1}{\mathcal{X}_{jt}\rho_{jt}} - 1\right] \tag{12}$$

where $\theta^{M}_{jt}(\theta^{X}_{jt})$ is the share of country *j* in world import (export) embodied emissions, $\theta^{M}_{jt} \equiv (\sum_{i \neq j} e^{M}_{ijt})/(WEE_t)$, $\theta^{X}_{jt} \equiv (e^{X}_{jt})/(WEE_t)$ and ρ_{jt} is the export–import ratio $\left(\rho_{jt} = \left(\tilde{X}_{jt}\right)/\left(\sum_{i \neq j} \tilde{M}_{ijt}\right)\right)$.[6]

Eq. (12) illustrates the inverse relationship between the PTT index and the net environmental gains from trade. In a long-run situation where trade is balanced ($\rho_{jt} = 1$), 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^{M}_{jt} or θ^{X}_{jt}). If trade is unbalanced ($\rho_{jt} \neq 1$), 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 $1/\rho_{jt}$.

Although the above relationship provides a useful basis to interpret 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.

4. Data preparation

To be able to identify the five distinct components of the PTT index shown in Eq. (10), two basic conditions need to be satisfied. First,

[6] Of course the simplest expression for (NEG_{jt}/WEE_t) is $\theta^{M}_{jt} - \theta^{X}_{jt}$, which is equivalent to Eq. (12) as $\mathcal{X}_{jt}\rho_{jt} = \theta^{X}_{jt}/\theta^{M}_{jt}$. 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.

environmental data must contain a specific pollution coefficient for each sector in each country and over time. This type of data has been recently made available for direct SO_2 emissions (the *D* vector) by Grether et al. (2009), combining information from various sources. Olivier and Berdowski (2001) report emission data for a large set of countries for years 1990, 1995 and 2000 for seven “dirty sectors”[7] which account for 45% of world SO_2 emissions, while the often used data by Hettige et al. (1995) provide emission intensities for 28 ISIC 3-digit sectors but only for the US in 1987. Merging this database with the Trade, Production and Protection (TPP) database of the World Bank (Nicita and Olarreaga, 2007) allows imputing emissions from “clean sectors” and deriving emission intensities which are country-, sector- and period-specific. The final emission intensities have been scaled to match total country- and period-specific manufacturing SO_2 emissions from Stern (2006), who has been particularly careful in taking technological change into account when elaborating his dataset. The obtained emission coefficients for 28 manufacturing sectors and 62 countries reflect both in terms of country and industry ranking the databases mentioned above. Moreover, national totals have been compared with emission data used in Cole and Elliott (2003) on OECD countries. Sample correlation and rank correlations are always larger than 0.73 and highly significant.[8] Thus, our emission coefficients reflect features described in state-of-the art databases, given the careful preparation. These emission coefficients have been used in Grether et al. (2010) to decompose world emissions into the well-known scale, composition and technique effects.

A second condition is to rely on input–output tables that report imports of intermediate inputs and are both country-specific and consistent with trade data for a large sample of countries. The TPP database of the World Bank is here the natural candidate satisfying these criteria as it provides trade and input–output data at the same level of disaggregation as our emission coefficient database. A number of adjustments were necessary to prepare the data for the empirical analysis (see Appendix I for more details). First, 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). Second, relying on data from the World Bank Development Indicators, the database was extended to include the rest of the economy as an additional aggregated sector, and the rest of the world as an additional aggregated trade partner. Third, on the basis of material balances for domestic and imported goods, simple adjustments were performed 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. Fourth, reexports were eliminated from the database in order to trace imports back to their original production site. This is done by minimizing the deviation with respect to reported reexport data from a subsample of countries. Finally, a fifth adjustment was necessary to construct the world input–output table. Following Johnson and Noguera (2012), we adopted the proportionality assumption to spread the imported input requirements across trade partners, i.e. we assumed that the import split across trade partners is the same for intermediate and for final goods.

Following these adjustments, a consistent data set is constructed on trade, pollution and production variables, covering 63 countries (i.e. 62 individual countries and the rest of the world), 3 years (1990, 1995, 2000) and 18 sectors (i.e. 17 manufacturing sectors and the rest of the economy).

5. Empirical findings

This section discusses results of the PTT indices that have been computed for each country for 1990, 1995 and 2000. Following Eq. (10), the final value added based PTT index has been decomposed into its five components. Detailed results for the two extreme years are reported in Appendix Table A2. We first discuss the eventual relation of the PTT indices with income per capita, and with two proxies for environmental regulation. Then we go a step further in terms of interpretation of the PTT index to identify environmental winners and losers. In a final robustness subsection we discuss results when outliers with extreme PTT values are excluded and when trade data are replaced by those estimated by Johnson and Noguera (2012).

5.1. PTT index and income per capita

To ease interpretation and relate our results with the pollution-haven debate, we present results with figures that plot the PTT index against GDP per capita, as richer countries tend to adopt more stringent environmental policies (see e.g. Copeland and Taylor, 2004). Each panel is split into four quadrants by a horizontal line at the PTT = 1 long-run 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. The pattern that emerges from Fig. 1 (with emission weights in 2000) is rather clear. Large, poor or emerging countries such as Indonesia, China and Chile, exhibit large PTT indices, while large, rich countries like the USA, Germany and Japan are characterized by PTT indices which are lower than one.

Fig. 2 reports detailed unweighted results at the country level using the same scale on the axis but for all effects for 2000 (results for 1990 are very similar although the technique effect is by definition absent). We start with the between sector effect, i.e. the PTT index based on the assumption made by Antweiler (1996), namely that US

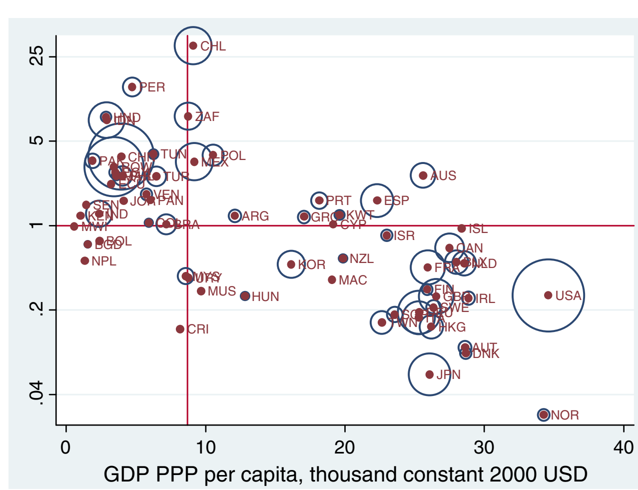

Fig. 1. PTT index against GDP per capita for 2000 weighted by trade embodied emissions.

[7] Namely: refineries, coke, gas; iron and steel; non-ferrous metals; chemicals; building material — cement; pulp and paper; fossil-fuel and biofuel.

[8] The correlations between our emission data with SO_2 concentration data used in the seminal paper by Antweiler et al. (2001) is high at the world-wide level across 1975–2000 but weak at the country level. Even though concentration data is the relevant variable when identifying health impacts of pollution, it has two main drawbacks. First, concentration levels depend also on non-anthropogenic (volcanic activity) and non-industrial (domestic heating) sources of emissions, on the type of measurement and on weather conditions such as wind speed, and temperature. Some of these variables are time-varying and difficult to control for. Second, concentration data do not allow attributing economic activity to given measurement sites. Hence, overall, we argue that emission data is more suitable for our analysis.

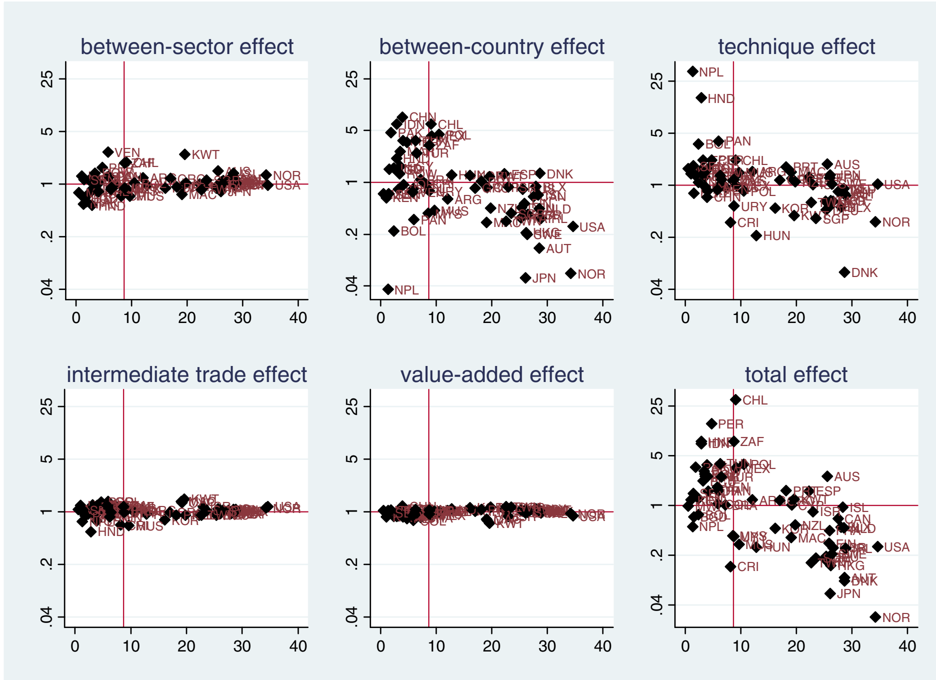

Fig. 2. PTT and its decomposition against GDP per capita 2000.
Notes: cf. Eq. (10) in the text for a definition of each effect. GDP PPP per capita figures are reported in thousand constant 2000 USD and are taken from the World Bank Development Indicators, 2007.

emission intensities for different industries are applicable to all other countries and observed gross trade flows are used. This leads to a distribution of points that is rather squeezed, with no obvious orientation. If any, the relationship with GDP per capita appears to be slightly positive, restating the paradox that had been found by Antweiler, namely that rich countries have relatively dirty average exports compared to low income countries.

When shifting to the between-country effect, the opposite pattern emerges. Apart from Bolivia and Nepal, the large majority of poor countries are located above the horizontal line, and a substantial number of rich countries are below the same line. Moreover the dispersion of the PTT index is much larger. 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. When introducing time varying emission coefficients the pattern is again in line with a pollution haven pattern. When adjusting trade flows to attribute production to final demand (intermediate trade effect) and when transforming gross trade flows into value added trade flows (value added effect), the PTT index stays almost unchanged. This suggests that these improvements in the measure of the PTT affect the average pollution intensity in exports and in imports in a similar way. The combination of all five effects leads to the total effect, i.e. the value added based PTT index distribution against GDP per capita. The total effect is mainly driven by the between country and the technique effect, i.e. by differences in emission intensities rather than by the adjustment of trade flows due to the presence of trade in intermediate goods.

Taking logs of Eq. (10), we also computed a simple variance decomposition of PTT indices. Whatever the year, the between-country effect represents almost two-third of the total variance. The technique effect grows up in importance to one third of total variance in 2000, with total variance slowly increasing over time. The other effects are rather small (the between sector effect being the third largest effect) and the only variance-reducing effect is the value added effect.

To further investigate the relationship between income and the PTT index and controlling for unobserved country and year -pecific effects, fixed effect regressions have been performed, with the PTT index and its components as explained variables and GDP per capita and its square term as explanatory variables. The square term allows for more flexibility in the relationship. It can be justified by reference to the Environmental Kuznets Curve (EKC) literature (see Grossman and Krueger, 1995), which argues that one might expect an inverted u-shape relationship between environmental performance and GDP per capita.[9]

Table 2 reports regression results. All regressions include country fixed effects, period dummies (1990 is the base year), observations are weighted by the average emission content of total trade and clustered standard errors are reported. When GDP per capita is introduced only linearly, the total PTT index is significantly negatively related to income. This means that a 1% increase in GDP per capita would lead to a 0.65% decrease in the PTT index. This negative relation is mainly due to the technique effect, which displays a very similar coefficient. The attribution of production to final demand via the intermediate trade correction is also negatively correlated with GDP per capita. These three effects are therefore in line with the pollution haven fear. The value added effect is positively correlated with income, which suggests, according to our discussion in Section 3.3, that higher income countries tend to have lower value added in exports. This is coherent with the analysis of Johnson and Noguera (2012) who argue that rich countries export relatively more in manufacturing sectors, and those sectors have a relatively lower value added over gross exports ratio.[10] Finally note that the between

[9] Low income countries might have a production structure that emits relatively few pollutants (e.g. capital might be missing to develop heavy polluting industries). With increased income, production and exports become dirtier, while at some critical level of income, stringent environmental regulation is put in place, reversing the trend in emission intensity.

[10] The same authors add that when the comparison is restricted to manufacturing the results are reversed, as rich countries tend to specialize in manufacturing activities with larger value-added shares. If we limit PTT calculations to manufacturing sectors, the value-added effect coefficient is no longer significant.

Table 2
Fixed effect regression results for GDP per capita.

Variables	Between sector PTT (Antweiler) (1)	Between country effect (2)	Technique effect (3)	Intermediate trade effect (4)	Value added effect (5)	Total value added based PTT (6)
lnGDP/CAP	−0.11	0.08	−1.14***	−0.13***	0.06***	−0.65***
	(0.00)	(0.06)	(0.33)	(0.02)	(0.01)	(0.14)
D1995	0.00	−0.12***	n.a.	0.02	0.00	−0.06
	(0.02)	(0.01)		(0.01)	(0.01)	(0.06)
D2000	0.00	−0.25***	0.12	0.05***	−0.00	−0.12
	(0.03)	(0.02)	(0.09)	(0.02)	(0.01)	(0.10)
N	189	189	126	189	189	189
# Countries	63	63	63	63	63	63
Within R^2	0.09	0.84	0.16	0.15	0.16	0.30
lnGDP/CAP	−0.35***	0.08	−0.20	−0.24***	0.07**	−0.36
	(0.06)	(0.10)	(0.33)	(0.08)	(0.03)	(0.22)
$(\ln GDP/CAP)^2$	0.11***	−0.00	−0.33***	0.05*	−0.01	−0.13
	(0.03)	(0.03)	(0.10)	(0.03)	(0.01)	(0.08)
D1995	−0.01	−0.12***	n.a.	0.01	0.00	−0.03
	(0.02)	(0.01)		(0.01)	(0.01)	(0.06)
D2000	−0.05*	−0.25***	0.21***	0.02	−0.00	−0.05
	(0.03)	(0.03)	(0.07)	(0.03)	(0.01)	(0.09)
N	189	189	126	189	189	189
# Countries	63	63	63	63	63	63
Within R^2	0.28	0.84	0.26	0.21	0.16	0.32

Note: all regressions include country fixed effects and year dummies, observations are weighted by the average emission content of total trade and clustered standard errors are in parenthesis. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

country effect is diminishing over time suggesting convergence across countries. When introducing also the square term of per capita income, the major change is for the between-sector effect, which displays a direct u-shape relation, providing evidence against an EKC-like interpretation.

Overall, results suggest that the between country and the technique effects are the main driving forces behind the value added based PTT index over the sample period. In coherence with the pollution haven argument, higher income countries report lower PTT indices, i.e. exhibit on average higher emission intensities in imports than in exports.

5.2. PTT index and environmental regulations

Next, by using proxies for environmental regulation we try to come closer to the link between environmental policy and its relation with average emission intensities in trade flows. Only few proxies of environmental regulation are available over time and even fewer cover years before 2000. We use the lead content in gasoline (Octel, 1983ff), which has repeatedly been used in the literature and has proven to be highly correlated with national environmental policy (Cole et al., 2006; Damania et al., 2003; Hilton, 2006; Grether et al., 2012). Note that the higher the lead content of gasoline, the lower environmental regulation. As a second measure we use participation in international environmental treaties (ENTRI (2002)). This assumes that participation leads to more stringent policy and that the level of regulation is the same for all participating countries. These are strong assumptions but this measure has still been used fault of any better measure (Javorcik and Wei, 2004 and Xing and Kolstad, 2002.). Since greater openness to trade is expected to magnify the possible effect of national environmental regulation on trade flows we interact the proxy for environmental regulation with average trade openness over the sample period.[11] Table 3 reports fixed effect regression results.

[11] We thank an anonymous referee for suggesting this specification. Trade openness is proxied by total trade over GDP.

Results for the two proxies of environmental regulation confirm each other (remembering that a lower lead content reflects higher stringency). We find a positive effect of the interaction term between trade openness and environmental regulation for the between sector effect meaning that high levels of environmental regulation combined with high levels of openness are correlated with higher PTT indexes based on raw gross trade flows and using only sectoral differences in pollution intensities. This is confirming the counter intuitive result found in Antweiler (1996). For the other effects no evidence can be found for a convincing relationship with environmental regulation in this context, where country and year fixed effects are controlled for. Considered alone, the indicator of openness is only significant for the intermediate trade effect (negatively) and the value-added effect (positively). The total value added based PTT shows however a weakly significant coefficient on the interaction term. This suggests that the more open and stringent a country is the lower is its PTT index. This puts forward some weak evidence for the pollution haven effect. This total effect might in part be due to the technique effect, although the latter turns out not significant over the limited sample of 2 periods (by construction there is no technique effect in 1990). In short, we find some counter-pollution haven effect for the between sector effect but some weak evidence in favor of the pollution haven effect when accounting for all effects.

5.3. Environmental winners and losers

Relying on the zero-sum game described in Section 3.4 we provide another interpretation of our results. According to this view, which is, as stated above, only a partial measure 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 in Eq. (12), this condition is fulfilled when the product between the PTT index ($\mathcal{X}_{jt}$) and the export over import ratio (ρ_{jt}) is smaller than 1. Fig. 3 reports the export-embodied (θ_{jt}^X, negative, left-hand side) and the import-embodied (θ_{jt}^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_{jt}^X or θ_{jt}^M is larger than 1%). Countries

Table 3
Fixed effects regression results — proxies of environmental stringency and openness.

Variables	Between sector PTT (Antweiler) (1)	Between country effect (2)	Technique effect (3)	Intermediate trade effect (4)	Value added effect (5)	Total value added based PTT (6)
LnTreaties	0.03	−0.12	−0.53	−0.01	−0.02	−0.17
	(0.10)	(0.08)	(0.40)	(0.08)	(0.03)	(0.37)
lnOpen	−0.23*	0.00	−0.27	−0.26***	0.09**	0.64
	(0.13)	(0.10)	(0.87)	(0.10)	(0.04)	(0.50)
lnTreaties* lnOpen	0.10***	0.01	−0.23	0.05	−0.01	−0.23*
	(0.04)	(0.04)	(0.21)	(0.04)	(0.01)	(0.13)
D1995	0.01	−0.05	n.a.	0.06	0.00	−0.16
	(0.06)	(0.05)		(0.05)	(0.02)	(0.22)
D2000	−0.00	−0.15**	0.08	0.08	0.00	−0.34
	(0.08)	(0.07)	(0.14)	(0.06)	(0.03)	(0.34)
N	180	180	120	180	180	180
# Countries	60	60	60	60	60	60
Within R^2	0.22	0.83	0.24	0.16	0.14	0.31
LnLead	−0.07	−0.04	0.52	−0.03	−0.01	0.53***
	(0.05)	(0.05)	(2.02)	(0.05)	(0.02)	(0.17)
lnOpen	0.04	0.04	0.10	−0.14***	0.07***	0.08
	(0.13)	(0.06)	(0.74)	(0.03)	(0.02)	(0.31)
lnOpen* lnLead	−0.06**	−0.01	0.44	−0.04*	0.01	0.14*
	(0.02)	(0.03)	(0.33)	(0.02)	(0.01)	(0.07)
D1995	−0.05	−0.15***	n.a.	0.03	−0.01	0.15
	(0.05)	(0.04)		(0.04)	(0.02)	(0.12)
D2000	−0.08	−0.27***	0.00	0.03	−0.01	−0.01
	(0.06)	(0.05)	(0.07)	(0.05)	(0.02)	(0.17)
N	179	179	119	179	179	179
# Countries	60	60	60	60	60	60
Within R^2	0.17	0.82	0.16	0.23	0.25	0.38

Note: all regressions include country fixed effects and year dummies, observations are weighted by the average emission content of total trade and clustered standard errors are in parenthesis. The higher (lower) the Treaties (Lead) indicator, the more stringent is environment policy. * $p<0.1$, ** $p<0.05$, *** $p<0.01$.

are ranked by decreasing order of the *effective* net environmental gain $(\theta_{jt}^{M}-\theta_{jt}^{X})$, represented by the dark diamond, while the *potential* net environmental gain that would result in case of balanced trade (ρ_{jt} set equals to 1 in Eq. (12)) is represented by the hollow diamond, illustrating the difference between the BEET and the PTT concepts. The largest winner, by far, appears to be the United States (USA), with a net gain larger than 15% of world trade-embodied emissions. The largest loser is China (CHN), with a net loss over 15%. For these two extreme countries, trade imbalances just reinforce the net gain or net loss implied by PTT figures. On the contrary, in the case of India (IND), this country is on the side of the winners in 2000 because of its trade imbalance but in the longer run, when equilibrating its trade balance, it would have to join the losers' side.

5.4. Robustness

Since PTT indices rely both on the quality of trade flows and the quality of emission coefficients, we perform robustness checks on both sides. First, as another set of emission intensities that vary by country, sector and over time for manufacturing sectors is not readily available, we decided to crudely test the robustness of the regression results when excluding countries with extreme values. Discarding countries with a PTT index in any year above 15 or below 0.08 led to the exclusion of Chile, Japan, Norway and Nepal, leaving a sample of 59 countries. Results are unchanged.[12]

Second, in order to further validate our results on the trade flow side, we used the data kindly provided by Johnson and Noguera (2012), which are based on 2004 GTAP data for a slightly different country sample (we are left with 54 countries) and sector aggregation. Data are for gross trade and value added content of trade. Since our emission intensities are available only for years 1990, 1995 and 2000, we have to make an additional assumption. For each country-sector combination, we take the (geometric) average between the average growth rate of the emission intensity at the country level and the average growth rate of the emission intensity at the sector level. This allows preserving country-sector variation without introducing implausible changes, which would have been the case if we had directly extrapolated intensities at the country-sector level. PTT indices for the different effects (in that case we can only report the combined effect between the intermediate trade and the value added effect) are reported in Fig. 4. The displayed patterns confirm our results for every

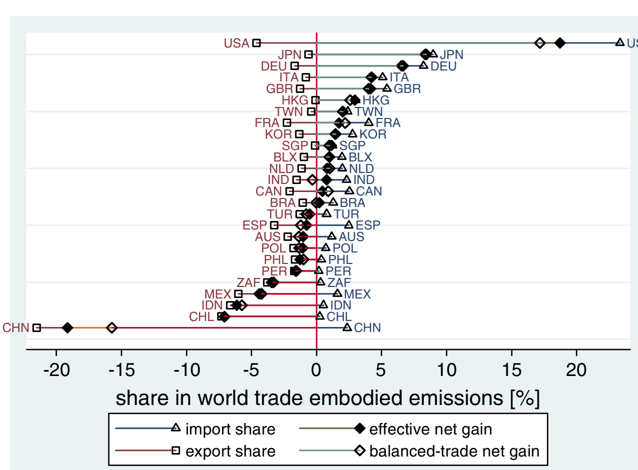

Fig. 3. Environmental winners and losers in 2000.

[12] Detailed results are available upon request from the authors.

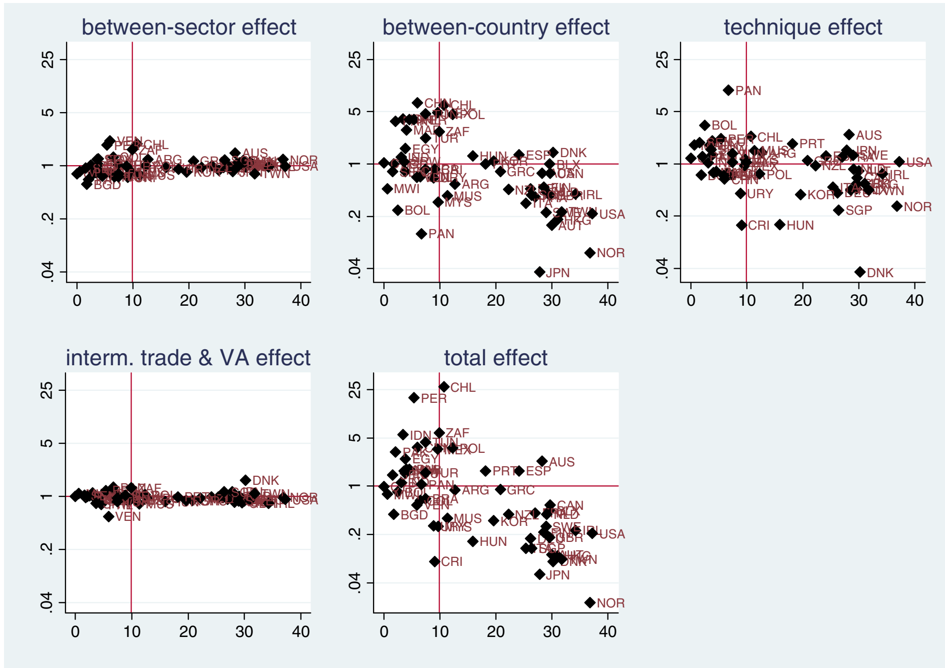

Fig. 4. Decomposition of the PTT index — trade data by Johnson and Noguera (2012).
Notes: cf. Eq. (10) in the text for a definition of each effect. GDP PPP per capita figures are reported in thousand constant 2000 USD and are taken from the World Bank Development Indicators, 2007.

effect. Moreover, the correlation between the final PTT index for 2000 and the one obtained for 2004 is 0.98 and highly significant.

6. Conclusions

In an increasingly integrated but highly heterogeneous world, international trade leads to a spatial distribution of pollution across countries that might benefit some countries and hurt others in a non-trivial way. Starting with trade imbalances, even if embodied emissions per dollar were identical for all goods, a country running a trade deficit would be able to shift emissions abroad as those emissions contained in its imports are larger than those included in its exports. But trade imbalances are normally temporary, and even if they persist, their effect on net imported emissions from abroad may be secondary when compared with the other main source of unbalanced trade in emission, which is the relative pollution content of exports, better known as the pollution terms of trade (PTT) of a country. The more a country specializes in clean activities, the lower its PTT index, and the more it manages to offshore pollution abroad. This paper discusses the issues surrounding the appropriate measurement of the PTT index and looks for empirical regularities based on SO_2 emission data for a large sample of countries.

Two major caveats are raised regarding measurement. First, one should control for differences in emission intensities, over time, between sectors and across countries, by relying on richer databases. This allows decomposing changes in the PTT index into three initial basic effects: the between sector, between country and technique effect. Second, as intermediate goods are traded as well as final goods, an appropriate calculation of trade-embodied emissions should be based on a world input–output table rather than separate national ones. This presents the additional advantage of attributing each production activity to the final demand it is aimed to satisfy, sorting out the complexities of internationally integrated production chains. Moreover, it avoids double counting in trade flows by relying on the value-added content of trade rather than output flows. This leads to two further correction terms adjusting the PTT index: an intermediate trade effect and a value-added effect.

Relying on a rich database for SO_2 emissions intensities, and controlling for input–output relationships and intermediate trade flows, our analysis suggests that of the two caveats raised above, the first one has the largest empirical importance. Amongst the five effects that compose the PTT index, the differences of emission intensities between countries and over time turn out to be the strongest determinants. Incidentally, this allows to overcome the original paradox reported by Antweiler (1996), as the adjusted PTT index turns out to be negatively associated with GDP per capita (and significantly so in a regression controlling for fixed effects, with an elasticity of −0.65). The intermediate trade and value-added effects exhibit a weaker influence. This may appear relatively surprising as these effects imply substantial modifications of trade flows, but one should keep in mind that the PTT index is a relative measure, and the fact that the intermediate trade and value-added effects do not change much PTT estimates simply means that the corresponding absolute changes in trade flows have not a strong correlation with emission intensities.

Overall, and combining PTT values with trade imbalances, the general pattern in terms of pollution offshoring is one under which most large environmental winners are large rich countries (except for India) and where large environmental losers are large emerging economies (except for Spain and Australia). Gains and losses are fairly concentrated, representing more than 15% of world trade embodied emissions for the two countries located at the extreme of the distribution (USA, the largest winner, and China, the largest loser). 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 emission intensities, input–output coefficients or implicit trade flows. More empirical efforts based on better quality data are certainly needed in the future, in particular for local pollutants and for those two effects of major revealed importance i.e. the between-country and the technique effect. 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 boomed to such an extent that the total amount of emissions embodied in world trade did increase. Whether these trends will continue or be reversed in the future is still an open question.

Appendix I. Data preparation

The basic trade, output and input–output figures used in this paper come from the Trade, Protection and Production of the World Bank (TPP hereafter, see Nicita and Olarreaga, 2007), reporting data for 17 manufacturing sectors and 62 countries. Import data being considered as more reliable than export data, all exports in this closed sample are estimated by mirror imports. Three-year moving averages are calculated around each "base" year (1990, 1995, 2000). Missing output data were extrapolated on the basis of simple rules already described in Grether et al. (2009), along with the description of the database for SO_2 emission intensities. This appendix describes the four adjustment steps that were necessary to perform PTT calculations.

a) Completing data for other economics sectors and the rest of the world. *Rest of economic sectors*. Input–output coefficients are available in the TPP database. Non-manufacturing exports and imports were inferred using the share of manufacturing in total exports and imports (from the World Bank Development Indicators, WDI hereafter), and spread across trade partners combining WDI information on regional export and import shares with the OECD International trade by commodity database. Production was inferred combining the share of manufacturing in GDP and the share of expenditures in gross output (from the IO table). Emission intensities were obtained as the unweighted average of manufacturing sectors for the corresponding country and year.
Rest of the world. Trade data were directly obtained from the TPP database. IO coefficients were assumed to be equal to the unweighted average value of IO coefficients on all other 62 countries, as well as emission intensities by sector and year. Overall manufacturing value-added was deduced from the GDP and manufacturing share data of the WDI and spread across manufacturing sectors applying the average shares obtained on the other countries. Output levels were obtained applying the share of expenditures in gross output from the constructed IO table.

b) Adjusting input–output coefficients. The combination of output figures with the two types of input–output matrices reported by the TPP database (the "input" and the "output" matrix) provides direct information on imported inputs by sector and country. However, those figures are not always consistent with reported output and trade figures in terms of the basic two material balances (Eqs. (1a) and (1b) in the main text), generating cases of apparent negative final demand on imports, on domestic goods or on imported inputs. Some inconsistencies may be due to reexports, which are controlled for in step c) below. Other inconsistencies were independent of reexports, and had to be corrected by an upward adjustment of output and/or a downward adjustment of input–output coefficients.
An iterative procedure was followed, which minimizes the necessary adjustment of IO coefficients in order to respect the basic material balances. The average decrease is less than 20%, the largest average adjustment being for Kuwait in 2000, with −42%. Regarding output figures, for more than 90% of the cases, the necessary increase in national production is smaller than 5% (the maximum is Honduras in 2000: plus 23%, then it drops to 12% for Rest of the World and 9% for Costa Rica the same year).

c) Correcting for reexports. *Estimating the amount of reexports*. Some deviations from material balances (in particular national production smaller than gross exports, as in the case of "entrepôt" countries like Hong Kong or Singapore) can be explained by the presence of reexports. We split the sample into "entrepôt" and "non-entrepôt" countries and assume that reexports are a fixed share of the final demand on imported goods for each year and each category. We rely on additional data sources from COMTRADE on reexports for a subsample of 17 countries and calibrate the reexport share in order to minimize the deviation between estimated and reported reexports for the subsample countries. This leads to an annual share of reexports that vary between 4% and 5% (67.5% and 75%) for non-entrepôt (entrepôt) countries.
Eliminating reexports from bilateral trade flows. In the absence of additional information, we proceed in a stepwise way, by allocating proportionally the required reduction of trade flows implied by reexports along either the columns or lines of the export matrix, by calculating the average between the two options, and by inferring the residual to be spread again in subsequent steps. This procedure creates new trade routes, which is to be expected when re-export flows are disentangled, and leads to an average decrease of trade flows that varies between 6.4% in 1990 and 10.5% in 2000.

d) Constructing the world input–output matrix. National IO matrices only report the total of imported inputs by sector. To spread it across trade partners, we follow Johnson and Noguera (2012) and apply the import shares observed for total trade, assuming therefore that the split across partners is the same for intermediate and for final goods.

Table A1
Correspondence table between input–output and ISIC sectors.

Input–output sector	ISIC rev. 2 3-digit	Description
1	311/312	Food products
2	353/354	Petroleum
3	313/314	Beverages and tobacco
4	321	Textiles
5	322	Wearing apparel
6	323/324	Leather and footwear
7	331/332	Wood and furniture
8	341/342	Paper and printing
9	351/352/355/356	Chemicals and plastic
10	361/362/369	Non-metal minerals
11	371	Iron and steel
12	372	Non-ferrous metals
13	381	Metal products
14	384	Transport equipment
15	382	Non-elect. machinery
16	383/385	Machinery and professional equipment
17	390	Other manufacturing products

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

1990							2000					
Country	Sector eff.	Country eff.	Tech. eff	IT eff.	VA eff.	PTT	Sector eff.	Country eff.	Tech. eff	IT eff.	VA eff.	PTT
ARG	1.15	0.76	1.00	1.08	0.97	0.91	1.22	0.59	1.54	1.05	1.03	1.20
AUS	1.48	1.08	1.00	1.07	0.99	1.70	1.49	0.81	1.92	1.10	1.02	2.59
AUT	1.00	0.16	1.00	0.90	1.06	0.16	0.98	0.13	0.77	0.94	1.06	0.10
BGD	0.68	1.63	1.00	0.94	0.96	1.00	0.65	1.49	0.79	0.97	0.94	0.70
BLX	1.04	0.95	1.00	0.95	1.05	0.99	1.07	0.88	0.51	0.94	1.10	0.50
BOL	1.71	0.19	1.00	1.22	0.84	0.34	1.14	0.22	3.60	0.94	0.88	0.75
BRA	1.12	1.17	1.00	1.16	0.87	1.33	0.97	1.08	0.95	1.22	0.83	1.02
CAN	1.26	0.94	1.00	1.01	0.98	1.17	1.15	0.64	0.82	1.04	1.03	0.65
CHL	2.12	8.41	1.00	1.16	0.97	20.09	1.96	6.07	2.19	1.14	1.03	30.63
CHN	0.93	8.66	1.00	0.82	1.14	7.46	0.79	7.60	0.69	0.76	1.18	3.72
COL	1.01	1.03	1.00	1.30	0.76	1.03	1.28	0.82	0.96	1.37	0.77	1.05
CRI	0.72	1.09	1.00	0.94	0.93	0.69	0.70	0.95	0.32	0.66	1.00	0.14
CYP	0.87	1.09	1.00	1.26	0.75	0.89	0.94	0.86	1.24	1.32	0.77	1.02
DEU	0.89	0.59	1.00	0.88	1.04	0.49	0.94	0.45	0.47	0.91	1.06	0.19
DNK	0.93	1.69	1.00	0.95	0.99	1.47	0.97	1.32	0.07	1.01	1.00	0.09
ECU	1.15	1.01	1.00	1.25	0.82	1.20	1.15	0.80	2.17	1.24	0.89	2.21
EGY	1.35	2.02	1.00	1.05	0.95	2.71	1.24	1.64	1.32	0.94	1.09	2.76
ESP	1.05	1.63	1.00	0.92	1.03	1.62	1.00	1.29	1.28	0.91	1.06	1.60
FIN	1.10	0.67	1.00	0.94	1.04	0.72	1.04	0.52	0.52	1.04	1.02	0.29
FRA	0.95	0.47	1.00	0.89	1.06	0.42	0.98	0.36	1.27	0.96	1.04	0.45
GBR	1.06	0.50	1.00	0.99	0.99	0.52	1.10	0.37	0.62	1.06	0.98	0.26
GRC	1.17	1.06	1.00	1.00	0.96	1.20	1.18	0.84	1.18	0.99	1.01	1.18
HKG	0.81	0.19	1.00	1.20	0.92	0.17	1.07	0.21	0.62	0.97	1.08	0.15
HND	0.70	2.28	1.00	1.15	0.87	1.58	0.52	2.12	15.02	0.55	0.87	7.91
HUN	1.18	1.58	1.00	0.97	1.06	1.92	0.96	1.26	0.21	0.93	1.09	0.26
IDN	1.14	9.89	1.00	1.30	0.84	12.38	0.85	6.06	1.63	0.97	0.92	7.41
IND	0.74	2.15	1.00	1.05	0.93	1.55	0.75	1.55	1.09	1.03	0.96	1.25
IRL	0.90	0.44	1.00	0.97	1.03	0.40	1.03	0.33	0.73	1.07	0.96	0.25
ISL	1.24	0.89	1.00	0.95	1.04	1.09	1.39	0.68	0.88	1.08	1.05	0.95
ISR	0.91	1.12	1.00	1.16	0.86	1.01	0.91	0.86	1.03	1.18	0.87	0.82
ITA	0.84	0.40	1.00	0.84	1.08	0.30	0.89	0.33	0.62	0.90	1.06	0.17
JOR	1.09	1.15	1.00	1.01	0.99	1.25	1.03	0.93	1.66	0.99	1.01	1.60
JPN	0.69	0.06	1.00	0.93	1.02	0.04	0.80	0.05	1.38	1.06	0.97	0.06
KEN	0.83	1.11	1.00	1.16	0.84	0.90	1.28	0.62	1.44	1.22	0.86	1.20
KOR	0.82	1.55	1.00	0.73	1.16	1.08	0.89	1.23	0.49	0.78	1.14	0.48
KWT	2.60	1.52	1.00	1.41	0.73	4.12	2.49	1.20	0.39	1.47	0.70	1.22
MAC	0.81	0.32	1.00	1.34	0.76	0.26	0.73	0.29	1.51	1.38	0.80	0.35
MAR	1.03	3.42	1.00	0.92	1.05	3.42	1.03	2.62	0.96	0.91	1.10	2.58
MEX	0.92	5.73	1.00	1.07	0.88	4.99	0.86	4.23	1.00	1.04	0.90	3.37
MUS	0.68	0.48	1.00	0.74	1.01	0.25	0.70	0.42	1.49	0.66	1.01	0.29
MWI	0.72	0.79	1.00	1.05	0.97	0.58	0.76	0.69	1.66	1.08	1.03	0.98
MYS	0.79	0.48	1.00	0.86	1.03	0.33	0.82	0.38	1.15	1.12	0.95	0.38
NLD	1.26	0.59	1.00	0.95	1.05	0.74	1.19	0.44	0.90	1.01	1.04	0.49
NOR	1.39	0.08	1.00	1.09	0.96	0.12	1.32	0.06	0.33	1.13	0.95	0.03
NPL	0.60	0.04	1.00	1.11	0.86	0.02	0.54	0.04	33.65	0.74	1.04	0.51
NZL	1.12	0.59	1.00	0.89	1.15	0.68	1.03	0.45	1.11	0.91	1.15	0.53
PAK	0.68	5.24	1.00	0.85	1.06	3.22	0.58	4.66	1.37	0.89	1.05	3.43
PAN	0.86	0.41	1.00	1.24	0.80	0.34	1.25	0.31	3.92	1.12	0.94	1.62
PER	1.76	3.89	1.00	1.29	0.84	7.46	1.65	3.47	2.20	1.36	0.82	14.00
PHL	0.97	4.18	1.00	1.03	0.96	4.00	0.80	3.62	0.85	1.22	0.85	2.57
POL	0.72	5.96	1.00	1.15	0.88	4.31	1.03	4.41	0.83	1.01	1.01	3.83
PRT	0.95	1.25	1.00	0.91	1.02	1.10	0.91	1.03	1.78	0.91	1.07	1.61
ROW	1.49	1.69	1.00	1.06	0.98	2.60	1.40	1.31	1.48	1.16	0.97	3.05
SEN	1.00	0.83	1.00	0.90	1.06	0.79	1.14	0.69	1.81	1.05	0.98	1.48
SGP	1.54	0.44	1.00	1.03	1.10	0.76	1.13	0.38	0.36	1.04	1.14	0.18
SWE	0.99	0.27	1.00	0.95	1.02	0.26	1.00	0.20	1.05	1.02	0.99	0.21
TUN	0.96	4.42	1.00	0.88	1.06	3.96	0.86	3.63	1.35	0.85	1.08	3.90
TUR	1.02	2.87	1.00	1.07	0.89	2.80	0.90	2.49	1.21	0.98	0.96	2.55
TWN	0.74	0.35	1.00	0.81	1.10	0.22	0.84	0.30	0.59	0.91	1.17	0.16
URY	0.88	0.97	1.00	1.07	0.95	0.86	0.89	0.76	0.53	0.98	1.05	0.37
USA	0.97	0.33	1.00	1.09	0.90	0.31	0.97	0.25	1.04	1.17	0.88	0.26
VEN	2.56	0.93	1.00	1.26	0.80	2.40	2.64	0.74	0.87	1.22	0.88	1.82
ZAF	2.26	4.18	1.00	1.13	0.97	10.38	1.91	3.18	1.19	1.18	0.94	8.01

Notes: cf. Eq. (10) in the text for the definition of each effect.

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