Is trade bad for the environment? Decomposing world-wide SO_2 emissions 1990-2000[*]

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Abstract

This paper proposes three simple exercises to estimate the impact of trade on the worldwide SO_2 emissions over the 1990-2000 period. Drawing on the relative constancy of emissions per worker across countries, it combines the disaggregated IPPS data of the World Bank and the recent aggregated data by Stern (2006) to estimate changes in emission coefficients over time and across countries. The first experiment on this basis is a growth-decomposition exercise which shows that the scale and the technical effects are the main driving force behind the global changes in SO_2 emissions. Contrarily to the concerns raised by environmentalists, the influence of trade, captured by the composition effects, is more limited and leads to a small reduction in emissions. The second exercise shows that trade, by allowing dirty countries to become net importers of emissions, leads to a rough 2% decrease in world emissions with respect to a non-trade scenario. The third exercise uses linear programming to identify extreme scenarios where world emissions are either maximal or minimal. It turns out that effective emissions correspond to a 60% reduction with respect to the worst case, but that another 60% reduction could be reached if emissions were minimal.

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Key Words: Trade, growth, environment, decomposition, embodied emissions in trade flows

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1 Introduction

Ever since the 'discovery' of an environmental Kuznets curve (EKC), a large literature has developed on the relation between growth and the environment and on the role that trade may have on the environment since the conjunction of differences in environmental policies and in the determinants of trade across countries may lead to the migration of 'dirty' industries to countries with emission-intensive techniques of production or to countries that have a comparative advantage in dirty industries. The rapid growth of world trade has given fuel to the alarmists who claim that trade is bad for the environment, and to a large and still unsettled debate about the 'pollution haven hypothesis (PHH)'. Suspicions about the validity of the PHH hypothesis have recently been echoed in doubts about the existence of an EKC. For example, it has been suggested that emissions are monotonic in income and reductions in emissions are time-related rather than income-related (see e.g. Stern (2004)) so that it is either a change in output composition or, most likely, in emissions per unit of output that would account for the reversal in emissions rather than income as postulated in the EKC. For example, in a recent study of global emissions of SO_2 in which a new data set is constructed using econometric estimates, Stern (2006) confirms the existence of an EKC (driven by a change in emissions intensity) previously identified by Olivier and Berdowski (2001) with a turning point around 1990. Overall it is fair to say that there is still a considerable debate about which part of the growth of world-wide emissions is attributable to economic growth, which part to technical progress and which part to the trade-related composition effect.

In this paper we argue that the combination of the IPPS coefficients of the World Bank with the exhaustive data set of worldwide SO_2 emissions elaborated by Stern (2006) and Oliver and Berdowski (2001) and a simple rule to determine the evolution of emission intensities provides a unique opportunity to address the shortcomings of previous studies and leads to interesting orders of magnitude that should help clarify the debate, at least for the case of SO_2. Section 1 presents the aggregate evidence regarding world-wide emissions of SO_2, suggests some broad sources of explanation and provides a detailed presentation of how the data sets were combined to capture both time and cross-country variation of emission intensities at a reasonably low level of disaggregation. Section 2 provides first estimates of the basic growth decomposition exercise over the 1990-2000 period for a large sample of countries. It turns out that the scale and the technique effect dominate, but as they work in opposite directions they cancel each other out. Overall, the net impact is thus basically due to the composition effects, that help to reduce emissions both across countries and across sectors, and where trade plays an important role. This finding is further confirmed in section 3, where an alternative methodology is proposed to estimate the share of trade in world-wide emissions of SO_2. Section 4 compares the real emission levels with simulated benchmark scenarii where we allocate labour in order to minimize or maximize world-wide emissions. A final section concludes and discusses the limits of the analysis.

2 Stylized facts and data sample

We begin this section by documenting at the aggregate level the decrease in manufacturing SO_2 emissions during the nineties. The discussion is limited to broad trends and simple diagrams, all series being based on the 62-country sample (31 developed and 31 developing countries)[1] used in the paper. The objective is to uncover the driving forces behind the decline in SO_2 emissions and likely orders of magnitude. In this preliminary exercise, we combine the aggregate sulfur emission data carefully constructed by Stern (2006) from his own econometric estimates estimates and country data compiled by Oliver and Berdowski (2001) on total manufacturing emissions.[2]

2.1 The Global Decline in Manufacturing Sulfur Emissions

Figure 1 presents the evolution of SO_2 emissions and indicators of economic activity in the manufacturing sector at the world level and over the 1990-2000 period. The contrast is striking between the decline in manufacturing emissions by 10%, while employment and output are concurrently rising by 10% and 20% respectively. Overall, manufacturing is thus becoming a lot cleaner at the world-wide level.

Insert figure 1: Global trends (1990=100)

The main sources of this decline are reviewed in the different panels of figure 2. A first possibility would be a structural change towards cleaner products in industry, as factors of production are reallocated from 'dirty' to 'clean' products (see table A2 in the Appendix for a definition of those categories at the ISIC 3-digit level). Figure 2(a) shows small changes in employment shares combined with a clear increase in the share of clean products and a decrease in the share of dirty products.

Insert figure 2: Possible explanations

A second possibility would be that, contrarily to what is normally feared by environmentalists, production has shifted towards cleaner countries. A crude approximation consists of splitting the sample between "North" and "South"

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[1] See Appendix table A1. The split into country groupings was done on the basis of GDP per capita (PPP). Countries from North America, High Income Asia and Europe are classified to be high income countries.

[2] We view Stern's recent global emission data as the most reliable (they also cover the whole period 1990-2000 whereas Oliver and Berdowski cover the period 1990-1995). On the other hand Oliver and Berdowski have detailed emission data per country for total manufacturing emissions. Since we are interested in manufacturing emissions (which account for approximately one third of SO_2 emisssions) we scaled the manufacturing data by Oliver and Berdowski on Stern's global data. This scaling did not alter significantly the global estimates (see the Annex for further discussion).

countries and looking again at shares in output and employment. The shares reported in figure 2(b) suggest that the environmentalist are right: the share of the South is rising, particularly for employment, which passes from 50% to 60% across the sample period, but overall, output shifts are small.

This leaves almost all the burden of the explanation on a third possibility, namely a shift towards cleaner technologies. Figure 2(c) is totally consistent with this argument. Whichever group of countries (North or South) and whichever indicator of manufacturing activity (output or labor), the average emission intensity is declining. Note that the difference is striking between North and South when intensity is measured in terms of emissions per unit output, with emission per unit of output about five times higher in the South and the gap remaining relatively constant. However, it is remarkable that, when measured in terms of emissions per unit labor, there is a virtual equality in the emission intensity per unit of labor. This stylized fact confirms the conjecture of Hettige et al. (2000) based on cross-country data for biological oxygen demand. They estimated that emissions per unit of labor are constant across time, and suggested that this might be the case for most pollutants issued from manufacturing activities. Thus, at least in the case of SO_2 over the period 1990-200, one can approximate emission intensities by the labor productivity gap, which is inded what we do below when extrapolating the US IPPS emission coefficients to other countries in the sample.

To sum up, at first sight, on the basis of aggregate data, technical progress would appear to be a major determinant in the decrease of global SO_2 emissions. Of course the above analysis is too crude. We may be wrong in a variety of ways. Our definition of what is a clean or a dirty sector may be imprecise, as well as our crude separation between North and South as reflecting clean and dirty countries. It could also be that changes in the patterns of trade between countries would account for this remarkable decline in sulfur emissions. A more disaggregated analysis is required, both at the country and at the sector level. We do this in the next sections, where we look first at scale, composition and technique effects and then at the role of international trade.

3 Scale, Composition and Technique Effect

3.1 A growth decomposition framework

Data on emissions per unit of manufacturing activity allow one to decompose the global growth of SO_2 emissions into four components. Let L_{kit} represent employment in activity k in country i, year t, and γ_{kit} the emission intensity per unit of labor. Then the resulting SO_2 emissions are given by:

$$E_{kit} = \gamma_{kit} L_{kit} \tag{1}$$

Aggregating over industries gives an expression for total emissions at the country level:

$$E_{it} = \sum_k \gamma_{kit} L_{kit} \tag{2}$$

Likewise, aggregating over countries, gives the global SO_2 emissions:

$$E_t = \sum_k \sum_i \gamma_{kit} L_{kit} \tag{3}$$

For each country, i, expression (2), can be decomposed into a scale (changes in manufacturing employment, L_{it}), composition (changes in the allocation of labor across sectors, L_{kit}) and technique effect (changes in emission intensity per unit labor, γ_{kit}) . The same decomposition carries across countries, and by implication sample-wide (adding another source of composition effect, across countries this time).

As the decomposition implies the frequent use of shares, we use below the convention that $\varphi_v^{Z_w}$ is the share of Z_v in the aggregate Z_w, where $z, w = kit, kt, it$ and $Z = L, E$. For example, $\varphi_{it}^{L_t}$ is the share of country i in world employment, $\varphi_{it}^{L_t} = \frac{L_{it}}{L_t}$, or $\varphi_{it}^{E_t}$ is the share of country i in global emissions, $\varphi_{it}^{E_t} = \frac{E_{it}}{E_t}$. Using this convention, and to carry out the decomposition, let us first rewrite (3) as

$$E_t = \sum_i L_t \varphi_{it}^{L_t} \overline{\gamma}_{it}, \tag{4}$$

where L_t is world manufacturing employment, $L_t = \sum_k \sum_i L_{kit}$ and $\overline{\gamma}_{it}$ is the average emission intensity of country i, $\overline{\gamma}_{it} = \frac{E_{it}}{L_{it}}$.

Total logarithmic differentiation of (4) yields expression (5) which shows that global growth of SO_2 emissions can be decomposed into a *scale* effect, $\widehat{L}_t$, a *between-country* effect, $\sum_i \varphi_{it}^{E_t} \left(\widehat{\varphi_{it}^{L_t}}\right)$, and a *within-country* effect $\sum_i \varphi_{it}^{E_t} \left(\widehat{\overline{\gamma}_{it}}\right)$[3].

$$\widehat{E}_t = \widehat{L}_t + \sum_i \varphi_{it}^{E_t} \left(\widehat{\varphi_{it}^{L_t}}\right) + \sum_i \varphi_{it}^{E_t} \left(\widehat{\overline{\gamma}_{it}}\right), \tag{5}$$

The average country intensity can also be written as a weighted average of sectoral intensities, with weights given by the share of each sector in national manufacturing employment, i.e. $\overline{\gamma}_{it} = \sum_k \varphi_{kit}^{L_{it}} \gamma_{kit}$ ($\varphi_{kit}^{L_{it}} = \frac{L_{kit}}{L_{it}}$). Thus, the third term in expression (5) can be decomposed further, leading to the final expression:

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[3] In all subsequent calculations, an "^" over a variable means the rate of growth of this variable. Interaction terms are neglected here, but not in the empirical part (see next section).

$$\widehat{E}_t = \widehat{L}_t + \sum_i \varphi^{E_t}_{it} \left(\widehat{\varphi^{L_t}_{it}}\right) + \sum_k \sum_i \varphi^{E_t}_{kit} \left(\widehat{\varphi^{L_{it}}_{kit}}\right) + \sum_k \sum_i \varphi^{E_t}_{kit} \left(\widehat{\gamma_{kit}}\right). \qquad (6)$$

In expression (6), the third term on the RHS represents the *between-sector* effect and the fourth one the *technical change* effect.

3.2 Estimating sector-level emission intensities

To capture all the above-mentioned factors we need consistent data on trade, output, employment and emission intensities at a sufficiently disaggregated level. Fortunately, the trade and production database of the World Bank (see Olarreaga and Nicita (2006) and the appendix) provides a reliable and updated datasource for the first three variables at the ISIC 3digit level[4]. The problematic variable is the fourth one. On the one hand, information on emission intensities at the ISIC 4digit level have been elaborated by the World Bank (the IPPS coefficients, see Hettige et al, 1995), but they are only valid for the US and year 1987. Since then, apart from isolated cases, no systematic attempt has been made to update the data over time and/or cover more countries. On the other hand, there is a large array of emission data at the national level, the study by Stern (2006) providing one of the most recent updates and a wide country coverage.

What we propose in this paper is to combine the two sets of data to derive disaggregated emission intensities that vary both across countries and over time. To do that, we rely on an empirical regularity established by Hettige et al (2000). According to these authors, emissions per unit labor tend to be constant both across countries and over time. It is true that this result was obtained for another pollutant (biological oxygen demand), but we would like to argue here that it deserves to be extended to SO_2 emissions as well. One reason for that is the striking result already mentioned in figure 2(c) above, namely that average emission intensities are remarkably similar between North and South, and tend to follow a similar time pattern. Another reason is that this similarity seems to also apply reasonably at the disaggregated level for the other country for which IPPS SO_2 coefficients are also available, i.e. China in 1991, 1993 and 1995.[5]. Although there are some differences in level, in particular in the petroleum refineries sector where Chinese emissions are a lot smaller, the rank correlation between Chinese and US intensities is more than acceptable. It is larger than

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[4] We also added a price index derived from the OECD STAN database to calculate real values.

[5] Chinese data are probably less reliable than US ones, cover less sectors and are expressed in constant local currency, all matters that make the comparison difficult. However, combining Chinese IPPS coefficients with productivity and unit value ratio estimated by Szirmai et al (2005) we were able to generate a set of intensities which is comparable to the US ones.

0.9 and slightly decreasing over time for unit labor intensities, and closer to 0.8 for per dollar intensities, a result which is again consistent with the finding of Hettige et al.

On the basis of the above evidence, we generate a set of region and year specific intensities using the following procedure. First, the 62 countries for which data are available are aggregated in 6 regions which reflect both geographical proximity and similarity in average income per capita (see table A1 in the Appendix). Given the scarcity of emission data, this simplification is necessary to avoid unrealistic variations in calculated intensities. Second, US intensities per unit labor are applied to all countries for the extreme and middle years of the sample period (1990, 1995, 2000 which we refer below as the "base" years). Using employment data at the ISIC 3digit sector level [6] we obtain the corresponding US-based total SO_2 emissions. Third, we compute the ratio between the actual emissions based on Stern (2006)[7] and the US-based emissions, which we call the conversion ratio[8]. Fourth, we adjust uniformely all computed intensities by the conversion ratio in order to match computed emissions with actual ones whatever the region and the year. As a result, we obtain a set of 18 different vectors (6 regions and 3 years) of emission intensities which is used in the remaining of the paper.

3.3 Estimates

The results of the growth decomposition over the whole sample period appear in the last panel of figure 3. As could be expected from the introductory discussion of section 2, the scale effect is clearly positive (i.e. leads to an increase in global emissions) while the technique effect is negative, both being of the same magnitude (around 10%). The total effect is thus equal to the sum of the composition effects, which are both negative, the between sector effect being three times larger than the between country effect. In sum, and as a rule of thumb, global emissions tend to decrease at an approximate rate of 1% a year over the sample period, because even though world manufacturing labor increases by 1% a year, cleaner production techniques and cleaner labor allocation across sectors and countries more than compensate the trend, each factor leading to an approximate annual decrease of emissions by 1%. Does this pattern hold across subperiods? The other panels of figure 3 show that scale and technique effects do cancel out each other in both subperiods, although their absolute magnitude falls. As a result, the total net effect is always roughly equal to the sum of the composition effects, which rise from 3% in 1990-1995 to 7% in 1995-2000. Also

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[6] To control for cyclical fluctuations, whenever we refer to employment, trade, output or emission data in the base years, what we mean is in fact three year averages centered on the base year (or 1999-2000 averages when 2001 data are missing).

[7] As Stern reports total anthropogenic emissions we combine his data with the share of manufacturing in total emissions estimated for the three base years by Olivier and Berdowski (2001) to obtain the actual manufacturing emissions.

[8] The values of the conversion ratio are given in table A3 in the Appendix.

to be noted is the strong increase of the between sector effect, which rise from half to almost four times the between country effect.

Insert figure 3: Growth decomposition of SO_2 emissions

To understand the structural changes that hide behind these aggregate results, table 1(a) provides a disaggregation of the decomposition exercise at the regional level. The first line just reproduces the global results, while the rest of the table gives the share of the specific region*effect combination (e.g. Europe and scale effect) in the total *gross* effect i.e. the sum of the absolute value of all possible combinations. This convention helps to overcome the problem of expressing the contribution of a specific component in a *net* total that includes both positive and negative components that tend to compensate each other. As a result, the difference between the total gross and the total net effect along a line or a column gives an idea of the extent of compensation effects along this line or column. The same presentation principle applies to table 1(b), which gives the decomposition at the sector level.

Of the three single components of table 1(a) that are larger than 10%, the largest one is the negative technical effect for Europe, that accounts for almost 17% of the gross total. The other two refer to Low Income Asia (basically China and India), but they are of opposite sign, the positive between country effect (12.4%) being almost counterbalanced by the negative between sector effect (-10.9%). As a result, the net impact of this region on world emissions is only 3% of the gross total, while its gross weight is above 30%. By contrast, the net impact of Europe is minus 22%, not far from its gross weight of 29%. Regarding columns' totals, the only effect that does not present compensation across countries is the scale effect, which is positive in every region. The opposite case is the between country effect, which is negative for every region but for Low Income Asia.[9]

Insert table 1(a): Decomposition results 1990-2000 - by region (%)

Regarding the decomposition by sector, the three largest elements of table 1(b) locate in the column of the between sector effect, with a large positive share for other non-metallic mineral products (+7.6%) and large negative ones for petroleum refineries (-14.9%), industrial chemicals (-6.1%) and iron and steel (-5.5%). Again, this amounts for large compensation, and a total gross effect which is twice the total net effect for this column. For the other three effects, the compensation is minimal, including for the technique effect, which is overwhelmingly negative whatever the sector, in contrast to the results in table 1(a),

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[9] The fact that the total net between country effect is negative suggests that Low Income Asia is cleaner than the world average. This may seem surprising at first sight, but one must recall that intensities per unit labor are in fact very close between North and South (see figure 2(b)).

where the technique effect was positive in South America and Africa, almost zero in High Income Asia and negative in the other three regions. Returning to table 1(b), as far as horizontal totals are concerned, the most influential sectors regarding the total net effect are the same ones as those already mentioned for the between sector effect, which is thus clearly the dominant effect.[10]

Insert table 1(b): Decomposition results 1990-2000 - by sector (%)

In short, the disaggregation of the decomposition exercise points towards two regions and four sectors as being the most influential ones. Europe contributed significantly to the overall decrease in emissions through the adoption of cleaner production techniques, while behind the small net impact of Low Income Asia hides a combination of strong countervailing forces, as it both attracted a larger share of the global workforce and shifted its industrial structure towards cleaner products. Regarding products, the structural change towards cleaner products is epitomized by the strong decline of petroleum refineries, industrial chemicals and iron and steel, which clearly overrides the countrevailing increase in non-metallic mineral products.

4 Does trade matter?

The evidence gathered so far suggests that trade, as it allows for a redistribution of the manufacturing labor force at the world wide level, has contributed to a modest decrease in global SO_2 emissions (less than 0.5% per year over the sample period as far as the between-group effect is concerned). This is surprising and calls for further analysis. This is the aim of this section, which proposes a simple framework to quantify the impact of trade, and applies it to our sample, contrasting the situation between the beginning and the end of the sample period.

4.1 Computing the first order effect of trade

The basic idea is to define a benchmark situation in which there is no trade, and compare global emissions in this theoretical anti-monde with the actual ones observed when trade relationships are present between the six regions defined in our sample. The basic intuition is that trade allows to produce less of undesirable products locally (e.g. on environmental grounds). Thus, if trade is allowed, and under the assumption that domestic consumption remains unchanged, national emissions will decrease provided the country becomes a net importer of the good. Of course the situation is reversed for the partner, so

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[10] When one still distinguishes further between subperiods (see table A4 in the Appendix), the main finding is that the shift away from petroleum refineries strongly increases while other non-metallic mineral products swing from a strongly positive to a negative contribution. This helps to explain the dramatic reversal in the size of the two composition effects already mentioned above.

the net change in global emissions will depend on the difference of intensities between countries. Applied to the real world (many countries and many goods) this reasoning also implies composition effects, but in the end, it is to be expected that if cleaner countries tend to be the largest net importers, trade will tend to increase global emissions.

Consider then the case of sector k in country i year t, and denote local production by Q_{kit}, domestic consumption by C_{kit}, and exports/imports by X_{kit}/M_{kit}, all values being expressed in current dollars. Market clearance implies that $Q_{kit} + M_{kit} = C_{kit} + X_{kit}$, but this relationship does not necessarily hold for emissions as imports (and thus part of consumption) are produced with a different technology. Our objective is to calculate ΔE_t, the change in production-embodied emissions generated by a shift from the autarkic to the trade situation. If we abstract from ressource constraints and assume that consumption remains unchanged, this amounts to calculate the change in embodied emissions when production shifts from the apparent consumption level, $C_{kit} = Q_{kit} + M_{kit} - X_{kit}$, to the actual production level, Q_{kit}. Let g_{kit} represent SO_2 emissions per unit dollar, while ℓ_{kit} represents labor productivity, so that the relationship between per dollar and per unit labor intensities is $g_{kit} = \gamma_{kit}/\ell_{kit}$. The desired change at the sector level becomes simply: $\Delta E_{kit} = g_{kit}Q_{kit} - g_{kit}C_{kit} = g_{kit}(X_{kit} - M_{kit})$, which means that the change in emissions generated by trade is just equal to the trade balance times the corresponding intensity coefficient. If we denote X_{it} (M_{it}) total exports (imports) of country i, and we aggregate across sectors, the total change in emissions at the country level becomes:

$$\Delta E_{it} = \overline{g}_{it}^{X} X_{it} - \overline{g}_{it}^{M} M_{it} \tag{7}$$

where $\overline{g}_{it}^{X} = \sum_k \varphi_{kit}^{X_{it}} g_{kit}$ ($\overline{g}_{it}^{M} = \sum_k \varphi_{kit}^{M_{it}} g_{kit}$) is the average export (import) intensity of country i. (we extend the convention of the $\varphi_v^{Z_w}$ notation to $Z = X, M, Q$). This is equivalent to the concept of the balance of embodied emissions in trade (BEET) already defined by Muradian et al (2002), although these authors did not interprete the figure as illustrative of the change in world-wide pollution emissions.[11] As this is precisely our aim here, the next logical step would be to aggregate equation (7) across countries. However, it is worthwhile to realize first that the disaggregated relationship at the country and sector level can also be aggregated across countries. Straightforward manipulations lead to the following change in world emissions for sector k:

$$\Delta E_{kt} = M_{kt} n \sigma_{kt} \tag{8}$$

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[11] Other differences with respect to the present study is that Muradian et al (2002) do not control for the technical effect and limit their analysis to 11 highly polluting sectors in order to convert intensities in weight units.

where M_{kt} is world imports (or exports[12]) of good k ($M_{kt} = \sum_i M_{kit}$), n is the number of countries in the world, and σ_{kt} is the covariance between pollution intensity and the difference between the export and the import share of country i, i.e. $\sigma_{kt} = cov(\frac{X_{kit}-M_{kit}}{M_{kt}}; g_{kit})$. The interpretation here, apart from the role of scaling factors (n,M,γ), is that the trade-induced change in world emissions will be particularly large if the countries with the largest trade deficits also tend to be the cleanest ones. This is consistent with intuition and the pollution-haven view, so we name this covariance term the *pollution-haven covariance.*

We can now aggregate either equation (7) or equation (8) to obtain the total change in emissions at the world-wide level, ΔE_t. For comparison purpose, we scale this change by the cum-trade level of world-wide emissions, $E_t = \overline{g}_t^Q Q_t$,where Q_t is world production and $\overline{g}_t^Q$ is the world average pollution intensity, $\overline{g}_t^Q = \sum_k \sum_i \varphi_{kit}^{Q_t} g_{kit}$.[13] This leads to the following expressions:

$$\frac{\Delta E_t}{E_t} = \frac{\sum_i \Delta E_{it}}{E_t} = \frac{X_t}{Q_t}\frac{\left[\overline{g}_t^X - \overline{g}_t^M\right]}{\overline{g}_t^Q} \tag{9a}$$

$$\frac{\Delta E_t}{E_t} = \frac{\sum_k \Delta E_{kt}}{E_t} = \frac{X_t}{Q_t}\frac{n\overline{\sigma}_t}{\overline{g}_t^Q} \tag{9b}$$

where $X_t = M_t$ is total exports or imports, $\overline{g}_t^X = \sum_i \varphi_{it}^{X_t} \overline{g}_{it}^X$ ($\overline{g}_t^M = \sum_i \varphi_{it}^{M_t} \overline{g}_{it}^M$) is the world average emission intensity in exports (imports) and $\overline{\sigma}_t$ is the world average pollution-haven covariance ($\overline{\sigma}_t = \sum_k \varphi_{kt}^{M_t} \sigma_{kt}$). Both expressions reflect the same idea, namely that trade exacerbates emissions when the largest importers of the most polluting products are also the cleanest producers. But while (9a) is helpful to identify those countries with the largest contribution to the overall change, (9b) is more convenient to identify the sectors that play the most important role.

4.2 Estimates

Contrary to expectations, the measured impact of trade is to *decrease* rather than increase total emissions. This is so because the world allocation of the most polluting products does not follow the pollution haven pattern where the cleanest countries are supposed to be the largest net importers of (trade-embodied) emissions and vice-versa. As it appears in table 2(a), which follows equations (7) and (9a), the regions to follow such a pattern are High Income Asia in the North and Africa and South America in the South. The remaining regions follow the opposite pattern, more consistent with the "factor-endowment" view

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[12] The derivation of equation (8) exploits the fact that $M_{kt} = X_{kt}$ at the world level.

[13] This definition is perfectly consistent with equation (3), given the relationship between per dollar and per unit labor emission intensities.

according to which more capital gives a comparative advantage in dirty products to the North, in particular Low Income Asia, which turns out to be by far the largest net importers of emissions in the world. The later effect dominates all the others, and as a result trade as modeled in this simulation leads to a global decrease of emissions of 1.5% in 1990. Apart from North America, which behaves more pollution-haven like, the situation is basically unchanged at the end of the period, and the global decrease implied by trade is even slightly larger (-2.5%).

Insert table 2(a): Impact of trade on total emissions, by region

The corresponding decomposition into sectors, based on equations (8) and (9b), is provided by table 2(b). Whether at the beginning or at the end of the period, the pollution-haven covariance turns out to be negative at the world level, which is consistent with the factor-endowment like results reported for table 2(a). This is so essentially because of the influence of two sectors: industrial chemicals and iron & steel, for which the cleanest countries in the world also tend to be net exporters. This effect is mildly counterbalanced by the opposite pattern in petroleum refineries and non-ferrous metals, which is more consistent with the pollution-haven view, but insufficient in magnitude to reverse to net effect at the global level.

Insert table 2(b): Impact of trade on total emissions, by sector

5 Are we in a good or a bad world?

So far we decomposed world wide emissions into different effects. The order of magnitude and the sign of these effects help us understand the world-wide production and trade structure of pollution. Ultimately, we would also like to know whether the present global labor allocation is environmentally friendly or not? This section provides an estimate by simulating the maximum and the minimum possible world emissions under given production, technology and labor force constraints.

Using linear programming techniques we minimize (maximize) for each base year total world emissions under the constraints that the aggregate world-wide production in a each sector and the aggregate labor endowment in each region are kept constant. It is also assumed that labor productivity and pollution coefficients for a given region in a particular sector are unchanged. The final outcomes of these computations (optimizing each time with respect to 168 variables under 34 constraints) are reported in table 3.

Insert table 3: Simulation of World-Wide SO2 Emissions, 1990-2000

Firstly, it turns out that we could reduce world-wide emissions by 60% if we would switch to a minimum emissions world. In the opposite scenario, we would increase global emissions by roughly 200% if we would switch to a maximum emissions world. Secondly, during the whole sample period, the world-wide allocation of labour is closer to the minimum possible emission level than to the maximum. This suggests that the real world is closer to an environmentally friendly world than to its opposite. Note however that this statement is only true concerning the composition effect since we abstract from the scale and the techniques effects.

In order to understand more in detail these global outcomes, we report different tables with the labor allocation across regions and industries. Tables 4(a, b) give the employment structure for the present situation in the three periods considered. Over time the structure is rather constant. Employment is highest in Low Income Asia with half of all employment in our sample in 2000. The most important sectors are machinery, food products and textile.

Insert tables 4(a, b):Initial Labor Shares by Region and Sector, 1990, 2000

Insert tables 5(a, b): Change in Labor Shares for Minimum Scenario w.r.t. Initial Situation, 1990, 2000

Insert tabes 6(a, b): Change in Labor Shares for Maximum Scenario w.r.t. Initial Situation, 1990, 2000

Tables 5(a, b) report the change in labor shares when going to the minimum emissions scenario. Note that regions and sectors are listed by increasing average emission intensities. To obtain the lowest possible emissions logically the employment shares for low pollution countries in highly polluting sectors increase strongly. On the other hand in order to maximize global emisssions, labor in dirty countries is allocated as much as possible to dirty sectors. These results are reported in table 6(a,b). Although the picture is slightly less clear, the strongest employment increases are obtained where the region and the sectors are dirty.

6 Conclusions

This paper decomposes world-wide SO_2 emissions into the well known scale, composition and technique effect for the period 1990-2000. In order to obtain the necessary reliable pollution coefficients we combine sector level emission data and employment and production data from the World Bank with aggregate cross-section emission data reported by Stern (2006). This allows us to obtain region, sector and year specific pollution emission coefficients in physical units per employee or per dollar of output. The decomposition exercises show big scale and technique effects that cancel each other out. Hence we are left with composition effects which are rather small (less than 0.5% a year) but lead to a decrease in overall SO_2 emissions.

An additional exercise based on the construction of a non-trade scenario suggests that trade allows to reduce emissions by a rough 2% because contrarily to the pollution haven argument large importers tend to be dirty regions and not clean ones. This result should however be taken with a grain of salt given that we neglect the fact that trade, by promoting growth, would also increase emissons. As a final exercise, we compute worldwide benchmark emission levels which would be achieved if labor were allocated to minimize or maximize world emissions. Comparing the actual world SO_2 emissions to these benchmark levels shows that emissions are reduced by 60% with respect to the worst case, but that emissions could still be reduced further by another 60% if emissions were to be minimized.

This paper is a further attempt to investigate the link between trade and the environment. We take into account region and sector heterogeneity as well as the time dimension. However, our simulation of the world under a non-trade scenario is probably too crude, as we do not control for income and price effects. An exhaustive treatment would require a real CGE which is out of the scope of this paper. Another shortcoming of these paper is that we do not incorporate transport costs in our estimation of the effect of trade on emission levels. Careful investigation of this aspect is certainly needed and would mitigate the positive impact of trade identified in this paper.

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Figures and Tables to
"Is trade bad for the environment? Decomposing world-wide SO2 emissions 1990-2000"

by J.-M.Grether, N.A. Mathys and J. de Melo

November 2006

Figure 1: Global trends (1990=100)

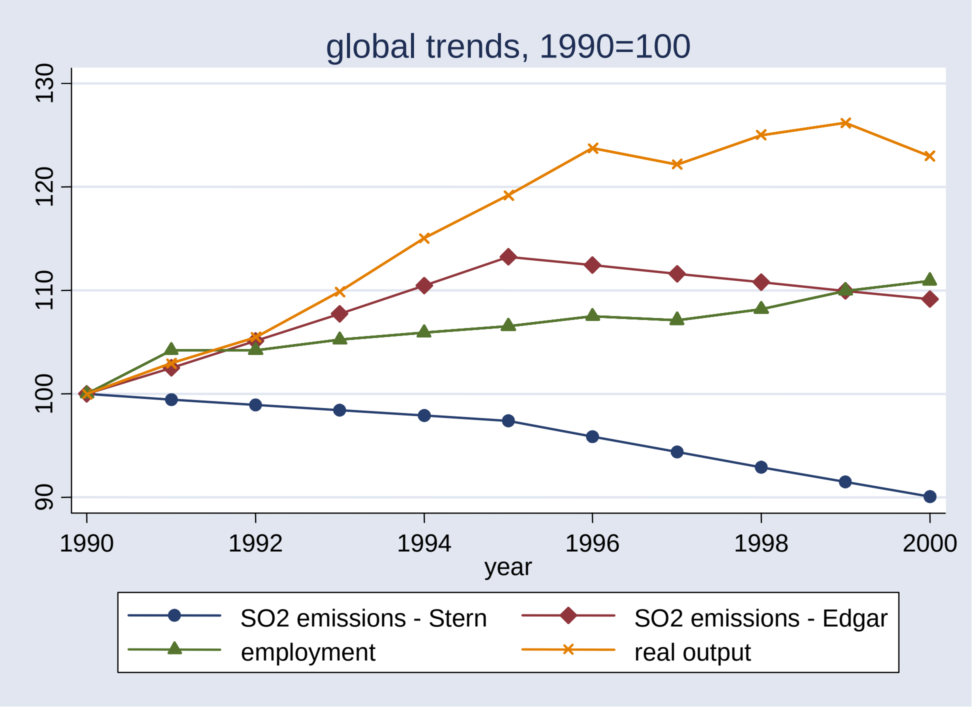

Figure 2: Possible explanations
(a) output and employment shares

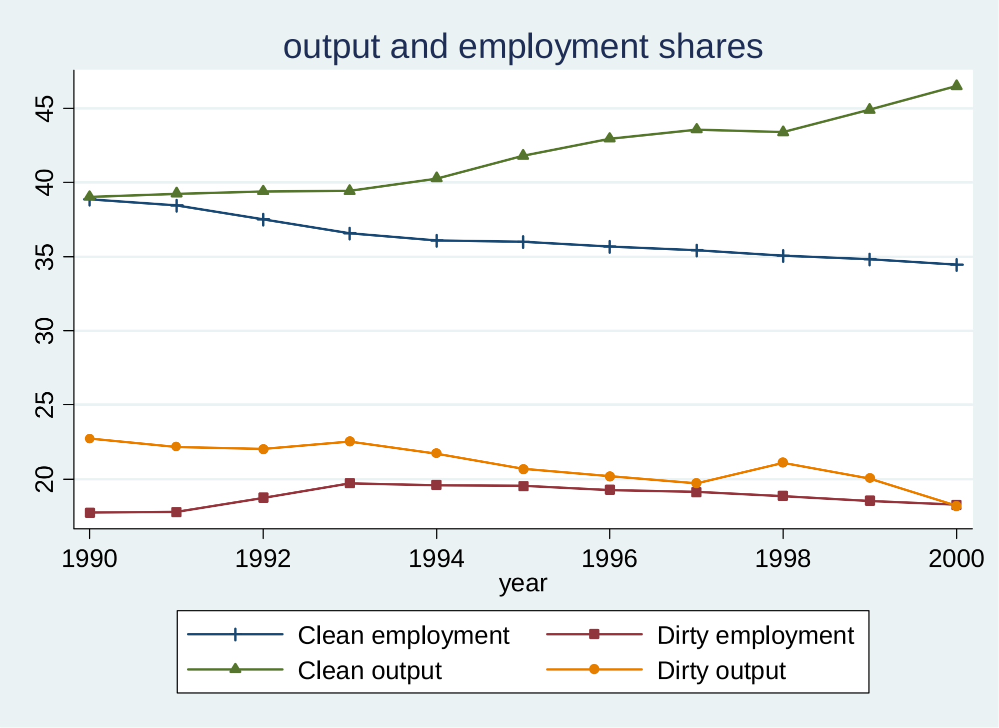

Figure 2: Possible explanations
(b) share in world total

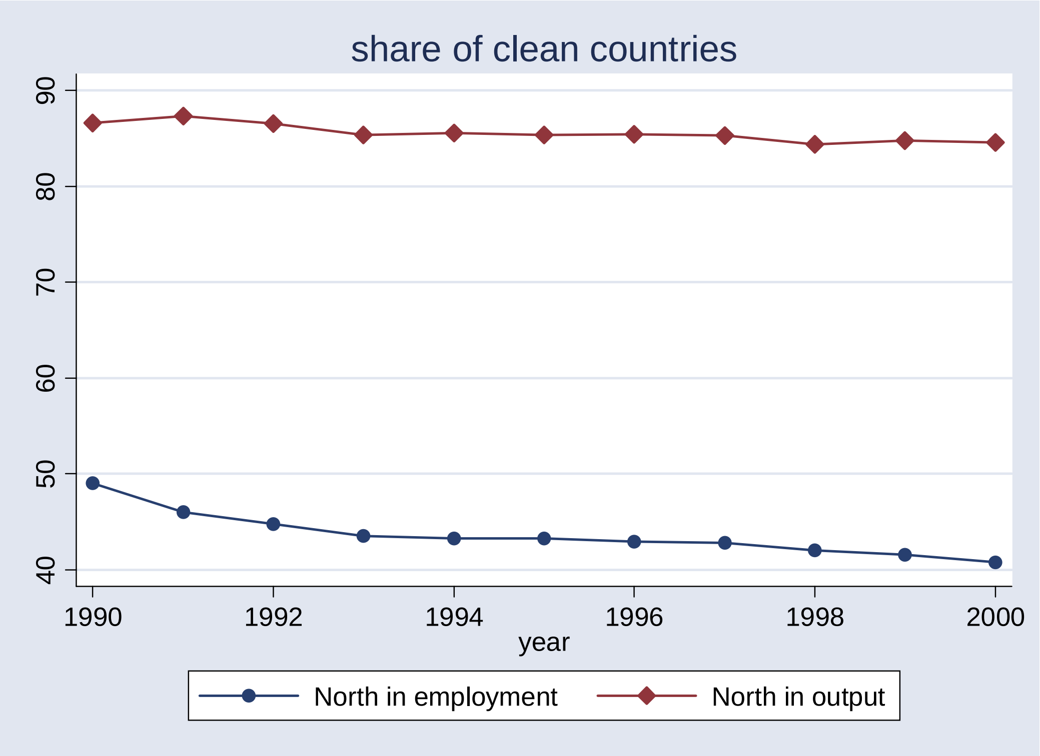

Figure 2: Possible explanations
(c) average intensities, 1990=100 for world

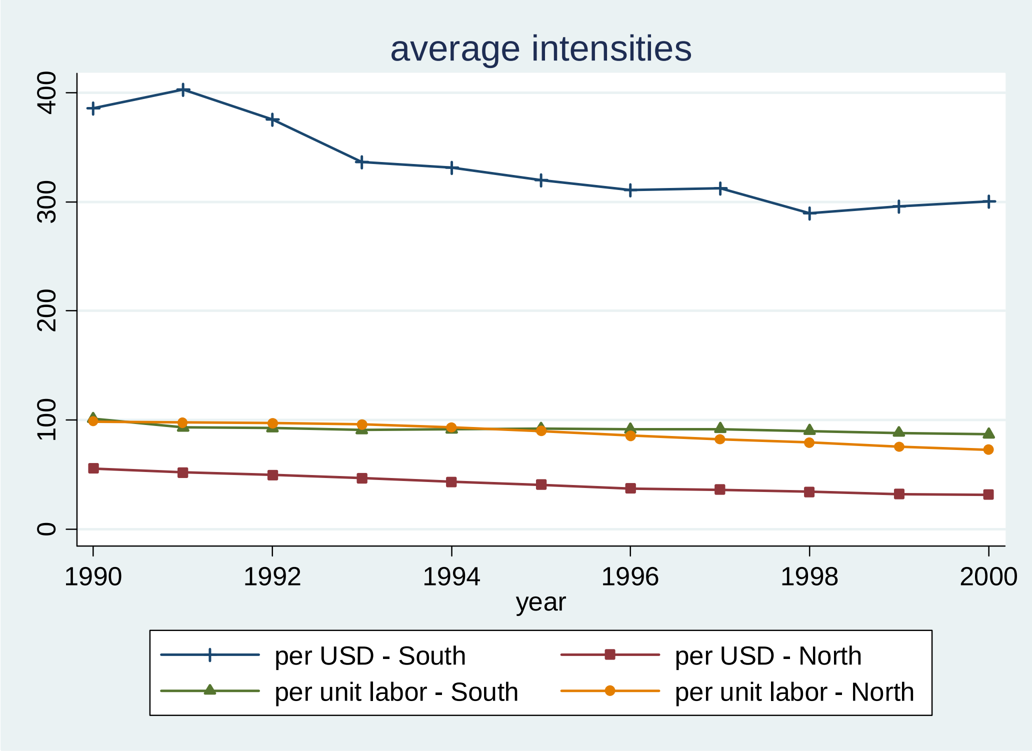

Figure 3: Growth decomposition of SO2 emissions

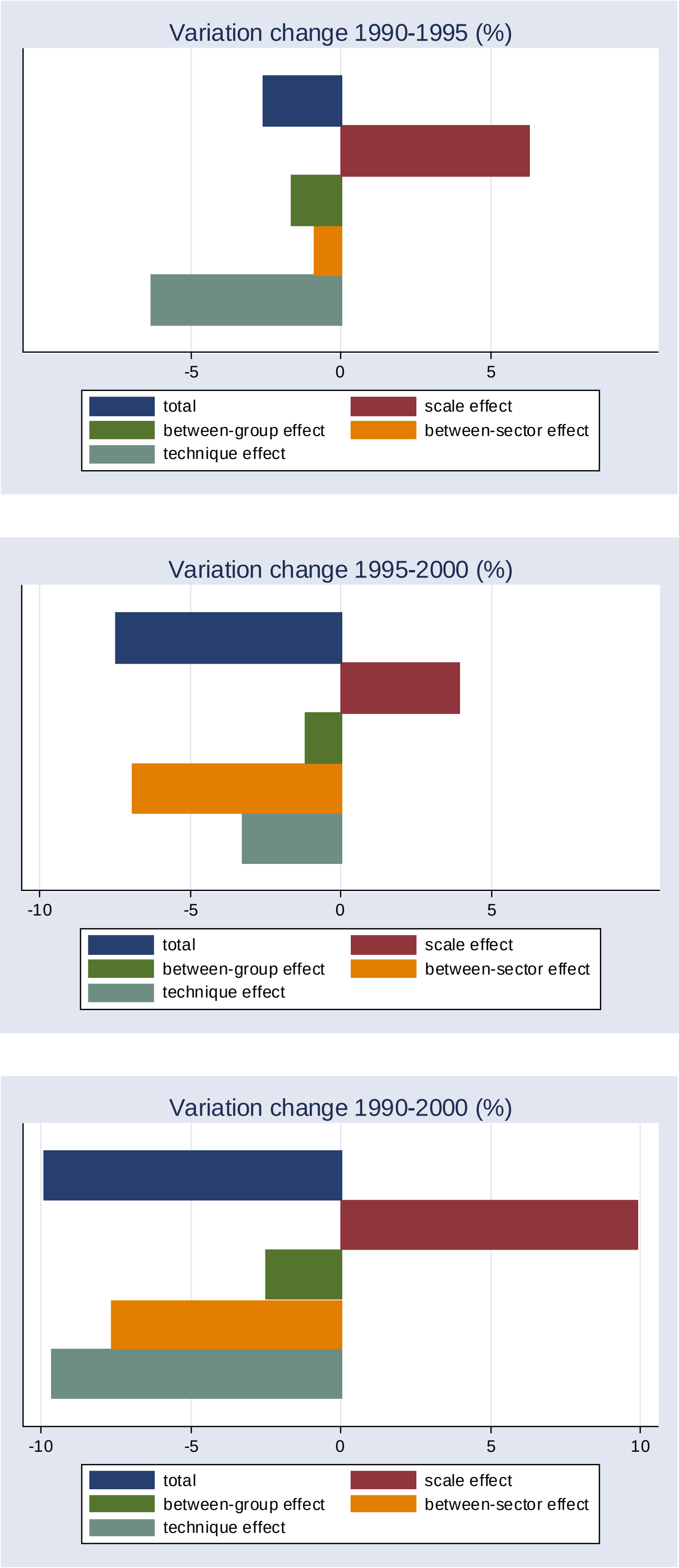

Table 1a: Decomposition results 1990-2000 - by regions (%)

	Scale effect (1)	Between country effect (2)	Between sector effect (3)	Technical effect (4)	Total net effect (1)+(2) +(3)+(4)	Total gross effect |(1)|+|(2)| +|(3)|+|(4)|
World [a]	9.89	-2.5	-7.65	-9.65	-9.91	
Share in total gross effect:[b]						
Asian High Income	1.5	-4.2	0.3	0.1	-2.3	6
Europe	3.4	-5.6	-3	-16.6	-21.7	28.5
North America	2.9	-2.8	-1.2	-3.2	-4.2	10
Africa	0.8	-0.6	-2.3	1.6	-0.4	5.3
Asian Low Income	6.6	12.4	-10.9	-5.1	3	35
South America	3	-3.9	2.9	5.4	7.4	15.3
Total net effect	18.2	-4.6	-14.1	-17.7	-18.2	54.6
Total gross effect	18.2	29.4	20.5	31.9	39.1	100

Notes: [a] growth rate over the sample period (see equation (6) in the text)
[b] share in the sum of absolute values of growth rates by region and type of effect

Table 1b: Decomposition results 1990-2000 - by sector (%)

	Scale effect (1)	Between country effect (2)	Between sector effect (3)	Technical effect (4)	Total net effect (1)+(2) +(3)+(4)	Total gross effect |(1)|+|(2)| +|(3)|+|(4)|
World [a]	9.89	-2.5	-7.65	-9.65	-9.91	
Share in total gross effect:[b]						
Food products	0.9	-0.7	0.9	-1	0.2	3.6
Beverages	0.5	-0.1	0.5	-0.4	0.5	1.5
Tobacco	0.1	0.1	-0.3	-0.1	-0.2	0.7
Textiles	0.3	0	-0.6	-0.3	-0.6	1.2
Wearing apparel except footwear	0	0	0	0	0	0
Leather products	0	0	0	0	0	0.1
Footwear except rubber or plastic	0	0	0	0	0	0
Wood products except furniture	0.1	-0.1	0.1	-0.2	0	0.4
Furniture except metal	0	0	0	0	0	0.1
Paper and products	2.1	-1.2	1.2	-2.7	-0.5	7.2
Printing and publishing	0	0	0	0	0	0
Industrial chemicals	3.1	0.5	-6.1	-4.3	-6.8	14
Other chemicals	0.6	-0.4	0.4	-0.9	-0.3	2.3
Petroleum refineries	4.3	-2	-14.9	-2.7	-15.2	23.8
Misc. petroleum and coal products	0.8	-0.6	-2.7	0.1	-2.4	4.1
Rubber products	0.1	-0.1	-0.1	-0.2	-0.2	0.5
Plastic products	0	0	0	0	0	0
Pottery china earthenware	0	0	0	0	0	0
Glass and products	0.1	-0.1	0	-0.2	-0.2	0.4
Other non-metallic mineral products	3.4	0.1	7.6	-2.7	8.3	13.8
Iron and steel	3.9	-0.4	-5.5	-4.1	-6.1	13.8
Non-ferrous metals	4.2	-1.1	0.3	-4.1	-0.7	9.7
Fabricated metal products	0.1	0	0.1	-0.1	0	0.2
Machinery except electrical	0.2	-0.1	-0.3	-0.3	-0.5	0.9
Machinery electric	0.2	-0.2	-0.3	-0.3	-0.6	1
Transport equipment	0.2	-0.1	0.1	-0.2	-0.2	0.5
Professional and scientific equip.	0	0	0	0	0	0
Other manufactured products	0	0	0	0	0	0
Total net effect	25.3	-6.3	-19.6	-24.7	-25.3	75.9
Total gross effect	25.3	7.7	42.2	24.8	43.6	100

Notes: [a] growth rate over the sample period (see equation (6) in the text)
[b] share in the sum of absolute values of growth rates by region and type of effect

Table 2a: Impact of trade on total emissions, by region

1990	Emission intensities [a)]		Shares (%) [b)]		Changes in emissions with respect to autarky [c)]	
Region	Exports	Imports	Exports	Imports	Level	Share in autarky emissions (%)
High Income Asia	0.28	0.74	34.12	23.31	-74.64	-0.44
Europe	1.3	1	23.18	25.85	41.51	0.25
North America	1.17	0.74	24.03	32.55	41.01	0.24
Africa	10.71	3.53	1.37	1.46	92.72	0.55
Low Income Asia	4.3	8.54	11.08	11.64	-503.99	-2.99
South America	4.39	3.13	6.22	5.19	107.88	0.64
World	1.58	1.88	100	100	-295.51	-1.75

2000	Emission intensities [a)]		Shares (%) [b)]		Changes in emissions with respect to autarky [c)]	
Region	Exports	Imports	Exports	Imports	Level	Share in autarky emissions (%)
High Income Asia	0.25	0.33	27.36	22.13	-10.76	-0.07
Europe	0.51	0.32	19.57	20.99	72.77	0.47
North America	0.49	0.4	22.52	32.25	-45.93	-0.3
Africa	9.18	2.63	1.19	1.72	149.53	0.97
Low Income Asia	1.62	4.57	21.93	13.22	-578.74	-3.75
South America	2.92	2.13	7.43	9.69	24.94	0.16
World	0.96	1.13	100	100	-388.19	-2.52

Notes: a) Average emission intensities by region and trade flow. b) Simple import and expot shares by region.
c) Change in regional emission levels when going from autarky to free trade. The change in emissions corresponds to the emissions trade balance, expressed in equations (7) and (9a) in section 4 of the paper.

Table 2b: Impact of trade on total emissions, by sector

1990			Changes in emissions with respect to autarky[b]	
Sector	**Covariance[a]**	**Import shares (%)**	**Level**	**Share in autarky emissions (%)**
Food products	0.04	4.60	12.79	0.08
Beverages	0.06	0.75	2.86	0.02
Tobacco	-0.03	0.31	-0.54	0.00
Textiles	0.02	3.61	4.77	0.03
Wearing apparel except footwear	0.00	2.81	0.28	0.00
Leather products	0.03	1.21	2.19	0.01
Footwear except rubber or plastic	0.00	1.13	0.04	0.00
Wood products except furniture	0.09	1.29	7.78	0.05
Furniture except metal	0.01	0.61	0.36	0.00
Paper and products	-0.30	2.05	-39.73	-0.24
Printing and publishing	0.00	0.55	-0.01	0.00
Industrial chemicals	-0.54	7.65	-264.48	-1.57
Other chemicals	-0.05	2.60	-7.83	-0.05
Petroleum refineries	0.32	2.32	46.79	0.28
Misc. petroleum and coal products	-0.77	0.12	-6.05	-0.04
Rubber products	-0.02	0.74	-0.91	-0.01
Plastic products	0.00	1.21	0.11	0.00
Pottery china earthenware	0.01	0.30	0.12	0.00
Glass and products	0.03	0.47	0.77	0.00
Other non-metallic mineral products	0.18	0.59	6.76	0.04
Iron and steel	-0.40	3.08	-78.32	-0.46
Non-ferrous metals	0.20	3.43	43.01	0.25
Fabricated metal products	0.00	2.49	-0.12	0.00
Machinery except electrical	-0.02	18.19	-20.78	-0.12
Machinery electric	0.00	14.66	-1.77	-0.01
Transport equipment	-0.01	14.56	-4.64	-0.03
Professional and scientific equip.	0.00	3.86	-0.02	0.00
Other manufactured products	0.00	4.80	1.06	0.01
Total	-0.17	100.00	-295.51	-1.75

Notes:

[a] Covariance between pollution intensity and the difference between the export and import shares.

[b] Change in industry emission levels when going from autarky to free trade. The change in emissions is formulated in equations (8) and (9b).

2000

Sector	Covariance a)	Import shares (%)	Changes in emissions with respect to autarky b)	
			Level	Share in autarky emissions (%)
Food products	0.03	3.13	12.50	0.08
Beverages	0.06	0.64	5.79	0.04
Tobacco	0.01	0.19	0.30	0.00
Textiles	0.01	2.71	3.29	0.02
Wearing apparel except footwear	0.00	3.91	1.30	0.01
Leather products	0.04	1.11	6.85	0.04
Footwear except rubber or plastic	0.00	0.85	0.14	0.00
Wood products except furniture	0.08	0.85	10.10	0.07
Furniture except metal	0.01	0.98	2.10	0.01
Paper and products	-0.47	1.54	-107.14	-0.69
Printing and publishing	0.00	0.53	0.00	0.00
Industrial chemicals	-0.35	6.78	-350.49	-2.27
Other chemicals	-0.05	3.24	-21.90	-0.14
Petroleum refineries	0.06	1.65	14.61	0.09
Misc. petroleum and coal products	-0.43	0.11	-7.15	-0.05
Rubber products	-0.02	0.71	-1.83	-0.01
Plastic products	0.00	1.49	0.57	0.00
Pottery china earthenware	0.01	0.22	0.33	0.00
Glass and products	0.01	0.46	0.72	0.00
Other non-metallic mineral products	0.92	0.53	72.03	0.47
Iron and steel	-0.30	1.88	-83.23	-0.54
Non-ferrous metals	0.17	2.16	54.02	0.35
Fabricated metal products	0.00	2.89	1.35	0.01
Machinery except electrical	0.00	18.59	1.36	0.01
Machinery electric	0.00	21.56	-1.30	-0.01
Transport equipment	0.00	12.33	-3.56	-0.02
Professional and scientific equip.	0.00	4.34	0.00	0.00
Other manufactured products	0.00	4.61	1.07	0.01
Total	-0.09	100.00	-388.19	-2.52

Notes:

a) Covariance between pollution intensity and the difference between the export and import shares.

b) Change in industry emission levels when going from autarky to free trade. The change in emissions is formulated in equations (8) and (9b).

Table 3: Simulation of World-Wide SO2 Emissions

Year	Initial (in 10^9 pounds)	Min (in %)	Max (in %)
1990	19.54	-59.44	181.63
1995	19.03	-64.31	158.17
2000	17.60	-64.00	212.53

Table 4a: Initial Labor Shares by Region and Sector - 1990

	Region						
Sector	**HIA**	**LIA**	**Europe**	**NA**	**Africa**	**SA**	**Total**
Footwear, except rubber or plastic	0.10	0.32	0.31	0.05	0.04	0.13	0.96
Wearing apparel, except footwear	0.83	2.93	0.89	0.63	0.27	0.24	5.79
Professional and scientific equipment	0.25	0.57	0.37	0.64	0.01	0.13	1.96
Printing and publishing	0.61	0.78	0.91	1.15	0.06	0.17	3.67
Other manufactured products	0.34	1.36	0.32	0.29	0.03	0.07	2.40
Plastic products	0.63	0.69	0.66	0.51	0.06	0.18	2.72
Fabricated metal products	1.08	1.30	1.69	0.99	0.16	0.39	5.59
Pottery, china, earthenware	0.11	0.29	0.18	0.03	0.02	0.04	0.67
Furniture, except metal	0.21	0.31	0.54	0.34	0.05	0.10	1.55
Machinery, except electrical	1.36	6.73	2.81	1.53	0.10	0.34	12.86
Transport equipment	1.02	2.01	2.26	1.45	0.14	0.43	7.31
Leather products	0.08	0.28	0.12	0.04	0.02	0.10	0.64
Machinery, electric	2.10	2.58	2.37	1.15	0.21	0.34	8.75
Textiles	0.98	4.36	1.26	0.62	0.34	0.44	8.01
Wood products, except furniture	0.33	0.79	0.48	0.42	0.06	0.12	2.20
Rubber products	0.25	0.71	0.30	0.16	0.02	0.09	1.52
Food products	1.19	3.58	2.16	1.06	0.41	0.89	9.29
Glass and products	0.09	0.43	0.25	0.11	0.02	0.06	0.95
Tobacco	0.02	0.72	0.07	0.03	0.02	0.03	0.90
Other chemicals	0.29	1.28	0.74	0.39	0.09	0.19	2.97
Beverages	0.10	0.77	0.31	0.11	0.05	0.20	1.56
Other non-metallic mineral products	0.35	2.32	0.60	0.28	0.12	0.37	4.05
Industrial chemicals	0.23	2.63	0.75	0.30	0.08	0.12	4.12
Paper and products	0.30	0.92	0.57	0.49	0.06	0.17	2.52
Iron and steel	0.38	2.42	0.83	0.32	0.14	0.26	4.35
Miscellaneous petroleum and coal products	0.04	0.20	0.04	0.03	0.01	0.08	0.39
Non-ferrous metals	0.15	0.76	0.28	0.20	0.08	0.10	1.57
Petroleum refineries	0.05	0.41	0.08	0.06	0.06	0.06	0.73
Total	13.47	42.43	22.16	13.37	2.73	5.84	**100.00**

Notes: Region definitions and abbreviations are liste in appendix A.

Table 4b: Initial Labor Shares by Region and Sector - 2000

	Region						
Sector	**HIA**	**LIA**	**Europe**	**NA**	**Africa**	**SA**	**Total**
Footwear, except rubber or plastic	0.05	0.83	0.24	0.02	0.03	0.12	1.30
Wearing apparel, except footwear	0.34	4.00	0.73	0.33	0.31	0.26	5.97
Professional and scientific equipment	0.22	0.79	0.50	0.53	0.01	0.13	2.19
Printing and publishing	0.51	0.84	0.96	1.06	0.07	0.17	3.60
Other manufactured products	0.20	1.01	0.23	0.27	0.02	0.06	1.80
Plastic products	0.50	1.59	0.70	0.61	0.06	0.17	3.64
Fabricated metal products	0.89	2.47	1.88	1.21	0.12	0.33	6.91
Pottery, china, earthenware	0.05	0.53	0.12	0.02	0.01	0.04	0.78
Furniture, except metal	0.16	0.59	0.61	0.48	0.05	0.09	1.98
Machinery, except electrical	1.19	6.23	2.11	1.19	0.08	0.24	11.03
Transport equipment	0.88	3.52	1.82	1.22	0.10	0.28	7.82
Leather products	0.05	0.65	0.09	0.03	0.02	0.09	0.92
Machinery, electric	1.54	2.01	1.57	1.05	0.23	0.20	6.59
Textiles	0.51	4.49	0.80	0.44	0.32	0.26	6.82
Wood products, except furniture	0.20	1.14	0.53	0.41	0.07	0.10	2.45
Rubber products	0.13	0.94	0.21	0.15	0.02	0.06	1.51
Food products	1.06	4.46	2.04	1.09	0.38	0.90	9.93
Glass and products	0.07	0.46	0.22	0.09	0.02	0.06	0.91
Tobacco	0.01	0.68	0.05	0.02	0.02	0.02	0.80
Other chemicals	0.27	1.31	0.72	0.38	0.10	0.20	2.97
Beverages	0.09	1.16	0.24	0.11	0.05	0.20	1.86
Other non-metallic mineral products	0.25	4.04	0.58	0.27	0.11	0.41	5.67
Paper and products	0.25	1.54	0.45	0.40	0.05	0.15	2.85
Industrial chemicals	0.19	2.51	0.47	0.25	0.05	0.10	3.57
Iron and steel	0.25	2.62	0.47	0.23	0.12	0.25	3.94
Non-ferrous metals	0.09	0.99	0.20	0.19	0.07	0.10	1.64
Miscellaneous petroleum and coal products	0.03	0.03	0.02	0.02	0.00	0.07	0.18
Petroleum refineries	0.05	0.12	0.09	0.05	0.02	0.06	0.39
Total	10.04	51.58	18.64	12.11	2.53	5.10	**100.00**

Notes: Region definitions and abbreviations are liste in appendix A.

Table 5a: Change in Labor Shares for Minimization Scenario w.r.t Initial Situation - 1990

	Region					
Sector	**HIA**	**LIA**	**Europe**	**NA**	**Africa**	**SA**
Footwear, except rubber or plastic	X	X	89	X	X	X
Wearing apparel, except footwear	X	X	-29	X	916	2312
Professional and scientific equipment	X	X	351	X	X	X
Printing and publishing	X	5341	X	-87	X	X
Other manufactured products	X	X	316	X	X	X
Plastic products	X	X	142	-23	X	X
Fabricated metal products	X	X	191	X	X	X
Pottery, china, earthenware	X	X	131	X	X	X
Furniture, except metal	X	X	112	X	X	X
Machinery, except electrical	X	X	98	19	X	X
Transport equipment	X	X	X	205	X	X
Leather products	X	X	214	X	X	X
Machinery, electric	71	X	2	X	X	X
Textiles	X	X	X	365	X	X
Wood products, except furniture	X	X	194	X	X	X
Rubber products	284	X	X	X	X	X
Food products	X	X	X	248	X	X
Glass and products	311	X	X	X	X	X
Tobacco	446	X	X	X	X	X
Other chemicals	359	X	X	X	X	X
Beverages	380	X	X	X	X	X
Other non-metallic mineral products	393	X	X	X	X	X
Industrial chemicals	419	X	X	X	X	X
Paper and products	400	X	X	X	X	X
Iron and steel	209	X	X	X	X	X
Miscellaneous petroleum and coal products	X	X	161	X	X	X
Non-ferrous metals	388	X	X	X	X	X
Petroleum refineries	517	X	X	X	X	X

Notes: Region definitions and abbreviations are liste in appendix A. x stands for -100 which means a 0 labor share in the minimization scenario.

Table 5b: Change in Labor Shares for Minimization Scenario w.r.t Initial Situation - 2000

	Region					
Sector	**HIA**	**LIA**	**Europe**	**NA**	**Africa**	**SA**
Footwear, except rubber or plastic	X	X	X	X	X	947
Wearing apparel, except footwear	X	-43	X	X	X	1392
Professional and scientific equipment	X	X	X	70	25242	X
Printing and publishing	X	3907	X	X	X	X
Other manufactured products	X	X	X	202	X	X
Plastic products	X	874	X	13	X	X
Fabricated metal products	X	X	X	222	X	X
Pottery, china, earthenware	X	X	267	X	X	X
Furniture, except metal	X	X	X	140	X	X
Machinery, except electrical	X	X	-54	194	X	X
Transport equipment	X	X	115	-4	X	X
Leather products	X	X	204	X	X	X
Machinery, electric	110	X	2	X	X	X
Textiles	X	X	265	X	X	X
Wood products, except furniture	521	X	X	X	X	X
Rubber products	X	X	217	X	X	X
Food products	X	X	194	X	X	X
Glass and products	383	X	X	X	X	X
Tobacco	494	X	X	X	X	X
Other chemicals	358	X	X	X	X	X
Beverages	319	X	X	X	X	X
Other non-metallic mineral products	401	X	X	X	X	X
Paper and products	X	X	247	X	X	X
Industrial chemicals	394	X	X	X	X	X
Iron and steel	241	X	X	X	X	X
Non-ferrous metals	444	X	X	X	X	X
Miscellaneous petroleum and coal products	X	X	112	X	X	X
Petroleum refineries	X	X	196	X	X	X

Notes: Region definitions and abbreviations are liste in appendix A. x stands for -100 which means a 0 labor share in the minimization scenario.

Table 6a: Change in Labor Shares for Maximization Scenario w.r.t Initial Situation - 1990

	Region					
Sector	**HIA**	**LIA**	**Europe**	**NA**	**Africa**	**SA**
Footwear, except rubber or plastic	82	X	23	X	X	X
Wearing apparel, except footwear	X	X	214	X	X	X
Professional and scientific equipment	360	X	X	-47	X	X
Printing and publishing	283	X	X	X	X	X
Other manufactured products	176	X	X	X	X	X
Plastic products	X	X	203	X	X	X
Fabricated metal products	245	X	X	X	X	X
Pottery, china, earthenware	X	X	X	1151	X	X
Furniture, except metal	X	X	112	X	X	X
Machinery, except electrical	225	X	X	X	X	X
Transport equipment	-28	X	X	142	X	X
Leather products	X	X	X	806	X	X
Machinery, electric	X	X	X	411	X	X
Textiles	X	X	226	X	X	X
Wood products, except furniture	X	X	X	195	X	X
Rubber products	X	X	195	X	X	X
Food products	X	X	168	X	X	X
Glass and products	X	X	156	X	X	X
Tobacco	X	X	171	X	X	X
Other chemicals	X	X	176	X	X	X
Beverages	X	X	149	X	X	X
Other non-metallic mineral products	X	X	X	524	1121	X
Industrial chemicals	X	886	X	X	1441	X
Paper and products	X	X	X	X	X	2296
Iron and steel	X	X	70	X	X	597
Miscellaneous petroleum and coal products	X	1176	X	X	X	X
Non-ferrous metals	X	1034	X	X	X	X
Petroleum refineries	X	1199	X	X	X	X

Notes: Region definitions and abbreviations are liste in appendix A. x stands for -100 which means a 0 labor share in the maximization scenario.

Table 6b: Change in Labor Shares for Maximization Scenario w.r.t Initial Situation - 2000

	Region					
Sector	**HIA**	**LIA**	**Europe**	**NA**	**Africa**	**SA**
Footwear, except rubber or plastic	X	X	98	X	X	X
Wearing apparel, except footwear	X	X	X	312	X	X
Professional and scientific equipment	X	X	250	X	X	X
Printing and publishing	X	X	204	X	X	X
Other manufactured products	264	X	X	X	X	X
Plastic products	X	X	237	X	X	X
Fabricated metal products	59	X	75	X	X	X
Pottery, china, earthenware	345	X	X	X	X	X
Furniture, except metal	X	X	156	X	X	X
Machinery, except electrical	234	X	X	X	X	X
Transport equipment	317	X	X	X	X	X
Leather products	X	X	204	X	X	X
Machinery, electric	X	X	243	-53	X	X
Textiles	X	X	X	317	X	X
Wood products, except furniture	X	X	X	146	X	X
Rubber products	X	X	174	-49	X	X
Food products	X	X	X	249	X	X
Glass and products	X	X	X	300	X	X
Tobacco	X	X	X	253	X	X
Other chemicals	X	X	X	247	X	X
Beverages	X	X	X	344	X	X
Other non-metallic mineral products	X	515	X	1	X	X
Paper and products	X	X	X	160	X	X
Industrial chemicals	X	638	X	X	X	X
Iron and steel	X	X	X	X	X	1897
Non-ferrous metals	X	727	X	X	X	X
Miscellaneous petroleum and coal products	X	X	X	X	15151	110
Petroleum refineries	X	X	X	X	7856	X

Notes: Region definitions and abbreviations are liste in appendix A. x stands for -100 which means a 0 labor share in the maximization scenario.

Appendix to
"Is trade bad for the environment? Decomposing world-wide SO2 emissions 1990-2000"
by J.-M.Grether, N.A. Mathys and J. de Melo
November 2006

Completing data for production and employment

We start with the 3-digit ISIC data on employment and production from the "Trade, Production and Protection, 1976-2004" World Bank database elaborated by Olarreaga and Nicita (2006). We compute three year moving averages. This leads to 23% of the employment data and 27% of the production data that are missing. We propose the following procedure to fill these missing data.

a.) Whenever we have datapoints (employment or output for a given sector and a given country) for at least half of the sample period we extra- and intrapolate the remaining missing data using a simple time trend.

b.) The table below lists countries where for some sectors (most of the time less than 4 sectors are concerned) we do have less than half of the time series, but after having looked at the non-missing series we still decided to apply the technique from a.):

Country	Share of nonmissing data (%)	Comments
Brazil, Denmark, Indonesia, Italy, Kuwait, Mexico, Norway, Pakistan, Poland, Honduras	44	
Benelux, Hungary	39	For BLX beginning and end of period data is available
Germany, Israel, Nepal, Panama	33	
France, Iceland, Nepal, Portugal, Senegal	28	Concerns only 1 sector except for Senegal

Points (a) and (b) leave us with 5.5% of the employment data and 7.4% of the prouduction data missing.

c.) For these final cases we propose a case-by-case analysis.

Benelux	growth rates of the corresponding 2-digit sector are applied to missing data in sector 324
Brazil	Recent employment (production) data for 9 (11) sectors (out of 24) are intra-extra polated using the average growth rate of the remaining sectors in the same 2 digit sectors
China	Attributing the same productivity to the missing two sectors as the corresponding 2-

	digit sectors report
Germany	Interpolate employment data for one sector using output
France, Hong Kong	Split by half 353 into 353 and 354
Iceland, Kuwait, Morocco, Mus, Malawi, Nepal, Panama	Impute output from average of the non-missing sectors in the same 2-digit class

d.) For the sectors where still some series are missing, productivities from a similar country (scaled by a factor computed from non-missing sectors) have been attributed in the following cases:

Replace	**by**
Brazil	Argentina
Kenya	Malawi
Mauritius	Chile
Benelux	Netherlands
Iceland	Denmark
Morocco	Egypt
Tunisia	Jordan and Hungary

e.) This procedure leads for some sectors to unrealistic predictions (mostly at the beginning or at the end of the sample period) and hence we perform some final adjustments. In order to avoid negative predictions we impose the last positive value as a lower bound for the following countries (and with the xecpetion for Panama only for one or two sectors): Austria, Canada, Greece, Costa Rica, Indonesia, Panama, Kuwait, Senegal, Macao, Venezuela, Denmark, Mauritius, Tunisia.

Figure A1: Growth decomposition of SO2 emissions - alternative data

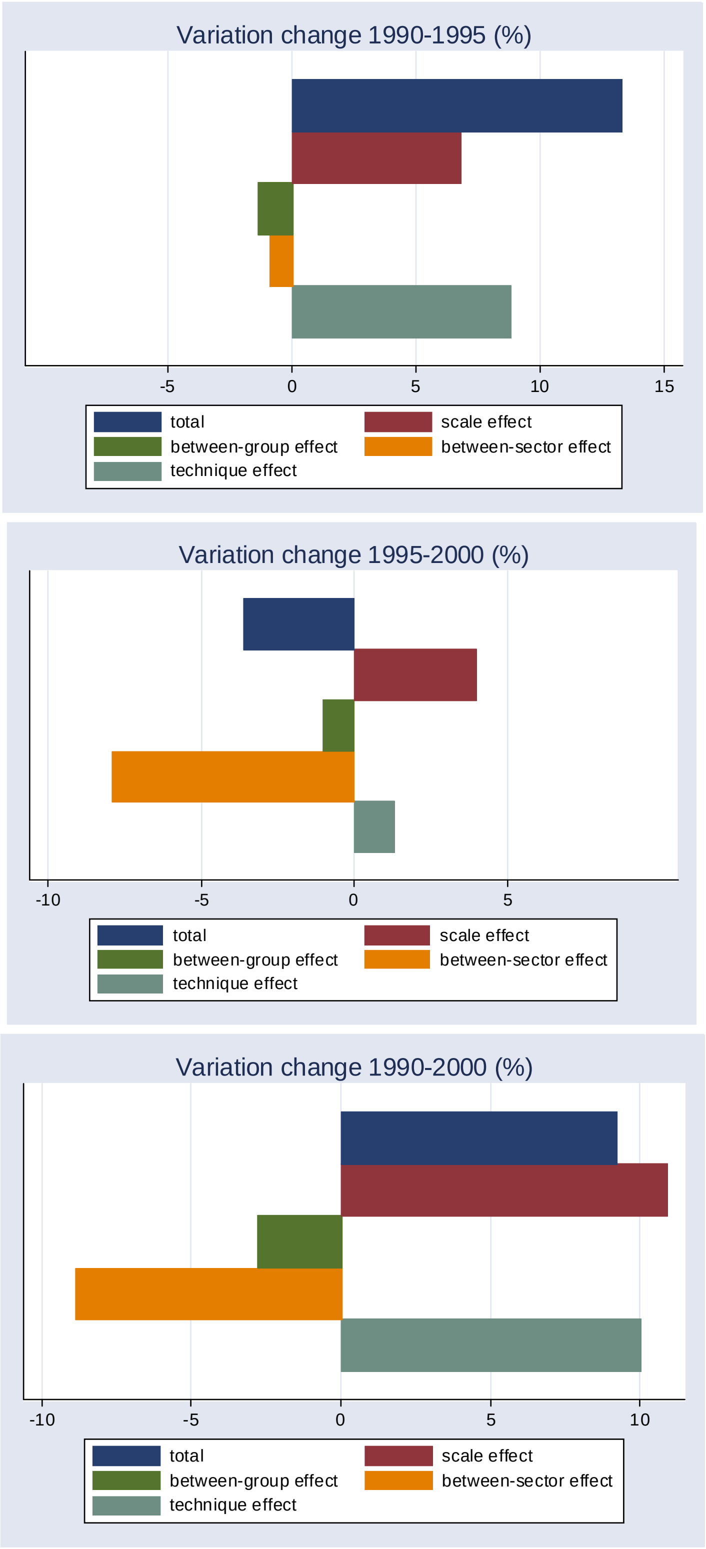

Table A1. Sample countries by geo-economic group:

North America,NA(2)	**High Income Asia , HIA(10)**	**Europe (19)**	**Africa (8)**	**Low Income Asia, LIA(10)**
Canada	Australia	Austria	Egypt	Bangladesh
USA	Hong Kong	Benelux	Kenya	China
	Israel	Cyprus	Morocco	India
South America,SA(13)	Japan	Denmark	Mauritius	Indonesia
	Korea	Finland	Malawi	Jordan
Argentina	Kuwait	France	Senegal	Malaysia
Bolivia	Macau	Germany	South Africa	Nepal
Brazil	New Zealand	Great Britain	Tunisia	Pakistan
Chile	Singapore	Greece		Philippines
Colombia	Taiwan	Hungary		Turkey
Costa Rica		Ireland		
Ecuador		Island		
Honduras		Italy		
Mexico		Netherlands		
Panama		Norway		
Peru		Poland		
Venezuela		Portugal		
Uruguay		Spain		
		Sweden		

Table A2: Dirty and Clean Industries

Dirty		**Clean**	
ISIC 3-digit	Description	ISIC 3-digit	Description
341	Paper and products	321	Textiles
351	Industrial chemicals	382*	Machinery except electrical
369	Other non-metallic mineral products	383*	Machinery electrical
371	Iron and steel	384	Transport equipment
372	Non-ferrous metals	385	Professional and scientific equipment

Note: * These sectors have been classified as overall clean. When only looking at pollution intensity in heavy metals however they are on ranks 8 and 9 respectively.
Source: Copeland and Taylor (2002).

Table A3: Conversion ratios 1990/1995/2000

Region	1990	1995	2000
High Income Asia	0.38	0.36	0.38
Europe	0.54	0.44	0.32
North America	0.66	0.7	0.59
Africa	0.42	0.37	0.51
Low Income Asia	0.25	0.22	0.23
South America	0.76	0.86	0.91

Table A4 (a): Decomposition results by regions (%)

	Scale effect (1)	Between country effect (2)	Between sector effect (3)	Technical effect (4)	Total net effect (1)+(2) +(3)+(4)	Total gross effect |(1)|+|(2)| +|(3)|+|(4)|
1990-1995						
World [a]	6.26	-1.66	-0.88	-6.34	-2.61	
Share in total gross effect:[b]						
Asian High Income	1.6	-3.6	1	-0.8	-1.8	7.2
Europe	4.2	-9.5	-2.1	-13.8	-21.2	29.5
North America	3.4	-4.3	-1	2.8	0.9	11.5
Africa	0.9	-0.3	-0.4	-1.6	-1.4	3.2
Asian Low Income	7.1	15.4	-0.7	-13.1	8.7	36.3
South America	3	-3	0.3	6	6.3	12.4
Total net effect	20.2	-5.4	-2.8	-20.5	-8.4	48.8
Total gross effect	20.2	36.1	5.5	38.1	40.3	100
1995-2000						
World [a]	3.9	-1.18	-6.93	-3.29	-7.5	
Share in total gross effect:[b]						
Asian High Income	1	-3.8	-0.5	0.9	-2.4	6.1
Europe	1.9	-1.4	-2.9	-15.1	-17.4	21.3
North America	2.1	-1	-1.1	-8.5	-8.5	12.7
Africa	0.6	-0.7	-3.6	4.4	0.6	9.3
Asian Low Income	4.8	7	-19.6	4.3	-3.5	35.7
South America	2.2	-4	5.3	3.4	6.9	14.9
Total net effect	12.6	-3.8	-22.4	-10.7	-24.3	49.5
Total gross effect	12.6	17.8	33	36.6	39.5	100

Notes: [a] growth rate over the sample period (see equation (6) in the text)
[b] share in the sum of absolute values of growth rates by region and type of effect

Table A4(b): Decomposition results by sector (%)
1990-1995

	Scale effect (1)	Between country effect (2)	Between sector effect (3)	Technical effect (4)	Total net effect (1)+(2) +(3)+(4)	Total gross effect |(1)|+|(2)| +|(3)|+|(4)|
World [a]	6.26	-1.66	-0.88	-6.34	-2.61	
Share in total gross effect:[b]						
Food products	1	-0.8	0.6	-0.8	0	3.1
Beverages	0.5	-0.2	0	-0.4	0	1.1
Tobacco	0.1	0.1	-0.2	-0.2	-0.1	0.7
Textiles	0.3	-0.1	-0.6	-0.3	-0.7	1.3
Wearing apparel except footwear	0	0	0	0	0	0
Leather products	0	0	0	0	0	0
Footwear except rubber or plastic	0	0	0	0	0	0
Wood products except furniture	0.1	-0.1	0.1	-0.1	0	0.4
Furniture except metal	0	0	0	0	0	0
Paper and products	2.1	-1.7	0	-1.7	-1.3	5.6
Printing and publishing	0	0	0	0	0	0
Industrial chemicals	3.3	0.3	-4.9	-4.8	-6.2	13.2
Other chemicals	0.6	-0.5	0.6	-0.7	0.1	2.4
Petroleum refineries	4.8	-1.1	-6.5	-4.1	-6.9	16.5
Misc. petroleum and coal products	0.9	-0.4	-1.3	-0.1	-0.9	2.7
Rubber products	0.1	-0.1	-0.2	-0.1	-0.3	0.5
Plastic products	0	0	0	0	0	0
Pottery china earthenware	0	0	0	0	0	0
Glass and products	0.1	-0.1	0	-0.2	-0.1	0.4
Other non-metallic mineral products	3.5	0.5	16.1	-3.6	16.4	23.7
Iron and steel	4	-0.7	-5.1	-4.7	-6.6	14.5
Non-ferrous metals	4.1	-1.6	-1.7	-3.9	-3.1	11.3
Fabricated metal products	0	0	0	0	0	0.2
Machinery except electrical	0.2	-0.1	-0.4	-0.3	-0.6	1
Machinery electric	0.2	-0.2	-0.2	-0.3	-0.5	0.9
Transport equipment	0.2	-0.2	0	-0.2	-0.1	0.5
Professional and scientific equip.	0	0	0	0	0	0
Other manufactured products	0	0	0	0	0	0
Total net effect	26.1	-6.9	-3.7	-26.5	-10.9	63.2
Total gross effect	26.1	8.6	38.8	26.5	44	100

Notes: [a] growth rate over the sample period (see equation (6) in the text)
[b] share in the sum of absolute values of growth rates by region and type of effect

Table A4(b): Decomposition results by sector (%)
1995-2000

	Scale effect (1)	**Between country effect (2)**	**Between sector effect (3)**	**Technical effect (4)**	**Total net effect (1)+(2) +(3)+(4)**	**Total gross effect |(1)|+|(2)| +|(3)|+|(4)|**
World [a]	3.9	-1.18	-6.93	-3.29	-7.5	
Share in total gross effect:[b]						
Food products	0.8	-0.6	1.3	-1.1	0.5	3.8
Beverages	0.4	-0.2	1.1	-0.2	1.1	1.9
Tobacco	0.1	0.1	-0.5	0	-0.3	0.6
Textiles	0.2	-0.1	-0.5	-0.1	-0.5	0.9
Wearing apparel except footwear	0	0	0	0	0	0
Leather products	0	0	0.1	0	0.1	0.1
Footwear except rubber or plastic	0	0	0	0	0	0
Wood products except furniture	0.1	-0.1	0.1	-0.2	-0.1	0.4
Furniture except metal	0	0	0.1	-0.1	0	0.1
Paper and products	1.8	-0.9	2.8	-3	0.7	8.5
Printing and publishing	0	0	0	0	0	0
Industrial chemicals	2.4	0.4	-6.6	-2.7	-6.4	12
Other chemicals	0.5	-0.3	0	-1	-0.7	1.8
Petroleum refineries	3.3	-2.5	-22.2	-2.1	-23.4	30.1
Misc. petroleum and coal products	0.6	-0.7	-3.9	-0.1	-4	5.3
Rubber products	0.1	-0.1	0.1	-0.2	0.1	0.4
Plastic products	0	0	0	0	0	0
Pottery china earthenware	0	0	0	0	0	0
Glass and products	0.1	-0.1	-0.1	-0.2	-0.3	0.5
Other non-metallic mineral products	3.3	0.2	-6.2	-0.9	-3.6	10.5
Iron and steel	3	-0.5	-5.1	-1.9	-4.4	10.5
Non-ferrous metals	3.4	-1	3	-2.9	2.6	10.2
Fabricated metal products	0.1	0	0.2	-0.1	0.1	0.3
Machinery except electrical	0.2	-0.1	-0.1	-0.3	-0.3	0.6
Machinery electric	0.2	-0.2	-0.5	-0.3	-0.8	1.1
Transport equipment	0.1	-0.1	0	-0.3	-0.2	0.4
Professional and scientific equip.	0	0	0	0	0	0
Other manufactured products	0	0	0	0	0	0
Total net effect	20.7	-6.3	-36.8	-17.5	-40	81.4
Total gross effect	20.7	7.5	54.3	17.5	50	100

Notes: [a] growth rate over the sample period (see equation (6) in the text)
[b] share in the sum of absolute values of growth rates by region and type of effect