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 world-wide SO_2 emissions over the 1990-2000 period. Combining three emission data sources (IPPS, EDGAR and Stern, (2006)) with sectoral output and employment data, we construct a database with time, country and sector-specific emission coefficients. A first growth-decomposition exercise shows that the scale and technique effects are the main driving force behind 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. A second exercise compares the actual trade situation with an autarky benchmark. It shows that trade, by allowing clean countries to become net importers of emissions, leads to a rough 10% increase in world emissions with respect to autarky in 1990, but that this figure shrinks to 3.5% in 2000. This decrease in the effect is consistent with the negative composition effects found in the first exercise. A third exercise uses linear programming to simulate extreme situations where world emissions are either maximal or minimal. It turns out that effective emissions correspond to a 90% reduction with respect to the worst case, but that another 80% reduction could be reached if emissions were minimal.

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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 production techniques, 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' (PH) hypothesis. Suspicions about the validity of the PH 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 emission trends rather than income changes 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 (2005) 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.

In spite of this growing evidence, the debate about the respective contribution of growth, technical progress and trade on world-wide emissions is largely unsettled. Taking SO_2 (a major source of pollution) as a representative example, one could say, at the risk of some oversimplification, that the debate is either informed by rigourous (and useful) methodology on indirect and relatively unrepresentative data (e.g. SO_2 concentrations across cities rather than industries by Antweiler et al. (2001)) or by better data that is not used to its full potential for addressing the growth-trade nexus (e.g. the studies cited above).

A common feature of available studies is that their estimates of the three effects are indirect because of lack of sufficiently disaggregated data. Specific assumptions combined with econometric methods allow to overcome these data problems, but choices regarding emission or abatement technologies are often difficult to justify and one is left unsatisfied by the lack of more direct empirical evidence. By contrast, this paper concentrates on the construction of a rich and consistent data set to which we apply simple methods to obtain more direct evidence on the relative importance of scale, composition and technique effects on SO_2 emissions. We combine two data sources, the IPPS coefficients of Hettige et al. (1995) and the more aggregated emissions of Olivier and Berdowski (2001). These are then scaled to be made compatible with the exhaustive data set of worldwide SO_2 emissions elaborated by Stern (2006).

As most previous studies, the paper concentrates on SO_2 manufacturing emissions because of data availability: during the nineties, the required data to perform a decomposition analysis are available for a very large number of countries and sectors. Second, reflecting the issues raised in the debate, our focus is on anthropogenic emissions and their relationship with trade: we are not directly concerned by other types of emissions related to natural phenomenons or non-traded goods.[1] Third, the growing evidence of an EKC pattern for SO_2 global emissions, makes it particularly interesting to analyze the contributing factors.

Section 2 reviews the results from the related literature. Section 3 outlines stylized facts suggesting that the observed reduction in SO_2 would be largely coherent with technical progress. Section 4 then presents a simple dynamic decomposition methodology into scale, composition and technical effects suitable for the data set constructed for this study. We show that the scale effect has been more than compensated by reductions in emission intensities (whatever the method used to measure emission intensities) and that composition effects are negative both between sectors and between countries. Counterfactual exercises are carried out in section 5. First, we compare world-wide emission levels coming from an anti-monde where every country returns to complete autarky to the actual emission levels in which countries trade with one another. We then apply LP techniques to compare actual emission levels with respect to those that would obtain if emissions were to be either minimized or maximized under the observed technical conditions.We find that the impact of trade on world wide emissions was non-negligeable in 1990 but has strongly decreased

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[1] Manufacturing emissions account for approximately one third of global anthropogenic SO_2 emisssions, the rest being roughly split in half between power generation and other activities (see Olivier and Berdowski (2001)).

in the meantime and that the actual world is situated on the better side of the emission spectrum. Section 6 concludes.

2 Literature background

The sources of SO_2 emissions and their temporal pattern have frequently been analyzed in the Energy and the Environment literature. The decomposition of emission changes into scale, composition and technique effects can be found in several studies, some relying on the Divisia index methods (e.g. Lin and Chang (1996) or Viguier (1999)) while other propose further decompositions of the technique effect (e.g. Selden et al (1999)). However, these studies are not primarily interested in the impact of trade, and, due to data limitation, usually refer to one or a few countries only.

Grossman and Krueger (1991) were the first to introduce scale, technique and composition effects into the trade and the environment literature, in the context of SO_2 emissions under NAFTA, and coined their estimated relation between emissions and income per capita an EKC. Copeland and Taylor (1994) later derived formally these three effects in a North-South general equilibrium trade model with a continuum of goods. Using SO_2 concentrations measured in 108 cities representing 43 countries over the 1971-1996 period, Antweiler et al (2001) estimate econometrically the contribution of the different effects on pollution concentration. The scale effect, measured by the elasticity of concentrations with respect to GDP/km^2, is estimated to lie between 0.1 and 0.4. Using the capital to labour ratio as a proxy for the composition effect leads to elasticity estimates between 0.6 and 1.0. The technique effect is captured by GDP per capita leading to an elasticity between -0.9 and -1.5. Finally the trade-induced composition effect is measured by (exports+imports)/GDP and gives an elasticity that lies between -0.4 and -0.9. [2]

Focusing on the income gains and sectoral production changes induced by the Uruguay Round and on several air pollutants (including SO_2), Cole and Rayner (2000) use the

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[2] Using the same theoretical framework but applied to national energy use in 32 countries, Cole (2006) obtains opposite results, namely that the scale effect outweighs the technique effect and that the trade-induced composition effect is positive.

IPPS database and rely on an EKC specification. They find that the Uruguay Round would decrease SO_2 emissions in the EU and the USA and that emissions would rise for developing and transition economies.[3] Stern (2002) compares the EKC approach with a specific decomposition approach for SO_2 emissions in 64 countries over 1973-1990. He finds that the scale and the technique effects are the dominant forces and that they tend to offset each other. The composition effects (input and output composition) may however be large for a particular country. He also argues that the EKC model imposes significant restrictions that are not imposed in his decomposition model which performs better even though he has to assume a specific emission function in this case.

Our approach in this paper is to dedicate more attention to building a large database, including as many countries and sectors as possible, and applying simple investigative techniques to assess the role of trade.

3 The Global Decline in Manufacturing Sulfur Emissions and other Stylized Facts

We start with an investigation of broad trends for the 62-country sample (31 "Northern"countries and 31 "Southern" countries)[4] used in the remainder of the paper. With the help of diagrams, we document the decrease in manufacturing SO_2 emissions during the nineties at the aggregate level. 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 country sulfur dioxide emission data carefully constructed by Stern (2006) with country-sector data compiled by Olivier and Berdowski (2001) on total manufacturing emissions.[5]

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[3] Unfortunately they do not report the exact effects even though it seems as they have computed them.

[4] 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.

[5] We view the former, which includes econometric estimates for missing data, as the most reliable source at the country level, while the latter provides detailed information of emission sources within countries. Since we are interested in manufacturing emissions, we scaled down the global Stern (2006) data applying the country-specific share of manufacturing derived from Olivier and Berdowski (2001).

Figure 1 presents the evolution of SO_2 emissions and indicators of economic activity in the manufacturing sector at the world level during the sample 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 only small changes in employment shares, but a clear increase in the output share of clean products and a decrease in the output share of dirty products.

Insert figure 2(a): Employment and output shares across sectors
Insert figure 2(b): Employment and output shares across zones
Insert figure 2(c): Emission intensities across zones

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

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 in levels 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, when measured in terms of emissions per unit labor, there is a virtual equality in the emission intensity per unit of labor. This stylized observation, which confirms the conjecture of Hettige et al. (2000) based on cross-country data for biological oxygen demand, will be used in section 4.2 to extrapolate the US IPPS emission coefficients to other countries in the sample.

4 Scale, Composition and Technique Effect

At first sight, and on the basis of aggregate data, technical progress would appear to be a major determinant in the decrease of global SO_2 emissions, being sufficiently strong to reverse the impact of the scale (more employment and output) and the between-country composition effect (shift towards the South), both of which work in the opposite direction (the between-sector effect depends on whether it is defined on employment or output). These stylized patterns deserve further scrutiny. First, more precise definitions of what is a clean or a dirty sector may, and a sharper distinction between clean and dirty countries would be welcome. Second, changes in the patterns of trade could also account for this remarkable decline in sulfur emissions. The framework below is designed to disentangle these effects. Descriptions of the construction of the data base and applications follow.

4.1 A growth decomposition framework

Data on emissions per unit of manufacturing activity allow one to decompose the global growth of $\mathrm{SO_2}$ 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[6]. Then the resulting $\mathrm{SO_2}$ emissions at the sector level are given by:

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

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[6] We could also have selected output to capture the scale effect. But then comparison across countries would be affected by real exchange rate fluctuations and as already seen in the stylized facts and as discussed in the next section, intensities per unit labor are empirically more appropriate.

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 $v, w = kit, kt, it$ 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 $\sum_i \varphi_{it}^{E_t} \left(\widehat{\overline{\gamma}_{it}} \right)$ [7].

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[7] In all subsequent calculations, an ”ˆ” over a variable means the rate of growth of this variable. Interaction

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

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:

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

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

4.2 Estimating sector-level emission intensities

Consistent data on trade, output, employment and emission intensities at a sufficiently disaggregated level is needed to carry out the above decomposition. Nicita and Olarreaga (2006)) provides reliable and updated data on trade, output and employment at the ISIC 3-digit level[8]. As to emissions, even though there is a large array of emission estimates at the national level (e.g. Stern(2006)), with two exceptions, information at the disaggregated level is virtually absent. Hettige et al. (1995) provide a set of IPPS coefficients on emission intensities at the ISIC 4 or 3-digit level. The second source is the Emission Database for Global Atmospheric Research (henceforth EDGAR) data set (see Olivier and Berdowski, (2001)), which gives SO_2 emissions for the main manufacturing polluting sectors (6 ‘dirty’ and one ‘clean’ sector, the latter representing all remaining manufacturing activities). Each data set has *specific* shortcomings. IPPS coefficients are only available for the US for one

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terms are neglected here, but they are taken into account in the empirical part (section 4.3), where they are equally shared among all relevant terms.

[8] Some output and employment figures were missing in the original data base. They were completed applying a set of reasonable conventions described in Appendix II.

year, 1987. EDGAR emissions are reported for many countries and three "base" years (1990, 1995, 2000). However, a substantial part of total manufacturing emissions corresponds to fossil fuel consumption, which is not attributed across industrial sectors.

We now explain how we combine these two data sources to derive a set of disaggregated emission intensities that vary both across countries and over time, which lead to national emissions that we render through scaling consistent with the aggregate results obtained by Stern (2006) over the 1990-2000 period. The EDGAR data base does not take into account the fact that "clean" sectors emit and neglects the presence of the non-imputed categories "fossil fuel and biofuel consumption" (F10 and B10) which represent a rough 40 percent of total manufacturing emissions. To remedy this shortcoming, we carry out the following 3-step procedure to allocate this non-imputed amount across industrial sectors: (i) estimate the share of clean sectors in overall emissions on the basis of IPPS coefficients and employment data; (ii) apply this share to the total of EDGAR-based manufacturing emissions (imputed plus non-imputed categories), obtaining an estimate of "virtual" clean sectors emissions, and: (iii) subtract the virtual amount from the non-imputed amount and spread the residual across dirty sectors according to the IPPS-derived share of each sector in dirty emissions. [9] Finally, all emission intensities are scaled so that total computed manufacturing emissions match the corresponding figure derived from Stern (2006) (the latter is estimated by applying the EDGAR-based share of manufacturing emissions to Stern's total estimates).

This is the first complete data base entered in the bottom left of table 1. It is labelled $EDGAR_{da}$(where subscript $a(d)$ corresponds to aggregated (disaggregated)), the first index referring to entities, the second to sectors). As indicated, it covers 62 countries and 7 industrial sectors. For comparison purposes (see below), these emission intensities have also been either aggregated into 6 regions ($EDGAR_{aa}$ data base) and into 28 sectors ($EDGAR_{dd}$ data base), assuming for the latter operation that the dispersion of intensities

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[9] If the residual is negative, all unaffected emissions are allocated to the clean sectors. Alternative procedures were also tested, either by using labor rather than emission shares in step (iii), or by skipping step (i) and directly splitting the non-imputed emissions among sectors. The selected procedure is the one that maximizes the Pearson's correlation coefficient (at 0.94) between the 1987 US-IPPS intensities (our unique reference case) and the corresponding EDGAR-based intensities.

within each EDGAR category is identical to the IPPS one.[10]

Table 1: Alternative databases on emission intensities

To exploit the IPPS coefficients, we rely on the conjecture proposed by Hettige et al (2000), namely that emissions per unit labor tend to be constant both across countries and over time (see figure 2(c) which shows that average emission intensities are remarkably similar between North and South, and tend to follow a similar time pattern). However, such a similarity cannot be taken for granted at the country level. To check that, boxplots of the logarithm of $EDGAR_{da}$ intensities are reported in figure 3(a) for1990 and 2000. Whatever sector is considered, there is a large dispersion of intensities across countries. However, when countries are grouped among six geographical regions (which reflect both geographical proximity and similarity in average income per capita, see table A1 in the Appendix), as shown in figure 3(b), the dispersion is strongly reduced . Thus, it appears that the assumption of constant per unit labor intensities is a lot more reasonable across regions than across countries.

Figure 3(a): Boxplots of EDGAR-based intensities across countries

Figure 3(b): Boxplots of EDGAR-based intensities across regions

Following the same logic as for the EDGAR-based construction, we generate several sets of intensities based on IPPS data. The first database, $IPPS_{dd}$, is simply obtained by scaling all original US-IPPS per-employee intensities so that, for each country and year, computed total manufacturing emissions match the corresponding figure derived from Stern (2006). A similar procedure is also applied when data are aggregated across countries ($IPPS_{ad}$) or across countries and sectors ($IPPS_{aa}$), thus completing the remaining cells of table 1. This gives us six potential databases to be compared in the next section.

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[10] More precisely it is assumed that the ratio between the emission intensity of each sector and its weighted mean at the EDGAR category level is identical to the one obtained when applying US-IPPS coefficients to the country's specific employment data.

4.3 Estimates and selection of the database

Results of the growth decomposition outlied in section 4.1 using each one of the data bases described above are reported in table 2. As figures are quite close no matter which data set is used, let us start by commenting the average findings, leaving the comparison issue temporarily aside. The scale effect, capturing the world wide increase in manufacturing employment, is responsible for a 9.5% increase in world emissions over the decade. The technique effect goes in the opposite direction. Due to lower average emission intensities, it decreases world wide emissions by roughly 12.5%. Both composition effects (between country and between sectors) reduce further world-wide emissions by 3.5% each. Adding up the four effects from the decomposition leaves us with a total decrease in SO_2 emissions of 10% from 1990 to 2000.

Table 2: Scale, composition and technique effects 1990-2000

It appears then that worldwide production of manufacturing goods has shifted towards cleaner countries and cleaner sectors. This seems to contradict the stylized fact established in figure 2(c) above, i.e. evidence of a shift towards a dirtier zone (the South). However, these two results are perfectly compatible, the difference arising from an aggregation bias. The South is indeed gaining in importance and is dirtier on average than the North, but *within* the South, the largest and fastest growing region is Low-Income Asia, which is on average a lot cleaner than Africa and South America (and even cleaner than the world average). In other words, by focusing only on North-South variation, figure 2(c) fails to capture intra-zone dispersion, which is important enough to reverse the sign of the between-country effect as reported in table 2.

Now let us compare the specific results across data sets (comparing lines of table 2). By construction the total effect is identical for all possible cases, given that, in each case, we match Stern total emissions. Furthermore, the scale effect is also almost identical across data sets, because employment data is the same for all bases. The small differences come from the fact that in the computations we attributed interaction terms (that were absent from the theoretical derivation in order so simplify the presentation) homogeneously across all main effects. These interaction terms turn out indeed to be negligible. But if the total effect and the scale effect are identical, then the sum of the other three effects must also be identical. This means that the differences between the lines of table 2 will only be due to different weights attributed to the two composition effects and the technique effect, while their combined effect remains constant (and roughly equal to -19.5%).

Aggregation across sectors (comparing lines 1 and 2 or 5 and 6) has very little impact suggesting that emission intensities are quite homogenous inside the seven EDGAR sectors and disaggregating further to the 28 ISIC sectors does not change the picture. This is not surprising given that in the EDGAR classification dirty sectors are considered explicitly, while all clean sectors, which have smaller differences in intensities, are lumped together into one sector. However aggregating across countries (comparing lines 2 and 3 or 4 and 5) does increase the magnitude of the negative between-country composition effect. This suggests an aggregation bias similar to the one mentioned above, but working in the opposite direction, i.e. intra-regional variation seems to be characterized on average by a shift towards the dirtiest countries within each region. As our main concern is trade between countries, we are more interested in the data sets that capture this phenomenon (lower part of table 2).

Last but not least, comparing EDGAR and IPPS data sets at the same level of aggregation (i.e. lines 1 and 4 or 3 and 6), we find no significant differences regarding the between-country effect but a stronger technique effect in the case of EDGAR (or equivalently a stronger between-sector effect in the case of IPPS). This difference appears reasonable given that EDGAR is the data set in which temporal variation is originally included. Moreover, the difference is not large, which again seems logical given that both sets of intensities were scaled to match the global emission estimates of Stern(2006). For the rest of the paper, we selected a data base that is as disaggregated as possible, and implying only few (and arguably plausible) assumptions. On this criterion, we chose *EDGARda*, for which we feel most confident on the underlying hypothesis, and which allows us to exploit the whole heterogeneity among countries.

Table 3 reports detailed results for the 20 most influential observations out of the 434 total combinations of the data base (62 countries times 7 sectors). At this level of disaggregation, only the between-sector and the technique effects are really observation-specific, while the scale and the between-country effects correspond in fact to the aggregate figure which is spread across observations according to emission shares. [11] As a result, the figures that appear in the "scale" column are a direct indication of the share of that particular combination in global emissions (e.g. Chilean emissions from the Non-ferrous metals – copper – sector correspond approximately to 6.8% (0.65/9.55) of world total manufacturing emissions, which is huge). Focusing on the net impact, the two most influential observations refer to Non-ferrous metals (Chile and China), and contribute to a strong increase in emissions. The following five major items, which include a diversity of sectors and countries, lean in the opposite direction, principally through a negative technique effect. The remaining observations contribute on average to reduce global emissions although they are individually quite small (less than 2.5% of the gross total).

Table 2: Growth decomposition by country and sector

Similar results are reported in the Appendix where results are aggregated by sector (table A4) or countries (table A5). It turns out that there are four influential sectors (each one representing more than 15% of the gross total), one which leads to an increase (Non-ferrous metals), and three that contribute to a decrease in global emissions (Petroleum and coal products, Chemicals, and Iron and steel). Regarding countries, four exhibit a net impact which corresponds to more than 5% of the gross total: Chile with a positive contribution, and Germany, Poland and the United States with a negative one. Note that China, which appears five times in table 3, "only" comes in the 9^{th} position in net terms, because of compensations across sectors.

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[11] Technically, each line of table 3 corresponds to one of the ik elements of the following expression, $\sum_k \sum_i \varphi_{kit}^{E_t} \left(\widehat{L}_t\right) + \sum_k \sum_i \varphi_{kit}^{E_t} \left(\widehat{\varphi_{it}^{L_t}}\right) + \sum_k \sum_i \varphi_{kit}^{E_t} \left(\widehat{\varphi_{kit}^{L_{it}}}\right) + \sum_k \sum_i \varphi_{kit}^{E_t} \left(\widehat{\gamma_{kit}}\right)$,which is nothing else than equation (6) rewritten in a more convenient way.

5 Does trade matter?

Exploiting the time series aspects of the production and pollution data, 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-country effect is concerned, and less than 1% a year if we add the between-sector effect in the picture). This section proposes a simple alternative to quantify the impact of trade.

5.1 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 62 countries[12] in our sample. The basic idea is that trade may allow to produce less of undesirable products (e.g. on environmental grounds) locally along the lines familiar from the pollution-haven debate. In this reasoning, we abstract from the gains from trade arguments (consuming more along an extended budget set and producing more because of the gains from specialization). Thus, in this simple world, 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 the net change in global emissions will depend on the difference in 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. In sum, this simple approach provides first-order effects that could otherwise be extended by simulating effects using general equilibrium techniques.

Consider then the case of sector k in country i year t, and denote local production

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[12] Note that we have substracted exports (and added imports) from the sample countries' production whenever the trading partner was not part of our closed sample.

by Q_{kit}, domestic consumption by C_{kit}, and exports (imports) by X_{kit} (M_{kit}), all values being expressed in current dollars. Neglecting inventories, $Q_{kit}+M_{kit}=C_{kit}+X_{kit}$. This relationship, however, does not necessarily hold for emissions because 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 resource constraints and assume that consumption remains unchanged, this amounts to calculating 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 then 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:

$$\Delta E_{kit}=g_{kit}Q_{kit}-g_{kit}C_{kit}=g_{kit}(X_{kit}-M_{kit}) \tag{7}$$

which means that the change in emissions generated by trade is just equal to the trade balance times the corresponding domestic 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:

$$\Delta E_{it}=\overline{g}_{it}^{X}X_{it}-\overline{g}_{it}^{M}M_{it} \tag{8}$$

where $\overline{g}_{it}^{X}=\sum_k\varphi_{kit}^{X_{it}}g_{kit}$ (and similarly: $\overline{g}_{it}^{M}=\sum_k\varphi_{kit}^{M_{it}}g_{kit}$) 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 they did not interpret this figure as illustrative of the change in world-wide pollution emissions.[13] As this is precisely our aim here, the next logical step would be to aggregate equation (8) across countries. Note first

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[13] Muradian et al (2002) do not control for the technical effect and use the IPPS coefficients of 11 highly polluting sectors in order to convert intensities into weight units.

that equation (7) can also be aggregated across countries. Straightforward manipulations lead to the following change in world emissions for sector k:

$$\Delta E_{kt} = M_{kt} n \sigma_{kt} \tag{9}$$

where M_{kt} is world imports (or exports[14]) 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 in world imports of good k, 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 (8) or equation (9) to obtain the total change in emissions at the world-wide level, ΔE_t. For comparison purpose, we scale this change by world-wide emission levels in autarky, $E_t = \overline{g}_t^Q C_t$, where C_t is apparent consumption and $\overline{g}_t^C$ is the world average pollution intensity, $\overline{g}_t^C = \sum_k \sum_i \varphi_{kit}^{C_t} g_{kit}$.[15] This leads to the following expressions:

$$\frac{\Delta E_t}{E_t} = \frac{\sum_i \Delta E_{it}}{E_t} = \frac{X_t}{C_t} \frac{\left[\overline{g}_t^X - \overline{g}_t^M\right]}{\overline{g}_t^C} \tag{10a}$$

$$\frac{\Delta E_t}{E_t} = \frac{\sum_k \Delta E_{kt}}{E_t} = \frac{X_t}{C_t} \frac{n \overline{\sigma}_t}{\overline{g}_t^C} \tag{10b}$$

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

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[14] The derivation of equation (9) exploits the fact that $M_{kt} = X_{kt}$ at the world level.

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

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 (10a) is helpful to identify those countries with the largest contribution to the overall change, (10b) is more convenient to identify the sectors that play the most important role.

5.2 Estimates

In line with the decomposition outlined above, the measured impact of trade is to *increase* total emissions. As shown in table 4 (last line, first and second column) overall, the opening up to trade leads to an increase of roughly 10% in emissions in 1990 while the corresponding increase is much smaller in 2000 (3.5%). From the positive percentage changes we can deduce that the largest net exporters are indeed also the dirtiest countries. This supports the pollution haven view even though a clear reduction of the magnitude of this effect takes place over time. This reduction is consistent with the negative composition effect found in section 4. But what changed exactly between the two periods?

One way to answer is to isolate the impact of each one of the four determinants of our trade impact measure that appears in equation (10a), namely emission intensities (γ), labour productivity (ℓ), trade flows (X, M) and world-wide consumption (C). More precisely, we compute again our measure of trade impact by setting all variables to their 1990 values, except for the specific variable that we want to isolate, which is set to its 2000 level. The corresponding results are reported in table 4, columns 3 to 6. Note that the average effect (last line) is positive in all cases, meaning that the pollution haven effect as interpreted above goes through. However, the magnitude of the effect depends on the scenario considered. Recall that the benchmark is given by the 10% increase in 1990. The emission intensity effect leads to a relatively more important pollution haven effect showing that emission intensities in dirty sectors and countries decreased relatively less than the world average emission intensity. The productivity effect shows a similar pattern indicating that productivity improvements over the sample period have been biased towards clean countries and sectors.

The average trade flow effect is very small compared to the benchmark effect. We interpret this strong decrease of the relative trade effect on global emissions as a decline of pollution-haven motivated trade. Finally the last column, measuring the scale effect, simply reflects the fact that apparent consumption, which appears in the denominator of equation (10a) has increased worldwide, while the numerator has been kept constant.

To sum up, this decomposition exercise suggests that the decrease in the relative importance of the trade effect on world emissions is mostly due to the fact that trade flows are less motivated by pollution-haven arguments, and possibly more by factor-endowment arguments.

Insert table 4: Percentage change in world wide emissions

Another way to explain the global results for the two years is to investigate influential countries and sectors. Table 4 also lists the twenty most important effects (in absolute values and on average over 1990, 2000), which means country-sector combinations that are of importance either for their scale and/or their dirtiness (see equation(7)). As long as the overall effect is positive, this means that the country is a net exporter of embodied emissions in the given sector. Although a bit far-fetched, we will call this case a “pollution-haven” combination, while the opposite case of a negative effect will be labelled a “green-haven” combination. Under this terminology, the most important pollution-haven during both periods is Chile for Non-ferrous metals (copper). Similarly, for the same sector, South Africa, Peru, Australia, Canada and Poland also work as pollution-havens, while Korea, Spain and Italy seem to be green-havens. We can further identify pollution-havens for Petroleum and coal products, namely Venezuela and Kuwait, while the United States behaves like a green-haven. An important part of the remaining cases switch sign over the sample period. For example Indonesia was a net exporter of Petroleum and coal products in 1990 but becomes a net importer in 2000. Other important country-sector combinations that had an increasing effect on total emissions in 1990 have now a decreasing effect in 2000. This helps to understand the sharp decrease in the impact of trade on global pollution.

Tables A6(a) and (b) in the Appendix show results by country (as proposed in equation (10a)). The countries reporting important pollution-haven behaviour in both periods are Chile, South Africa and Peru and countries that display green-haven patterns are: Korea in 1990 and Mexico, China, Honduras, and the United States in 2000. Indonesia switches from a pollution-haven earlier to a green-haven. Based on equations (10b) and (9), tables A7(a) and (b) in the Appendix are informative for identification of pollution haven sectors. The pollution haven covariance (first column) is of importance only for Non-ferrous metals and Petroleum and coal products. The former follows a pollution-haven pattern in both periods while the latter switches sign and displays a green-haven pattern for the recent period.

6 Are we in a good or a bad world?

Ultimately, we would also like to know whether the present global allocation of production is environmentally friendly or not. Using emission coefficients, γ_{kit}, we answer this question using linear programming to compute the patterns of labor allocation that would, under the assumptions of costless labor mobility across sectors and labor immobility across countries, either minimize or maximize emissions while replicating observed world-wide outputs in each sector. The programming problem is given by:

$$\begin{aligned} \underset{L_{kit}}{Min}\left(\underset{L_{kit}}{Max}\right)E_t &= \sum_k \sum_i \gamma_{kit} L_{kit} \\ s.t.\ \overline{L}_{it} &= \sum_k L_{kit} \quad \forall\ i = 1,...,62 \\ \overline{Q}_{kt} &= \sum_i \ell_{kit} L_{kit} \quad \forall\ k = 1,...,7 \end{aligned} \tag{11}$$

where $\overline{L}_{it}$ is the observed number of workers in the manufacturing sector of country i in period t and $\overline{Q}_{kt}$ is the observed world wide production in sector k at period t. The results of this optimization exercise are reported in table 5. As is typical of linear programming optimization, fixed coefficients lead to extreme labor allocations, so that the estimates should be viewed as upper and lower bounds.

Results in table 5 suggest that we could have reduced world-wide emissions in both periods considered by 80% if production was assigned to lowest emission producers. Likewise, under the opposite scenario, global emissions would have increased by roughly 800% if production was assigned to highest emission producers. This is a huge range of potential emission levels reflecting the disparities in emission intensities across the world, where the maximum emission is 46 (58) times the minimum emission in 1990 (2000). Second, from 1990 to 2000 the effective level of emission decreases, but the upper and the lower bound of the interval also decrease. Third, over the sample period the relative location of effective emissions does not change. Fourth, during the sample period, the world-wide allocation of labour is in absolute and relative terms closer to the minimum possible emission level than to the maximum. This suggests that, given the emission coefficients observed, the world allocation of SO_2 emitting activity is closer to an environmentally friendly one than to its opposite.

Insert table 5: Simulation of World-Wide SO_2 Emissions, 1990-2000

7 Conclusions

Combining data from different sources to obtain country, sector and year specific pollution coefficients, this paper decomposes in a direct manner world-wide SO_2 emissions into the well-known scale, composition and technique effects for the period 1990-2000. At a general level, in contrast with previous indirect evidence, estimates in this paper could be used to guide policy-making targeted at reducing SO_2 emissions. The hypothesis necessary to construct a coherent data base also indicate where data collection could be improved. Turning to the specific results, our direct decomposition exercises show big scale and technique effects in opposite direction of approximately the same magnitude, and slightly smaller, but always negative (in the sense of reduction in emissions) composition effects between countries and sectors. Should these composition effects hide trade-induced production allocations, then one could conclude that trade reduces SO_2 emissions.

However, the construction of a no-trade counterfactual scenario indicate that the first-order effect of trade was to increase emissions by a rough 10% in 1990, and only by 3.5% in 2000. This suggests that in both periods, large net importers tend to be clean countries but this pollution-haven pattern looses its importance over time. Since the fact that trade, by promoting growth, would also increase emissions, these first order effects represent a lower bound. As a final exercise, we compute worldwide benchmark emission levels which would be achieved if within each country, 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 90% with respect to the worst case, but that emissions could still be reduced further by another 80% if emissions were to be minimized.

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Tables and Figures

Figure 1: Global trends (1990=100)

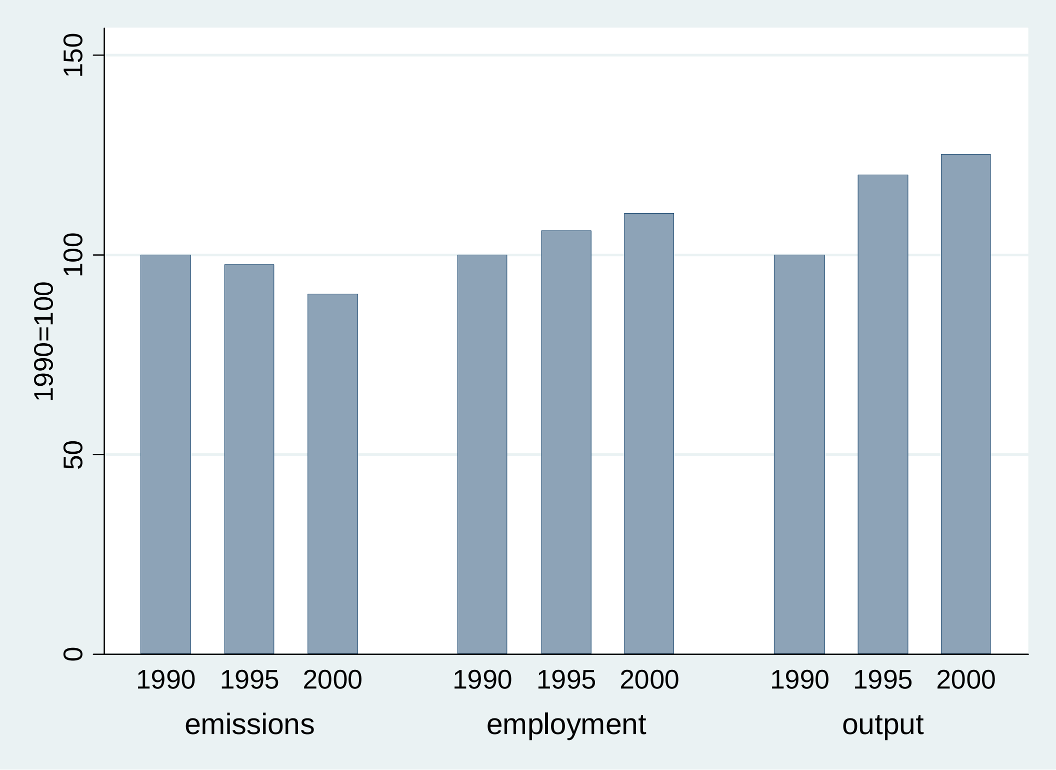


Figure 2(a): Employment and output shares by sector

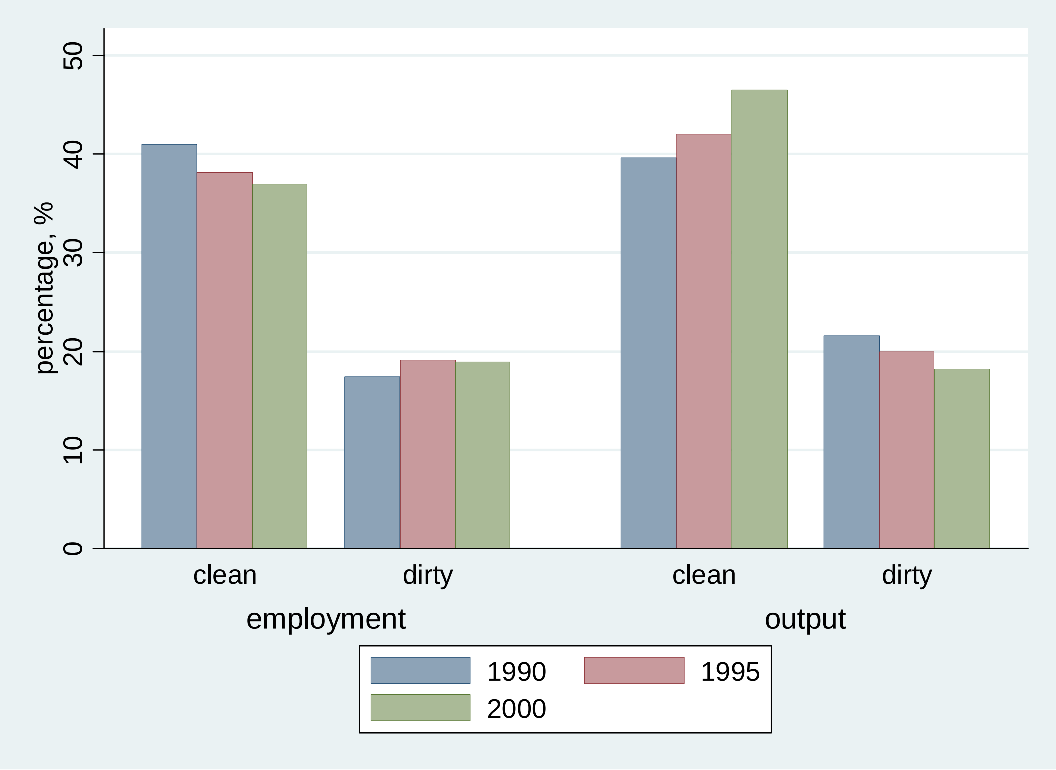


Figure 2(b): Employment and output shares by zone

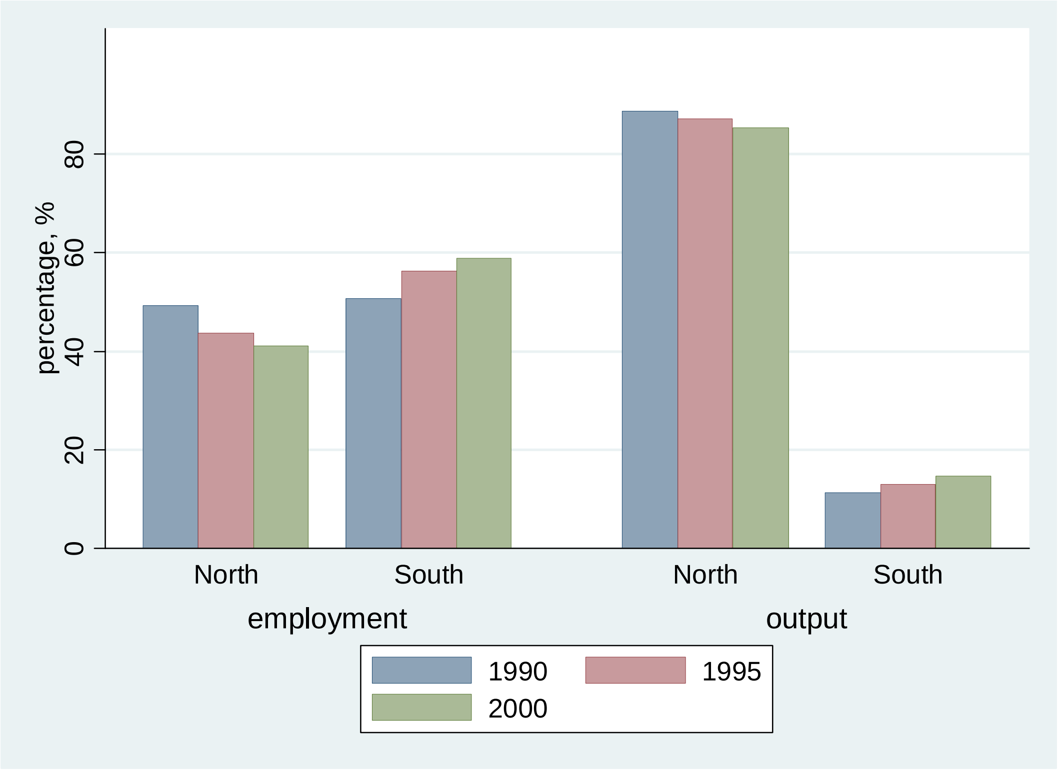


Figure 2(c): Emission intensities by zone

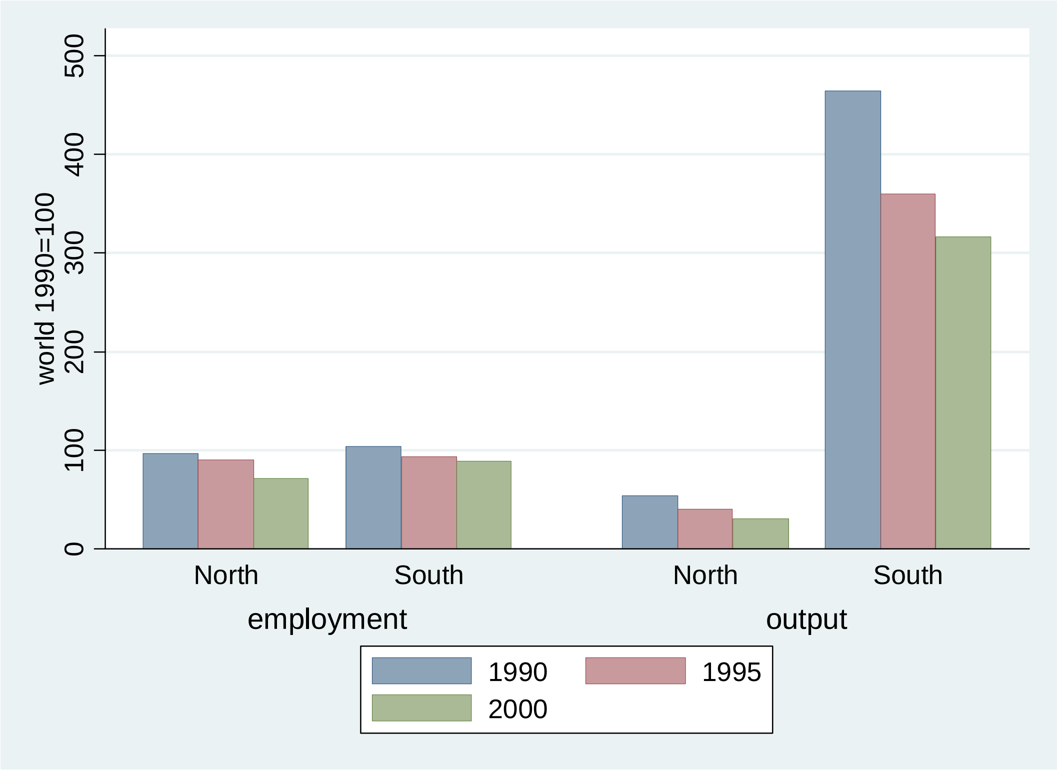
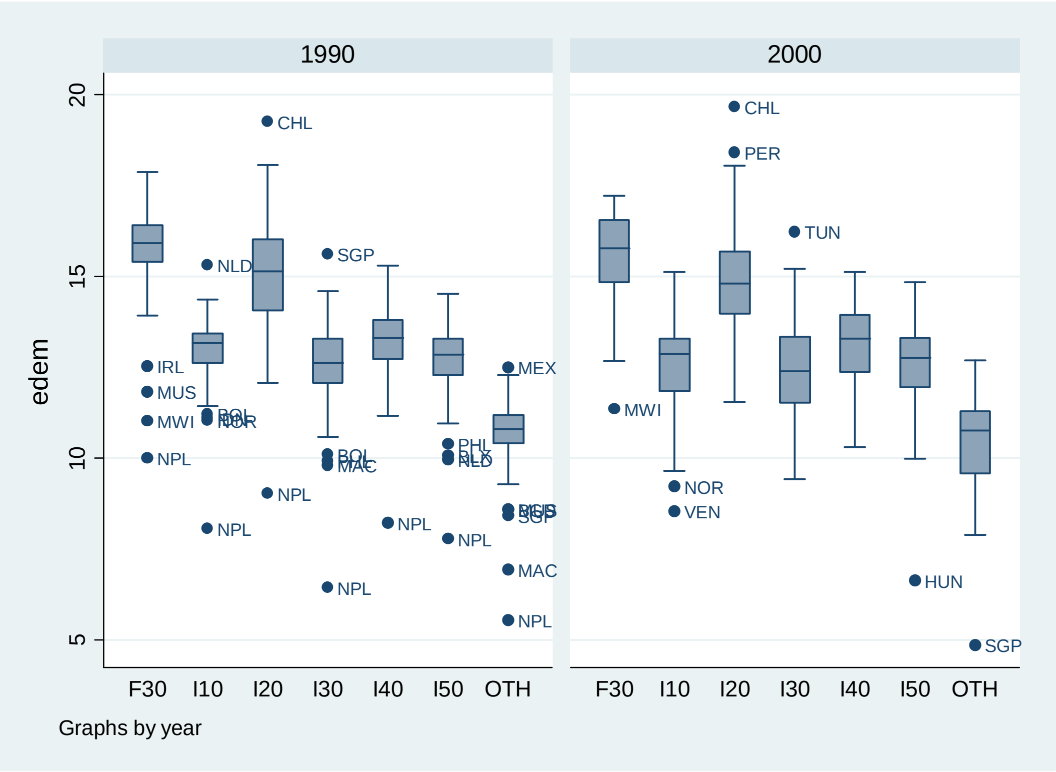


Table 1: Alternative databases on emission intensities

Sectors(a,d) Entities(a,d)	**7-EDGAR sectors**	**28 ISIC sectors**
6 regions	IPPSaa EDGARaa ↑	← **IPPSad** ↑
62 countries	↑ **EDGARda** →	IPPSdd EDGARdd

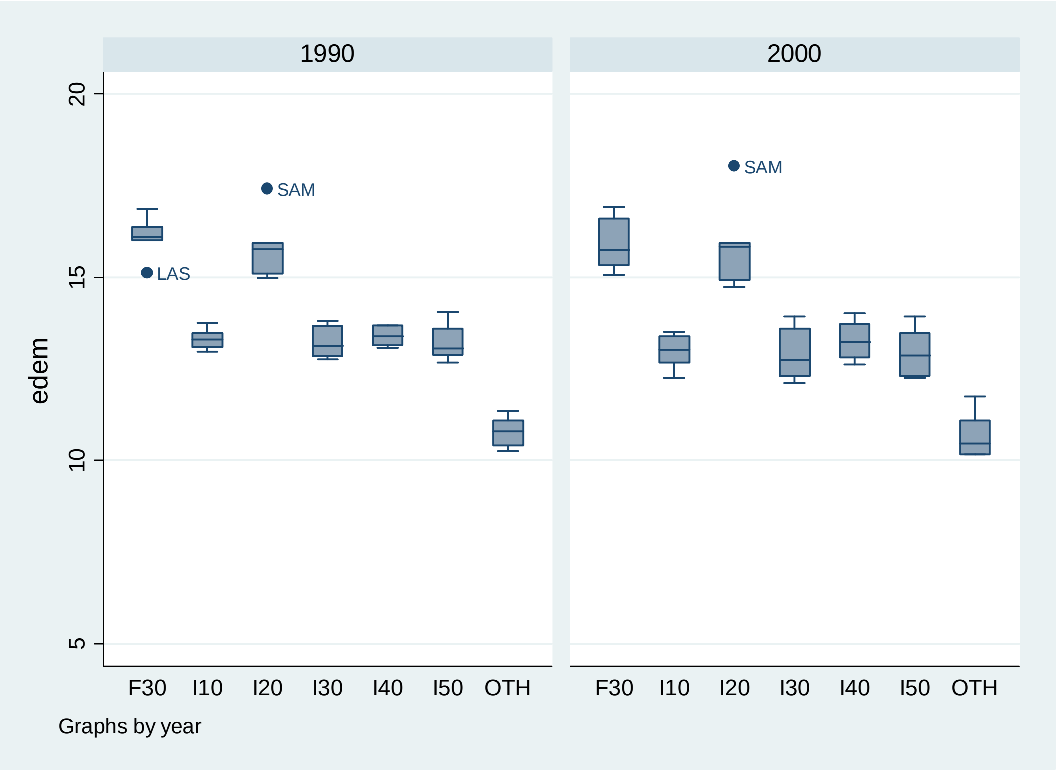
Notes: All data bases are available for the three years (1990, 1995, 2000). Subscript a(d) corresponds to aggregated (disaggregated), the first index referring to entities (regions or countries) the second to manufacturing sectors.

Figure 3(a): Boxplots of emission intensities across countries



Note: see table A3 in the Appendix for a description of EDGAR categories; OTH means all other (clean) sectors.

Figure 3(b): Boxplots of emission intensities across regions



Note: see table A3 in the Appendix for a description of EDGAR categories; OTH means all other (clean) sectors.

Table 2: Scale, composition and technique effects 1990-2000

	Database			**1990-2000 Growth Decomposition (%)**				
		Entities	Sectors	Scale effect	Between country	Between sector	Technique	Total
1	EDGARdd	62	28	9.57	-2.46	-2.73	-14.25	-9.85
2[a]	**EDGARda**	**62**	**7**	**9.55**	**-2.44**	**-3.03**	**-13.94**	**-9.85**
3	EDGARaa	6	7	9.53	-4.36	-2.39	-12.64	-9.85
4	IPPSdd	62	28	9.51	-2.43	-3.65	-13.29	-9.85
5	IPPSad	6	28	9.52	-4.41	-4.43	-10.53	-9.85
6	IPPSaa	6	7	9.53	-4.43	-4.16	-10.80	-9.85

Notes: [a] denotes the selected database for the remainder of the paper.

Table 3: Growth decomposition by country and sector

		Total Effect			Decomposition of total effect			
Country	**Sector**	**Net**	**% of gross total** [a]	**Cumul.% of gross total** [a]	**Scale**	**Between country**	**Between sector**	**Technique**
Chile	**Non-Ferrous Metals**	3.59	9.87	9.87	0.65	-0.64	0.95	2.64
China	**Non-Ferrous Metals**	1.94	5.32	15.19	0.68	1.53	0.73	-1
Germany	**Petroleum and Coal Products**	-1.74	4.78	19.97	0.09	-0.27	-0.16	-1.41
China	**Chemicals**	-1.42	3.89	23.86	0.42	0.94	-0.36	-2.41
China	**Iron and Steel**	-1.41	3.86	27.72	0.29	0.67	-0.24	-2.13
United States	**Chemicals**	-1.19	3.26	30.98	0.15	-0.16	0.03	-1.21
Germany	**Non-Ferrous Metals**	-0.98	2.7	33.68	0.12	-0.38	-0.21	-0.52
Peru	**Non-Ferrous Metals**	0.83	2.28	35.96	0.16	-0.36	-0.06	1.09
China	**Non-Metallic Mineral Products**	0.76	2.09	38.05	0.36	0.82	1.94	-2.36
Poland	**Petroleum and Coal Products**	-0.76	2.08	40.13	0.07	-0.14	-0.07	-0.62
United States	**Petroleum and Coal Products**	0.72	1.98	42.11	0.58	-0.62	0.26	0.51
Poland	**Non-Ferrous Metals**	-0.64	1.77	43.88	0.17	-0.35	-0.66	0.2
Mexico	**Non-Ferrous Metals**	0.55	1.52	45.4	0.13	0.42	-0.42	0.42
Kuwait	**Petroleum and Coal Products**	-0.5	1.38	46.78	0.05	0.1	-0.11	-0.53
Germany	**All other sectors**	-0.5	1.37	48.16	0.04	-0.13	0.01	-0.42
China	**Petroleum and Coal Products**	-0.5	1.36	49.52	0.54	1.23	-1.52	-0.74
Germany	**Chemicals**	-0.48	1.32	50.84	0.03	-0.09	-0.03	-0.39
United States	**Non-Ferrous Metals**	-0.48	1.31	52.15	0.15	-0.16	0.06	-0.52
Korea, Rep.	**Non-Ferrous Metals**	-0.4	1.11	53.26	0.11	-0.28	-0.05	-0.18
Belgium-Luxembourg	**Non-Ferrous Metals**	-0.38	1.04	54.31	0.05	-0.09	-0.34	0
Sum over 20 most important effects		-2.98	54.31	54.31	4.84	2.04	-0.26	-9.61
Residual Effect		-6.88	45.69	100	4.71	-4.48	-2.77	-4.34
Total Effect		**-9.85**	**100**		**9.55**	**-2.44**	**-3.03**	**-13.94**

Notes: [a] Gross total is the sum of the absolute value of all net total effects.

Table 4: Percentage changes in total emissions when opening up to trade with respect to autarky emissions

Country	Sector	Overall results for both sample periods		Explaining the strong decrease in the total PH effects			
		1990	2000	Emission Intensity	Labour Productivity	Trade Flows	Scale
Chile	**Non-Ferrous Metals**	3.63	6.86	6.27	4.57	4.67	2.20
Indonesia	**Petroleum and Coal Products**	1.91	-3.38	0.76	6.16	-3.89	1.16
South Africa	**Non-Ferrous Metals**	2.74	3.04	3.01	3.09	3.65	1.66
Peru	**Non-Ferrous Metals**	0.78	1.67	1.79	0.84	1.01	0.47
Australia	**Non-Ferrous Metals**	0.76	1.18	1.17	1.11	0.78	0.46
Mexico	**Petroleum and Coal Products**	-0.41	-0.99	-0.36	-0.48	-1.43	-0.25
China	**Chemicals**	-0.46	-0.67	-0.29	-0.45	-1.58	-0.28
Korea	**Non-Ferrous Metals**	-0.52	-0.42	-0.51	-0.35	-0.96	-0.31
Canada	**Non-Ferrous Metals**	0.62	0.31	0.46	0.60	0.65	0.38
Mexico	**Non-Ferrous Metals**	0.32	-0.62	0.50	0.28	-0.66	0.19
Poland	**Non-Ferrous Metals**	0.53	0.25	0.68	0.36	0.43	0.32
Venezuela	**Petroleum and Coal Products**	0.48	0.27	0.42	0.42	0.54	0.29
China	**All other Sectors**	0.21	0.74	0.17	0.18	1.58	0.13
Kuwait	**Petroleum and Coal Products**	0.49	0.13	0.15	0.37	0.83	0.30
Canada	**Paper and Products**	0.33	0.18	0.22	0.37	0.35	0.20
USA	**Petroleum and Coal Products**	-0.16	-0.34	-0.20	-0.21	-0.31	-0.10
Spain	**Non-Ferrous Metals**	-0.16	-0.23	-0.24	-0.18	-0.21	-0.10
China	**Iron and Steel**	-0.28	-0.17	-0.15	-0.27	-0.47	-0.17
Italy	**Non-Ferrous Metals**	-0.28	-0.13	-0.18	-0.33	-0.26	-0.17
China	**Petroleum and Coal Products**	0.13	-0.30	0.13	0.08	-0.78	0.08
Sum over 20 most important shares		10.66	7.37	13.79	16.14	3.94	6.45
Residual Effect		-0.91	-4.03	-1.17	-1.49	-3.42	-0.55
Total Effect		**9.76**	**3.35**	**12.62**	**14.65**	**0.52**	**5.90**

Table 5: Global emission optimization

Period	Minimum Emissions (10^9 pounds)		Effective Emissions (10^9 pounds)		Maximal Emissions (10^9 pounds)
1990	3.80	-80% ←	18.86	828% →	174.99
2000	2.64	-84% ←	17.01	794% →	152.05

Appendix I: Tables

Table A1. Sample countries by geo-economic group

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

Table A2: ISIC 3-digit rev. 2 classification

ISIC 3-Digit	Description
311	Food products
313	Beverages
314	Tobacco
321[b]	Textiles
322	Wearing apparel, except footwear
323	Leather products
324	Footwear, except rubber or plastic
331	Wood products, except furniture
332	Furniture, except metal
341[a]	Paper and products
342	Printing and publishing
351[a]	Industrial chemicals
352	Other chemicals
353	Petroleum refineries
354	Miscellaneous petroleum and coal products
355	Rubber products
356	Plastic products
361	Pottery, china, earthenware
362	Glass and products
369[a]	Other non-metallic mineral products
371[a]	Iron and steel
372[a]	Non-ferrous metals
381	Fabricated metal products
382[b]	Machinery, except electrical
383[b]	Machinery, electric
384[b]	Transport equipment
385[b]	Professional and scientific equipment
390	Other manufactured products

Notes: [a]([b]) denotes dirty (clean) sectors based on Copeland and Taylor (2003).

Table A3: Manufacturing Edgar sectors

Edgar	Description	ISIC rev. 2 Correspondence
F30	Other Transformation sectors (refineries, coke ovens, gas works)	353 and 354
I10	Iron and Steel	371
I20	Non-ferrous Metal	372
I30	Chemicals	351 and 352
I40/41	Building Materials / NME-Cement	369
I50	Pulp and Paper	341
n.a.	All other Sectors	all other Sectors

Note: Fossil fuel use and biofuel consumption (F10, B10) have been attributed to all sectors based on US IPPS shares in emissions.
Source: Edgar 3.2 (Olivier et Berdowski, 2001)

Table A4: Growth decomposition by country

	Total Effect			Decomposition of total effect			
Country	**Net**	**% of gross total [a]**	**Cumul.% of gross total [a]**	**Scale**	**Between country**	**Between sector**	**Technique**
Germany	-4.4	17.11	17.11	0.32	-1	-0.42	-3.3
Chile	3.96	15.4	32.52	0.69	-0.68	0.97	2.99
Poland	-1.64	6.37	38.89	0.3	-0.63	-0.74	-0.57
United States	-1.44	5.6	44.49	1.33	-1.42	0.16	-1.51
United Kingdom	-1.22	4.75	49.24	0.15	-0.34	-0.14	-0.89
Canada	-1.21	4.71	53.95	0.24	-0.08	-0.49	-0.88
Korea, Rep.	-1.1	4.28	58.22	0.21	-0.53	-0.14	-0.64
France	-1.09	4.22	62.45	0.19	-0.8	0.09	-0.57
China	-1.05	4.09	66.54	2.58	5.84	0.63	-10.11
Peru	0.87	3.38	69.92	0.18	-0.41	-0.07	1.17
Italy	-0.65	2.53	72.45	0.14	0.4	-0.05	-1.15
India	0.56	2.17	74.61	0.45	-0.05	-0.27	0.43
Kuwait	-0.5	1.94	76.55	0.05	0.1	-0.11	-0.54
South Africa	-0.48	1.86	78.41	0.23	-0.31	-0.2	-0.2
Indonesia	0.44	1.7	80.11	0.07	0.28	0.19	-0.1
Belgium-Luxembourg	-0.44	1.7	81.81	0.06	-0.11	-0.35	-0.04
Hungary	-0.43	1.66	83.46	0.04	-0.1	0.29	-0.66
Philippines	0.43	1.66	85.12	0.09	-0.04	0.29	0.09
Portugal	0.4	1.55	86.68	0.05	0	-0.01	0.35
Spain	-0.38	1.48	88.16	0.27	0.34	-0.45	-0.54
Pakistan	0.25	0.96	89.12	0.07	-0.11	-0.03	0.31
Finland	-0.24	0.94	90.06	0.03	-0.03	-0.01	-0.23
Japan	-0.24	0.93	90.98	0.16	-0.49	-0.14	0.23
Taiwan, China	-0.22	0.85	91.83	0.05	-0.08	0.05	-0.24
Australia	0.22	0.84	92.67	0.21	-0.43	0.08	0.35
Netherlands	-0.19	0.72	93.39	0.03	-0.07	-0.03	-0.12
Egypt, Arab Rep.	-0.15	0.57	93.97	0.08	-0.13	0.14	-0.23
Malaysia	0.15	0.57	94.53	0.02	0.11	0.03	-0.02
Denmark	-0.13	0.51	95.04	0.01	-0.01	0.02	-0.16
Tunisia	0.12	0.46	95.5	0.06	-0.26	-0.5	0.82
Sweden	-0.11	0.44	95.94	0.02	-0.02	-0.02	-0.09
Venezuela	-0.09	0.36	96.3	0.06	-0.18	0.13	-0.1
Colombia	0.09	0.33	96.63	0.03	-0.05	-0.03	0.13
Ecuador	0.08	0.3	96.94	0.01	0	0.02	0.04
Morocco	0.07	0.29	97.23	0.03	0.04	-0.02	0.03
Greece	-0.07	0.28	97.51	0.04	-0.12	0.04	-0.03
Austria	-0.06	0.24	97.75	0.01	0	0	-0.06
Hong Kong, China	-0.05	0.19	97.94	0.01	-0.06	0.02	-0.02
Jordan	0.05	0.19	98.13	0.01	0.07	-0.06	0.02
Panama	0.05	0.18	98.31	0	0	0	0.04
Norway	-0.04	0.17	98.48	0	0	-0.01	-0.04
Singapore	-0.04	0.17	98.64	0.01	-0.01	0.08	-0.12

Table A4: Growth decomposition by country (ct'd)

Country	Total Effect			Decomposition of total effect			
	Net	% of gross total [a]	Cumul.% of gross total [a]	Scale	Between country	Between sector	Technique
Uruguay	-0.03	0.13	98.78	0.01	-0.06	0.02	0
Argentina	0.03	0.13	98.91	0.05	-0.15	-0.12	0.26
Israel	0.03	0.13	99.04	0.02	0	0	0.01
Ireland	0.03	0.12	99.16	0.01	0.03	0.01	-0.01
Brazil	-0.03	0.11	99.27	0.32	-1.99	-0.54	2.18
Honduras	0.03	0.11	99.38	0	0.04	-0.01	-0.01
Costa Rica	-0.03	0.1	99.49	0	0	0	-0.03
Bolivia	0.02	0.1	99.58	0	0.01	0	0.02
Turkey	0.02	0.09	99.67	0.21	0.18	-0.54	0.17
New Zealand	-0.02	0.08	99.75	0.01	-0.02	-0.03	0.02
Kenya	-0.02	0.07	99.83	0.01	0	0	-0.03
Mexico	0.01	0.05	99.88	0.29	0.89	-0.75	-0.41
Senegal	0.01	0.04	99.92	0	-0.01	0	0.01
Nepal	0.01	0.04	99.96	0	0	0	0.01
Bangladesh	0.01	0.02	99.98	0	0.02	-0.01	-0.01
Cyprus	0	0.01	99.99	0	-0.01	0	0
Mauritius	0	0.01	100	0	0	0	0
Iceland	0	0	100	0	0	0	0
Macao	0	0	100	0	0	0	0
Malawi	0	0	100	0	0	0	0
Total	**-9.85**			**9.55**	**-2.44**	**-3.03**	**-13.94**

Notes: [a] Gross total is the sum of the absolute value of all net total effects

Table A5: Growth decomposition by sector

Sector	Total Effect			Decomposition of total effect			
	Net	% of gross total [a]	Cumul.% of gross total [a]	Scale	Between country	Between sector	Technical
Petroleum and Coal Products	-4.33	25.72	25.72	2.29	-0.76	-2	-3.85
Chemicals	-3.61	21.47	47.2	1.05	-0.01	-0.64	-4.02
Non-Ferrous Metals	3.07	18.22	65.42	3.22	-1.5	-1.2	2.55
Iron and Steel	-3.07	18.22	83.64	0.66	0.18	-1	-2.9
All other sectors	-1.27	7.54	91.19	1.07	-0.46	0.02	-1.9
Paper and Products	-1.07	6.33	97.51	0.45	-0.26	0.03	-1.28
Non-Metallic Mineral Products	0.42	2.49	100	0.82	0.39	1.75	-2.54
Total	**-9.85**			**9.55**	**-2.44**	**-3.03**	**-13.94**

Notes: [a] Gross total is the sum of the absolute value of all net total effect

Table A6(a): Impact of trade on total emissions, by country, 1990

Country	Emission Intensities [a] (kg/1000$)		Shares (%) [b]		Changes in emissions with respect to autarky [c]	
	Exports	Imports	Exports	Imports	Level (10^9 kg)	Share in autarky emissions (%)
Chile	115.65	4.37	0.25	0.24	629.30	3.59
South Africa	50.71	n.a.	0.45	0.00	505.11	2.88
Indonesia	74.26	25.89	0.47	0.79	327.51	1.87
Canada	2.86	1.09	4.37	4.48	169.34	0.97
Peru	59.09	3.00	0.11	0.09	135.71	0.77
Australia	8.08	1.12	0.87	1.51	118.83	0.68
Poland	20.65	30.97	0.29	0.04	102.11	0.58
Korea, Rep.	1.35	3.38	2.29	2.26	-100.71	-0.57
Kuwait	30.89	2.90	0.13	0.09	80.57	0.46
Venezuela	14.47	1.89	0.29	0.31	80.28	0.46
China	5.71	9.28	2.90	2.14	-73.52	-0.42
Brazil	4.83	3.19	1.08	0.61	72.88	0.42
United States	0.73	0.71	13.68	17.50	-52.96	-0.30
Italy	0.53	0.92	5.52	5.52	-48.00	-0.27
Pakistan	2.62	10.38	0.15	0.24	-46.44	-0.26
Germany	0.80	1.11	12.97	11.15	-44.49	-0.25
Spain	2.21	2.08	1.81	2.87	-43.92	-0.25
Philippines	13.00	5.32	0.30	0.37	42.53	0.24
Turkey	5.75	5.80	0.26	0.56	-39.95	-0.23
Netherlands	1.40	1.19	4.54	4.10	32.64	0.19
Hong Kong, China	0.30	0.59	1.74	3.31	-31.79	-0.18
France	0.69	0.80	6.94	7.62	-29.03	-0.17
Belgium-Luxembourg	1.62	1.49	4.24	3.76	28.59	0.16
Denmark	1.28	2.24	1.10	1.08	-22.50	-0.13
Singapore	2.38	1.27	1.50	2.04	21.97	0.13
Taiwan, China	0.26	0.84	2.83	1.95	-20.12	-0.11
Hungary	3.89	n.a.	0.22	0.00	18.78	0.11
India	3.50	6.55	0.47	0.38	-17.86	-0.10
Portugal	1.45	1.90	0.53	0.82	-17.63	-0.10
Mexico	8.12	9.86	1.17	1.04	-16.69	-0.10
Finland	1.47	0.80	0.92	0.82	15.20	0.09
Malaysia	0.59	1.04	0.98	1.16	-14.10	-0.08
Tunesia	14.74	8.64	0.06	0.17	-12.21	-0.07
Greece	3.21	1.74	0.22	0.68	-10.33	-0.06
Japan	0.08	0.25	12.25	5.56	-9.25	-0.05
Argentina	2.08	1.55	0.33	0.20	8.27	0.05
Bangladesh	2.36	4.66	0.04	0.09	-7.45	-0.04
Sweden	0.47	0.38	2.17	1.84	6.84	0.04
Marocco	7.63	4.92	0.09	0.19	-5.26	-0.03
United Kingdom	0.98	0.79	5.53	7.17	-4.79	-0.03
Costa Rica	0.77	3.83	0.03	0.05	-3.66	-0.02
Egypt, Arab. Rep.	13.70	4.17	0.05	0.22	-3.44	-0.02
Israel	1.15	1.25	0.39	0.47	-3.17	-0.02
Norway	0.47	0.17	0.62	0.92	3.15	0.02
Cyprus	1.14	1.29	0.02	0.09	-2.00	-0.01
Honduras	1.86	3.93	0.01	0.02	-1.61	-0.01
Kenya	1.55	1.30	0.01	0.06	-1.49	-0.01
Uruguay	2.51	2.64	0.07	0.04	1.42	0.01
Iceland	2.50	1.87	0.02	0.06	-1.31	-0.01

Ireland	0.72	0.74	0.86	0.75	1.17	0.01
Jordan	3.80	1.79	0.02	0.06	-0.89	-0.01
Ecuador	6.85	2.10	0.02	0.08	-0.83	0.00
Senegal	1.11	1.40	0.01	0.04	-0.80	0.00
Austria	0.26	0.23	1.29	1.65	-0.76	0.00
Mauritius	0.23	0.81	0.03	0.05	-0.70	0.00
Colombia	6.66	3.04	0.08	0.19	-0.40	0.00
Panama	0.95	1.35	0.06	0.03	0.39	0.00
Bolivia	0.77	0.85	0.01	0.03	-0.35	0.00
Malawi	0.45	0.52	0.00	0.02	-0.22	0.00
Nepal	0.02	0.29	0.01	0.02	-0.10	0.00
New Zealand	0.93	0.80	0.30	0.35	0.09	0.00
Macao	0.03	0.08	0.05	0.06	-0.07	0.00
Total	**2.38**	**1.61**	**100.00**	**100.00**	**1711.85**	**9.76**

Notes: [a] Average emission intensities by country and trade flow. [b] Country share in world imports or exports. [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 (8) and (10a) in section 4 of the paper.

Table A6(b): Impact of trade on total emissions, by country, 2000

	Emission Intensities [a] (kg/1000$)		**Shares (%) [b]**		**Changes in emissions with respect to autarky [c]**	
Country	**Exports**	**Imports**	**Exports**	**Imports**	**Level (10^9 kg)**	**Share in autarky emissions (%)**
Chile	111.38	6.22	0.26	0.28	1152.34	6.74
Indonesia	16.98	53.98	0.83	0.50	-553.96	-3.24
South Africa	27.61	2.22	0.47	0.41	522.09	3.06
Mexico	2.41	3.97	2.88	3.41	-284.63	-1.67
Peru	72.47	3.39	0.10	0.13	278.61	1.63
China	1.96	5.37	7.61	3.82	-241.19	-1.41
Australia	8.92	1.54	0.70	1.28	185.12	1.08
Honduras	4.00	98.64	0.06	0.04	-156.60	-0.92
United States	0.34	0.38	15.17	21.16	-127.83	-0.75
Canada	0.87	0.46	4.78	4.55	88.29	0.52
India	2.64	6.26	0.71	0.61	-84.29	-0.49
Korea, Rep.	0.62	1.52	3.24	2.24	-59.86	-0.35
Spain	1.32	1.41	2.00	2.75	-52.75	-0.31
Pakistan	2.27	10.12	0.16	0.14	-47.57	-0.28
Venezuela	5.90	1.00	0.22	0.30	42.15	0.25
Turkey	3.35	3.34	0.43	0.70	-38.39	-0.22
Portugal	1.63	2.05	0.48	0.75	-32.51	-0.19
Hong Kong, China	0.11	0.18	1.04	4.15	-27.35	-0.16
Greece	2.32	1.66	0.13	0.51	-23.52	-0.14
France	0.38	0.46	5.43	5.46	-20.59	-0.12
Poland	5.31	2.66	0.50	0.83	19.84	0.12
Italy	0.20	0.33	4.09	3.91	-19.31	-0.11
Philippines	2.40	2.82	0.87	0.60	16.66	0.10
Tunesia	6.95	6.47	0.10	0.16	-16.36	-0.10
Kuwait	4.90	2.08	0.12	0.12	16.08	0.09
Netherlands	0.50	0.43	3.34	3.01	15.89	0.09
Bolivia	1.25	8.39	0.01	0.04	-12.91	-0.08
Brazil	2.44	1.89	0.92	1.03	12.90	0.08
Ireland	0.31	0.23	1.60	0.99	11.51	0.07
Bangladesh	0.33	2.17	0.10	0.13	-11.04	-0.06
United Kingdom	0.33	0.23	4.90	6.03	10.18	0.06
Germany	0.21	0.24	9.99	7.87	9.87	0.06

Singapore	0.40	0.22	1.82	2.26	9.78	0.06
Finland	0.40	0.27	0.83	0.54	8.12	0.05
Argentina	1.52	0.81	0.34	0.47	5.90	0.03
Malaysia	0.35	0.59	2.09	1.45	-5.06	-0.03
Sweden	0.22	0.22	1.68	1.19	4.66	0.03
Belgium-Luxembourg	0.50	0.39	2.84	3.40	4.62	0.03
Taiwan, China	0.12	0.21	3.19	2.21	-3.73	-0.02
Egypt, Arab. Rep.	6.81	2.74	0.07	0.19	-3.09	-0.02
Cyprus	1.00	1.19	0.01	0.07	-2.99	-0.02
Panama	3.66	3.42	0.03	0.05	-2.98	-0.02
Jordan	2.07	1.52	0.01	0.06	-2.61	-0.02
Costa Rica	0.05	0.50	0.09	0.12	-2.30	-0.01
Marocco	3.76	2.73	0.11	0.17	-2.15	-0.01
Japan	0.07	0.13	9.80	5.11	2.12	0.01
New Zealand	0.57	0.67	0.24	0.27	-1.98	-0.01
Senegal	1.68	2.00	0.01	0.02	-1.74	-0.01
Kenya	0.89	0.79	0.01	0.05	-1.45	-0.01
Ecuador	5.73	2.76	0.03	0.08	-1.21	-0.01
Mauritius	0.21	0.84	0.03	0.04	-1.17	-0.01
Uruguay	0.63	0.77	0.04	0.06	-0.84	0.00
Denmark	0.08	0.09	0.75	0.84	-0.82	0.00
Norway	0.09	0.03	0.41	0.67	0.66	0.00
Austria	0.10	0.09	1.01	1.24	-0.58	0.00
Iceland	2.24	0.79	0.02	0.05	0.53	0.00
Hungary	0.19	0.20	0.55	0.58	-0.43	0.00
Colombia	2.94	1.50	0.11	0.23	-0.43	0.00
Nepal	0.56	n.a.	0.01	0.00	0.34	0.00
Malawi	0.49	0.63	0.00	0.01	-0.27	0.00
Israel	0.68	0.65	0.58	0.60	0.24	0.00
Macao	0.04	0.07	0.04	0.04	-0.06	0.00
Total	**1.36**	**1.22**	**100.00**	**100.00**	**571.94**	**3.35**

Notes: [a] Average emission intensities by country and trade flow. [b] Country share in world imports or exports. [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 (8) and (10a) in section 4 of the paper.

Table A7(a): Impact of trade on total emissions, by sector 1990

Sector	Covariance [a]	Import Shares	Changes in emissions with respect to autarky [b]	
			Level (10^9 kg)	Share in autarky emissions (%)
Petroleum and Coal Products	0.11	2.77	455.65	2.60
Iron and Steel	-0.01	4.01	-67.89	-0.39
Non-Ferrous Metals	0.30	3.49	1452.01	8.28
Chemicals	-0.01	11.36	-160.32	-0.91
Other Non-Metallic Mineral Products	0.01	0.84	13.01	0.07
Paper and Products	0.00	3.16	17.44	0.10
All Other Sectors	0.00	74.38	1.95	0.01
Total		100.00	1711.85	9.76

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 (9) and (10b).

Table A7(a): Impact of trade on total emissions, by sector 2000

Sector	Covariance [a]	Import Shares	Changes in emissions with respect to autarky [b]	
			Level (10^9 kg)	Share in autarky emissions (%)
Petroleum and Coal Products	-0.15	2.26	-944.63	-5.53
Iron and Steel	-0.01	2.55	-37.24	-0.22
Non-Ferrous Metals	0.26	2.48	1736.00	10.16
Chemicals	-0.01	11.71	-262.81	-1.54
Other Non-Metallic Mineral Products	0.02	0.64	37.00	0.22
Paper and Products	0.00	2.37	-11.96	-0.07
All Other Sectors	0.00	77.98	55.60	0.33
Total		100.00	571.94	3.35

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 (9) and (10b).

Appendix II: Completing the output and employment database

The selected database consists of output and employment data for 62 countries, 28 ISIC 3-digit sectors and 3 “base” years: 1990, 1995, 2000.

The original database (see Olarreaga and Nicita, 2006) includes annual data for the 1976-2004 period, but complete series for the 3 base years are only available for 8 countries. In the majority of the other cases, there are a few missing sectors, normally at the end of the sample period. Overall 14% of employment and 20% of output data is missing for the three base years.

Output and employment data were first smoothed using a 3-year moving average. Then four techniques were used to replace missing values by reasonable estimates.

a) **constant proportions**: identify the “replacement year”, i.e. the closest year for which there is non-missing data for the relevant sector and variable (output, employment, or both). Identify the subset of sectors which are non-missing in both the base and the replacement year, and calculate the share of the relevant sector in the (output or employment) subset total in the replacement year. Apply this share to the subset total in the base year to obtain the relevant replacement value. This is by far the most frequently applied technique. However, it cannot be used when the relevant variable is missing for all years, or when one of the two variables (output or employment) is missing for all sectors in the base year, in which case techniques b) or c) below are applied.

b) **absent sectors**: when missing values for **both** output and employment are reported for **every** year, it is normally considered that the country does not produce at all the good corresponding to this ISIC category (i.e. Cyprus does not produce petroleum products). The only exception to that rule is Brazil, where it was unrealistic to assume that economic activity in this large country would only take place in 15 out of 28 sectors. In this case, the constant proportions technique was used but using contemporaneous data from Argentina as a reference instead of the usual replacement year.

c) **constant productivity**: when missing values for the relevant variable (i.e. output or employment) are reported for all years but non-missing data is available for the **other** variable (i.e. employment or output), then contemporaneous productivity of a related sector (i.e. textiles and clothes) is applied to obtain the replacement value. If no contemporaneous related sector is available, then productivity from the closest year is used. If no related sector is available in another year, then productivity from a similar country is used (the single such case is Egypt for Tunisia).

d) **closest year using simple trend**: when there is no data reported for year 2000, the closest available year is used with the available time trend to extrapolate employment and output (1996 for Brazil and Honduras, 1997 for Iceland, Pakistan, Peru, South Africa and Taiwan, 1998 for Bangladesh, China, Malawi, the Philippines and Venezuela, 1999 for Denmark, Greece, and Mauritius, and the average between 1999 and 2001 for Egypt. For Morocco, data for 1990 is approximated by 1991 data).