Trade, Technique and Composition Effects: What is Behind the Fall in World-Wide SO2 Emissions 1990-2000?

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Summary

Combining unique data bases on emissions with sectoral output and employment data, we study the sources of the fall in world-wide SO_2 emissions and estimate the impact of trade on emissions. Contrarily to concerns raised by environmentalists, an emission-decomposition exercise shows that scale effects are dominated by technique effects working towards a reduction in emissions. A second exercise comparing the actual trade situation with an autarky benchmark estimates that trade, by allowing clean countries to become net importers of emissions, leads to a 10% increase in world emissions with respect to autarky in 1990, a figure that shrinks to 3.5% in 2000. Additionally, back-of-the-envelope calculations suggest that emissions related to transport are of smaller magnitude, roughly 3% in both periods. In a third exercise, we use 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.

Keywords: Trade, Growth, Environment, Decomposition, Embodied Emissions in Trade, Transport

JEL Classification: F11, Q56

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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 effect that trade may have on the environment. Since the conjunction of differences in environmental policies and in 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. Academic research intervene with 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, in a recent study of global emissions of sulfur dioxide (SO_2) in which a new data set is constructed using econometric estimates, Stern (2006) confirms the curbing down of emissions driven by a change in emissions intensity that would appear to be time rather than income related with a turning point around 1990 (see also Olivier and Berdowski (2001)). Since SO_2 emissions have characteristics that make them suitable to study the effects of trade on the environment (a by-product of goods production; strong local effects; regulation across many countries; and available abatement technologies), they have attracted much attention. Indeed, a deeper understanding of SO_2 emissions contributes to a better understanding of three environmental problems: air pollution and smog, acid rain, and global climate change. As pointed out by Stern (2005), better data on SO_2 emissions gives a more accurate picture of sulfate aerosols which have a cooling effect and are an important contributor to climate change.

In spite of growing evidence, the debate about trade and the environment is largely unsettled. Taking again SO_2 as a representative example of the debate, there is still uncertainty about the orders of magnitude regarding the respective contribution of growth, technical progress and trade (often referred to as scale, technique, and composition effects) on worldwide emissions. At the risk of oversimplification, one might say that the debate bas been principally informed by studies following a rigorous (and useful) methodology, but applied to indirect and potentially relatively unrepresentative data (e.g. SO_2 concentrations rather than production-related emissions by Antweiler, Copeland and Taylor (2001) or Frankel and Rose (2005), or economy-wide emissions rather than industry-specific ones as in Cole and Elliott (2003)). With the exception of the recent work by Levinson (2007), but which is limited to the US case, a common feature of these studies is that their estimates of the growth, technical progress and trade effects are indirect due to lack of disaggregated data linking pollution directly to production and to the resulting trading activities. As best as they can, these studies attempt to control for lack of data (e.g. introducing time and site-specific dummy variables when using city-concentration data). It remains however that choices regarding the measure of pollution or of technique effects are open to criticism. Moreover, in the absence of data at the sector level, how does one know if a change in the average emission intensity of a country is due to cleaner production techniques (i.e. more abatement activities) or to structural change (i.e. a shift towards cleaner activities)? In short, at the global level, one is left in want of more direct and detailed evidence.

This paper provides orders of magnitude, at the world-wide level, of the role of trade on production-related emissions. It follows a bottom-up approach based on direct measurements rather than statistical inferences. To achieve that goal, we construct a large and consistent database of SO_2 manufacturing emission intensities which vary across time, country and sectors. This allows for a simple but novel and complete decomposition of overall emission growth into a scale, a technique, and *two* composition effects (across countries and across sectors). This constitutes a new framework to analyze how trade, by reallocating production across countries and sectors, affects the overall level of SO_2 emissions. Our focus is on anthropogenic manufacturing emissions and on their relationship with trade: we are not directly concerned with other types of emissions related for example to natural phenomena or non-traded activities (e.g. volcanic eruptions or household energy consumption). For reference, manufacturing emissions account for approximately one third of global anthropogenic SO_2 emissions, the rest being roughly split in half between power generation and other activities. Note that the focus of the paper is on positive analysis: we are interested in linking pollution to potentially traded production. That is why we use data on emissions rather than on concentration, even though the latter would be more appropriate to address welfare issues.

Following a description of stylized facts in section 2, section 3 presents and applies a simple decomposition methodology that attributes emissions to scale, composition and technique effects. Application to data over the 1990-2000 period shows that the scale effect has been more than compensated by reductions in emission intensities and that composition effects are negative both between sectors and between countries thereby also contributing to a reduction in emissions. However, when applied to exports rather than total production, the scale effect dominates the technique effect even though world exports have moved towards cleaner industries and also cleaner countries.

Counterfactual exercises are carried out in sections 4 and 5. First, we compare world-wide emission levels coming from an anti-monde where every country returns to autarky to the observed emission levels in the actual trading world. Under this counterfactual, the possibility to depart from autarky raises emissions, but more so in 1990 than in 2000. Adding transport-related emissions to the analysis roughly adds another 3% to the estimated impact of trade on global emissions. Section 5 applies linear programming techniques to compare actual emission levels to those that would obtain if observed production were reshuffled across countries so as to either minimize or maximize emission levels. We find that the actual world allocation of production is situated on the better side of the emission spectrum. Section 6 concludes.

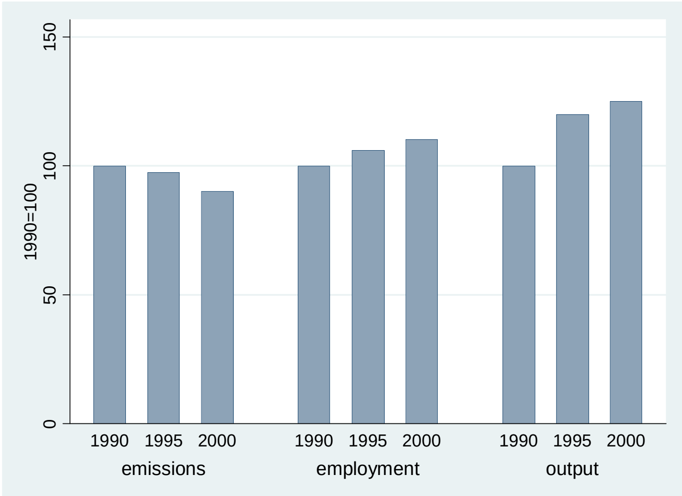
2 Stylized Facts on the Global Decline in Manufacturing Sulfur Emissions

This introductory section highlights the global trends regarding manufacturing emissions during the selected time period (1990-2000). Data sources and further details on the sample are given in section 3.2 below. Suffice here to note that the sample includes 62 countries (31 "Northern" countries and 31 "Southern" countries[1]), which account for more than 70% of world sulfur emissions.

Figure 1 presents the evolution of SO_2 emissions and two 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.

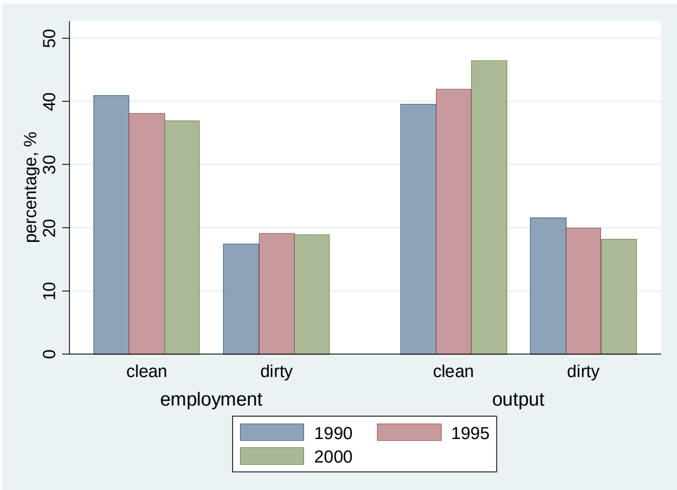
[1] See table A1 in the Appendix. The split into country groupings was done on the basis of GDP per capita (PPP). Countries from North America, High income Asia and Europe are classified to be high income countries.

Figure 1: Global trends (1990 = 100)



What are the sources of this global decline in the world average emission intensity? Three explanations are reviewed in the different panels of figure 2. A first possibility would be a structural change towards cleaner products in manufacturing, as factors of production are reallocated from 'dirty' to 'clean' products.[2] Figure 2(a) shows indeed an increase in the output share of clean products and a decrease in the output share of dirty products. However, the trend is opposite regarding employment shares, casting doubt about the appropriateness of this explanation.

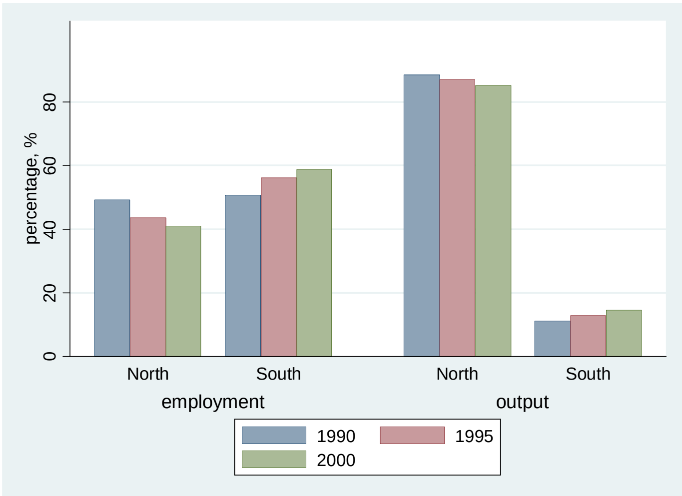
Figure 2(a): Employment and output shares for clean and dirty sectors



[2]Table A2 in the Appendix indicates clean and dirty sectors at the ISIC 3-digit level.

A second possibility would be that, contrarily to what is feared by environmentalists, production could have shifted towards cleaner countries. Splitting the sample into a 'North' and 'South' group in figure 2(b) gives amunitions to the environmentalists: the share of the South is rising, particularly for employment, which increases from 50% to almost 60% across the sample period. Thus the global shift towards cleaner countries seems even more inadequate than the previous one (although it remains to be confirmed that Southern countries are indeed dirtier, see below).

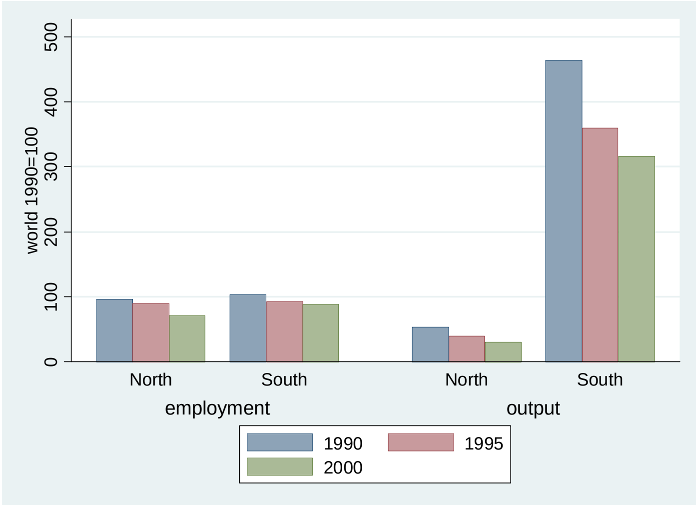
Figure 2(b): Employment and output shares for North and South



So we are left with the third explanation: a possible shift towards cleaner technologies. Figure 2(c) is consistent with this view, as it shows that average emission intensity (whether manufacturing activity is measured by output or labor) is declining for both North and South. Note also that the difference in levels between North and South is quite striking when intensity is measured in terms of emissions per unit of output, with emission intensity about five times higher in the South and the relative gap remaining roughly constant. However, when measured in terms of emissions per unit of labor, there is a virtual equality in the emission intensity.[3]

Figure 2(c): Emission intensities for North and South

[3] See Grether et al. (2007b) for more details on this observation.



This far, it appears that the major force behind the decline in manufacturing emissions has been technical progress, which seems to have affected both poor and rich countries alike. Moreover, this technique effect has been stronger than the scale effect, as global emissions have declined in spite of the increase in both indicators of manufacturing activity. However, one may rightly argue that an analysis based on two regions and the distinction between dirty and clean goods is just too crude to properly identify the (trade related) composition effects. Thus the need to perform the analysis at a more disaggregated level, which is what we describe in the next section.

3 Scale, Composition and Technique Effects

We first present simple decomposition formulas of the scale, technique and composition (across sectors and countries) effects identified in the literature.[4] This decomposition is then applied to our sample leading to estimates of the four effects and a classification of countries and sectors according to their relative importance in SO_2 emissions.

3.1 Emission-decomposition framework

We define emissions per unit of employment (rather than per unit output) to capture the scale effect by total employment (rather than total output). This should help us to minimize measurement error by avoiding the use of

[4] See for example Grossman and Krueger (1991).

price and real exchange rate deflators (except when we discuss the results of the decomposition by end use between exports and domestic use). Let then 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 (E) at the sector, country and global levels are given by:

$$E_{kit} = \gamma_{kit} L_{kit} \ ; \ \ E_{it} = \sum_k \gamma_{kit} L_{kit} \ ; \ \ E_t = \sum_k \sum_i \gamma_{kit} L_{kit} \tag{1}$$

For each country, national emissions can be decomposed into a scale (changes in manufacturing employment), composition (changes in the allocation of labor across sectors) and technique effect (changes in emission intensity per unit labor). The same decomposition carries across countries (adding another source of composition effect, across countries this time). To this end, world emissions (E_t) have first to be rewritten as the product of world manufacturing employment (L_t) times world average emission intensity, the latter being a weighted average across all countries:

$$E_t = L_t \sum_i \varphi_{it}^{L_t} \overline{\gamma}_{it}, \tag{2}$$

where $\varphi_{it}^{L_t}$ is the share of country i in world employment, $\varphi_{it}^{L_t} \equiv \frac{L_{it}}{L_t}$,[5] and $\overline{\gamma}_{it}$ is country i's average emission intensity, $\overline{\gamma}_{it} \equiv \frac{E_{it}}{L_{it}}$.

Using a "^" to denote percentage changes and neglecting interaction terms (which are uniformly allocated to main effects in the application), total logarithmic differentiation of (2) yields expression (3) 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 $\sum_i \varphi_{it}^{E_t} \left(\widehat{\overline{\gamma}_{it}} \right)$

$$\widehat{E}_t = \widehat{L}_t + \sum_i \varphi_{it}^{E_t} \left(\widehat{\varphi_{it}^{L_t}} \right) + \sum_i \varphi_{it}^{E_t} \left(\widehat{\overline{\gamma}_{it}} \right), \tag{3}$$

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. $\overline{\gamma}_{it} = \sum_k \varphi_{kit}^{L_{it}} \gamma_{kit}$ ($\varphi_{kit}^{L_{it}} = \frac{L_{kit}}{L_{it}}$).

[5] The following notational convention is used: $\varphi_v^{Z_w}$ 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, $\varphi_{it}^{L_t} \equiv \frac{L_{it}}{L_t}$, or $\varphi_{it}^{E_t}$ is the share of country i in global emissions, $\varphi_{it}^{E_t} \equiv \frac{E_{it}}{E_t}$.

Thus, the third term in expression (3) can be decomposed further, leading to the final expression:

$$\widehat{E_t} = \widehat{L}_t + \sum_i \varphi_{it}^{E_t} \left(\widehat{\varphi_{it}^{L_t}}\right) + \sum_k \sum_i \varphi_{kit}^{E_t} \left(\widehat{\varphi_{kit}^{L_{it}}}\right) + \sum_k \sum_i \varphi_{kit}^{E_t} \left(\widehat{\gamma_{kit}}\right) \quad (4)$$

In expression (4), the third term on the RHS represents the *between-sector* effect and the fourth the *technique* effect. Below, we present results of this decomposition first for the data at the national level used by previous authors (i.e. equation (3)), then for the disaggregated manufacturing data assembled here (i.e. equation (4)).

3.2 Growth decomposition estimates

The decomposition uses the data of Nicita and Olarreaga (2007) for trade, output and employment at the ISIC 3-digit level. For reasons explained in detail in Grether et al. (2007b) we report here estimates based on the Emission Database for Global Atmospheric Research (henceforth 'EDGAR') data set compiled by Olivier and Berdowski (2001) for each one of the six main manufacturing polluting sectors (all remaining manufacturing activities are grouped in a seventh "clean" sector).[6] 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. Grether et al. (2007b) explains how fossil fuel consumption is attributed to our manufacturing sectors and why finally, the data is made consistent with the aggregate results obtained by Stern (2005) over the 1990-2000 period by proportional scaling.

Before turning to the sectoral decomposition, table 1 applies the decomposition from equation (3) to the aggregate data and time periods used by Cole and Elliott (2003) and Stern (2005).[7] In this table, the within-country effect lumps together the between-sector and technique effects. All decompositions are in broad agreement showing a reduction in emissions, and the

[6] See Appendix table A3 for a correspondence between the EDGAR and ISIC-3digit classification.

[7] We tried without success to apply this decomposition to Antweiler et al. (2001), but failed. First, one cannot add up concentrations. Second, we failed to convert these concentration data into emission data because the link between the two is complex and data demanding (see for an example Schichtel (1996)). Indeed, when we used the method proposed by Giannitrapani et al. (2006) to recover emission data from the concentration data, the regression lacked explanatory power.

results are very close when there is period (1980-90) and sector overlap. This is because the sample used by Cole and Elliott (2003) includes all the major emitters present in Stern's sample. Comparing our results with those in Stern (2005) over the period 1990-2000 indicates larger differences. This is because Stern's economy-wide estimates capture the Engel-related shift of activities from manufacturing to largely non-polluting service activities.

Table 1: Comparison of SO_2 decomposition across studies

Data Set	Period	Number of countries	Sector [3]	Scale effect	Between country effect	Within country effect	Total effect [2]
This study	*1990-2000*	*62*	*Manufacturing*	*9.51*	*-2.36*	*-17.00*	*-9.85*
Cole and Elliott (2003)	1980-1990	26	Economy-wide	21.7	-6.64	-16.71	-1.65
	1975-1990			33.6	-9.93	-24.87	-1.25
Stern (2005)	1960-1970	146	Economy-wide	20.79	-4.73	15.43	31.49
	1970-1980			23.13	-6.48	-7.82	8.83
	1980-1990			22.28	-6.74	-17.06	-1.52
	1990-2000	144		15.47	-3.86	-33.52	-21.92
	1960-2000			89.50	-19.36	-60.45	9.68

Notes:
[1] See equation (3) for decomposition formula. All effects are expressed in percentage points.
[2] Total effect = scale effect + between country effect + within country effect.
[3] This study is restricted to manufacturing-related emissions while the other studies contain total anthropogenic emissions (coming from manufacturing, transport, heating, ...).

Two further comments are in order. First, apart from the 1960-1970 period, all studies reflect negative between-country and within-country effects that help mitigate the impact of the strong scale effect. This suggests that the composition effects brought up by trade throughout the period have not been so devastating. One possible explanation is that pollution-generating activities being largely weight-reducing, the scope for 'Pollution Haven' (PH) effects have been rather limited, resulting in quite effective pollution-reduction policies.[8] Second, the Stern data by decade indicate that the turning point regarding world sulfur emissions took place in the eighties and that the main driving factor behind this reversal is the within-country effect, which becomes negative in the seventies and ever stronger since then. This may hide both a shift towards cleaner activities and the adoption of cleaner techniques, which we now try to disentangle.

[8] Based on a gravity model, Grether and de Melo (2004) provide evidence that 'dirty' industries have higher transport costs than 'clean' industries.

Application of equation (4) in the first line of table 2 shows that the large within-country effect (17%) contributing to a decline in emissions identified before mainly works through the technique effect which reduced emissions by 14% over the 1990-2000 period. This suggests a substantial greening of production technologies throughout the period. More generally, the trends identified by this decomposition, with all effects negative but for the scale effect, are difficult to reconcile with a "PH view" of the world. If PH effects were prevalent, one would expect a global shift of manufacturing labor towards dirtier countries and dirtier activities (as labor productivity tends to be smaller in dirty countries), and little incentives to adopt cleaner technologies.[9]

Table 2: Scale, composition and technique effects

	Shares in 1990			Decomposition of total effect			
	Labour share	Emission share	Total effect	Scale	Between country	Between sector	Technique
Total Effect [a]	100	100	-9.85	9.55	-2.44	-3.03	-13.94
Decomposition by end use							
Domestic use	79.40	77.38	-19.17	-12.61	-1.86	11.88	-16.57
Exports	20.60	22.62	22.00	80.80	-19.66	-32.57	-6.57

Notes: [a] Slight differences in results with those in table 1 come from the inclusion of one additional interaction term. The total effect is a weighted average of the different end use effects where emission shares are used as weights.

The small significance of PH effects is confirmed when the decomposition is carried separately for exports and for domestic use (bottom part of table 2).[10] Exports, which accounted for 22% of emissions in 1990, contributed significantly both to the growth in emissions because of the increasing share of trade in manufacturing (80%) but also to the decline in emissions through the composition effects (between country and between sector). This pattern confirms that export growth was concentrated in "other" (i.e. in clean) sectors. Here again, if PH forces were strong, the between-sector effect would be negative for domestic use and positive for exports, the opposite of the observed pattern.

[9] Note that if the same decomposition is applied to the initial EDGAR data (i.e. in the absence of the above-mentioned proportional scaling of emission intensities), one obtains positive technique and total effects, altough the between country and the between sector effects remain virtually unchanged (for more details, see Grether et al (2007b)).

[10] Labor is allocated by end use in proportion of output. In table 2, the total effect of the first line is equal to the emission-weighted average of the total effects of the second and third lines, but this property does not extend to the other effects.

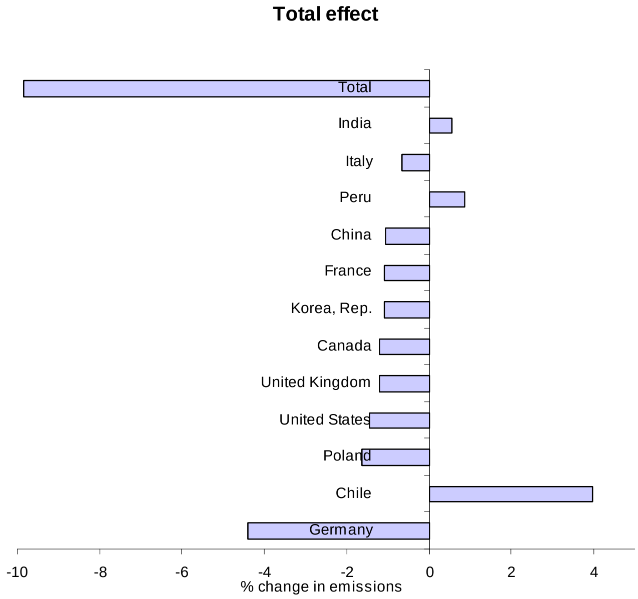
These aggregate results are based on summing the elements of equation (4) over 62 countries and 7 sectors (434 combinations). Hence it is natural to identify influential countries and sectors by grouping together the relevant combinations.[11] Figure 3 ranks the countries (figure 3a) and activities (3b) that account for the bulk of the change in emissions. We concentrate here on absolute effects to isolate the combinations of sectors and countries that have experienced the largest (be it positive or negative) structural change in SO_2 emissions. Figure 3a lists 12 countries that account for three quarters of the cumulative effects. Except for Chile, Peru and India, all show a decline in emissions. The right-hand side carries out the same decomposition as in table 2. We find negative technique effects for all countries but for the three mentioned above and also large technique effects for China (-10%) and Germany (-3.3%).[12] Figure 3b reports the ranking for the 6 dirty industries and the residual "clean" sector. Looking at the net contribution to the decline in emissions, the leading sectors are petroleum and coal products, followed by chemicals and iron and steel, with most of the contribution to the decline coming from the adoption of cleaner technologies. Non-ferrous metals stands out as the only sector with a strong net growth in emissions.

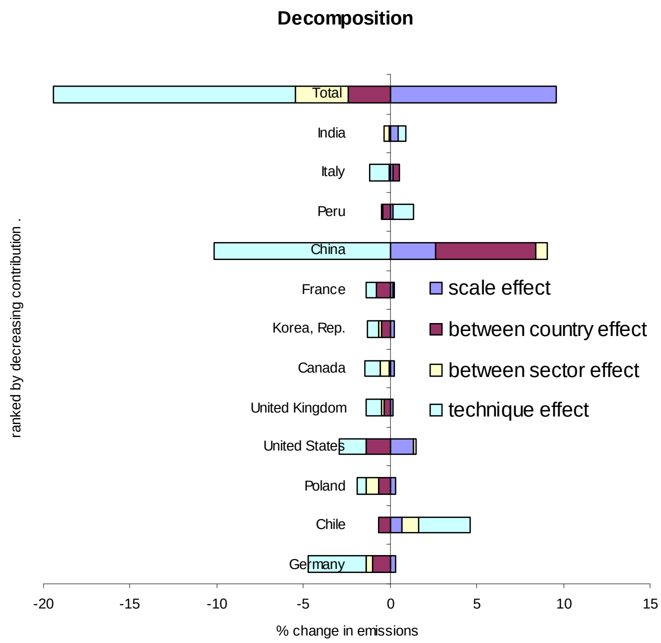
[11] Detailed results are reported in tables A4 and A5 in the Appendix. Note that in these tables, only the between-sector and technique effects are really observation specific.

[12] These estimated magnitudes for China should be interpreted with caution, since the emission totals are computed from official statistics which are believed to exaggerate the reduction in intensities (see Stern (2005), p. 170, for a discussion of differences in estimates across sources).

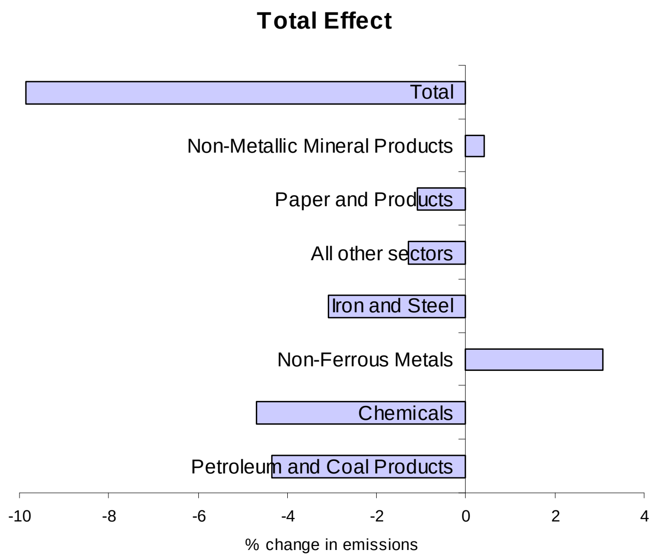
Figure 3: Growth decomposition by country and sector

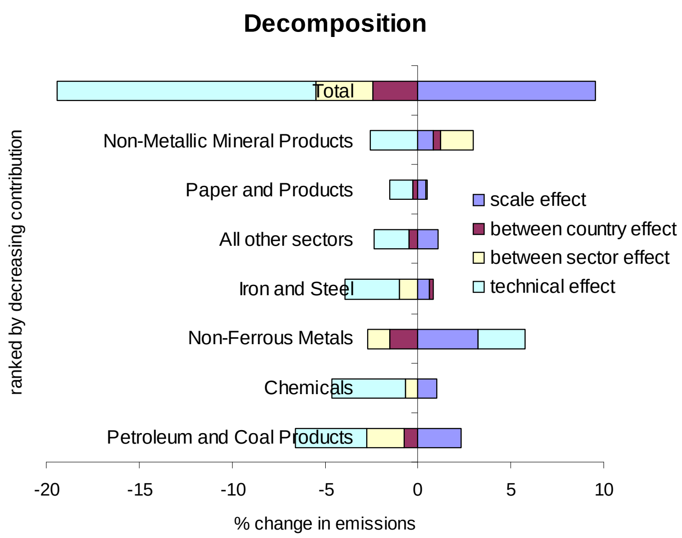
3a) Contribution of each country to total effect (ranked by decreasing absolute total effect, based on table A4 in the Appendix)





3b) Contribution of each sector to total (ranked by decreasing absolute total effect, based on table A5 in the Appendix)





These findings are broadly confirmed when the results are reported at the most disaggregated level (see table A6 in the Appendix which presents the 20 country-sector combinations with the largest absolute contribution). Among the influential commodity-country combinations, Chile and Peru stand out with a positive rather than negative technique effects for their copper smelting activities.[13] Non-ferrous metals is also the most influential sector in China.

Summing up main results, we find overall small negative composition effects, large technique and scale effects going in opposite direction and some influential countries (e.g. Chile and China) and sectors (e.g. non ferrous metals). Broadly speaking, the PH hypothesis is not consistent with the observed composition effects, suggesting that over the 1990-2000 period, the observed changes have been driven by other types of trade determinants.

4 How Much Does Trade Matter?

The decomposition of emissions by end use shows a growing role of trade in SO_2 emissions, even if the growth in trade was oriented towards clean industries. This of course does not tell the contribution of trade to emissions since in the absence of trade, emissions would have occurred anyway, but with a different pattern across sectors and countries. We now set up a simple no-trade benchmark to obtain an estimate of what trade might have contributed to emissions. To these estimates we add a back-of-the-envelope calculation of emissions coming from transport activities associated with international trade.

4.1 A no-trade benchmark

We define a simple no-trade benchmark by assuming that each country produces now what it was importing under the (observed) trade equilibrium.[14] This line of reasoning abstracts from resource constraints or price effects in order to focus on the interaction between trade patterns and emission intensity differences. If the cleanest countries tend to be the largest importers of dirty goods, then trade will tend to increase global emissions, by shifting dirty production towards dirty countries, much along the lines of the PH argument. However, this very direct estimate should be taken

[13] Although Olivier et al. (2002) indicate that SO_2 emission for non-ferrous metals have a large uncertainty estimate, it is clear that this sector is an important contributor to SO_2 emissions and that Chile is the world's largest producer (see for example Anthony et al., 2004). Miketa and Mulder (2005) have shown that this sector is also the only one where energy productivity divergence has been observed, while Newbold (2006) stresses recent efforts to implement environmental systems, leaving hope for a negative technique effect after 2000.

[14] In the calculations, whenever the trading partner was not part of the closed sample, we have substracted exports and added imports from the sample countries' production.

with a grain of salt, since the great bulk of trade in dirty products comes from natural-resource-based products, which, by definition are not subject to comparative advantage, and could not be produced under the constructed no-trade counterfactual (could France produce its observed consumption of copper products?). In sum, this simple approach provides, at best, suggestive first-order effects that would have to be extended by building a no-trade anti-monde using general equilibrium techniques (see also Antweiler (1996) for the inclusion of intput-output relationships in a similar context).

Take then sector k in country i year t, and denote local production by Q_{kit}, domestic (so-called 'apparent') 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, will not hold for emissions to the extent that imports (and thus part of consumption) are produced with a different technology. To estimate ΔE_t, the change in production-embodied emissions, generated by a shift from the autarkic to the trade situation, we compute 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 change in emissions at the sector level becomes:

$$\Delta E_{kit} = g_{kit}Q_{kit} - g_{kit}C_{kit} = g_{kit}(X_{kit} - M_{kit}) \tag{5}$$

which means that the change in emissions generated by trade is just equal to the trade balance times the corresponding domestic intensity coefficient. Aggregating across sectors:

$$\Delta E_{it} = \overline{g}_{it}^{X} X_{it} - \overline{g}_{it}^{M} M_{it} \tag{6}$$

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 $Z = X, M, Q$). To bring out the role of trade, it is convenient to also aggregate (5) across countries. Straightforward manipulations lead to the following expression for the change in world emissions for sector k:

$$\Delta E_{kt} = M_{kt} n \sigma_{kt} \tag{7}$$

where M_{kt} is world imports (or exports) 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 expression shows that, apart from the role of scaling factors (n,M,g), 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 (PH) view, so we name this covariance term the *pollution-haven covariance*.

We can now aggregate either (6) or (7) 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, $E_t = \overline{g}_t^C C_t$, where C_t is apparent consumption and $\overline{g}_t^C$ is the world average pollution intensity, $\overline{g}_t^C = \sum_k \sum_i \varphi_{kit}^{C_t} g_{kit}$. This leads to the following expressions:

$$\frac{\Delta E_t}{E_t} = \frac{\sum_i \Delta E_{it}}{E_t} = \frac{X_t}{C_t} \frac{\left[\overline{g}_t^X - \overline{g}_t^M\right]}{\overline{g}_t^C} \quad (8a)$$

$$\frac{\Delta E_t}{E_t} = \frac{\sum_k \Delta E_{kt}}{E_t} = \frac{X_t}{C_t} \frac{n\overline{\sigma}_t}{\overline{g}_t^C} \quad (8b)$$

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 fact that trade exacerbates emissions when the largest importers of the most polluting products are also the cleanest producers. Both expressions also show that the impact of trade on world emissions corresponds to the product between an average trade openness ratio ($\frac{X_t}{C_t}$) and a PH ratio (either $\overline{g}_t^X - \overline{g}_t^M$ or $n\overline{\sigma}_t$ divided by $\overline{g}_t^C$). But while (8a) is helpful to identify those countries with the largest contribution to the overall change, (8b) is more convenient to identify the sectors that play the most important role.

4.2 Counterfactual estimates

Table 3 summarizes results of this simple counterfactual applied to 1990 and 2000. As shown in the first line of the table, under this scenario where apparent consumption is replaced by observed production, opening up to trade leads to an increase of roughly 10% in emissions in 1990. Interestingly, the corresponding estimate for 2000 shows a much smaller increase of 3.5%. On the one hand, subject to the caveat that much of trade in pollution-intensive products is natural-resource-based trade as mentioned earlier, this supports the PH view. Indeed, the average PH covariance is positive whatever the year, which means, in a static sense, that the largest net exporters tend to be the dirtiest producers. However, on the other hand, and perhaps more importantly, the results also show that the PH pattern has been almost vanishing over time. The decrease in the PH ratio, by more than 75% over 10 years, is particularly dramatic, and even more so when one takes into account the decrease by more than 25% of the average pollution intensity (which appears at the denominator of the PH ratio).

Table 3: Impact of trade on world emissions and its decomposition

	Formula [a]	Effect	1990	2000	% change
(a)*(b)	$\frac{\Delta E_t}{E_t}$	**Total emission change**	**9.75%**	**3.35%**	**-66**
(a)	$\frac{X_t}{C_t}$	Trade openness ratio	0.20	0.29	+46
(b)=(c)/(d)	$\frac{n\overline{\sigma}_t}{\overline{g}_t^C}$	Pollution Haven ratio	0.49	0.12	-77
(c)=(e)-(f) [b]	$n\overline{\sigma}_t$	Pollution Haven covariance	1.52	0.26	-83
(d) [b]	$\overline{g}_t^C$	Average pollution intensity	3.12	2.28	-27
(e) [b]	$\overline{g}_t^X$	Average export pollution intensity	4.76	2.72	-43
(f) [b]	$\overline{g}_t^M$	Average import pollution intensity	3.24	2.46	-24

Notes: [a] see equations (8a) and (8b) in the text, [b] expressed in g/USD.

In other words, these results suggest that during the 90s, there has been both a general shift towards cleaner technologies and a relative shift of dirty production towards cleaner countries that strongly reduced the PH pattern that characterized the beginning of the period. As a result, at the end of the period, even if trade intensity has increased, the PH-bias has been so much reduced that the net contribution of trade to global emissions has been reduced by two-thirds.

As in the previous section, disaggregated results help to identify the largest contributors to these overall effects. When the contribution is positive, it is of the "pollution haven" type, while it is of the "green-haven" type when the contribution is negative. Regarding countries first, the most preeminent pollution havens in both periods are Chile, South Africa and Peru, while China is a green haven and Indonesia switches from pollution haven in 1990 to green haven in 2000. Regarding sectors, the most influential ones are non-ferrous metals, a strong pollution haven contributor in both periods, and petroleum and coal products, which switches from pollution to green haven over the sample period (the signs reversals are the driving factors behind the decrease in the PH pattern described above; for more details see tables A7, A8 and A9 in the Appendix).

4.3 Transport-related emissions

A discussion of the role of trade on emissions would be incomplete if transport-related emissions were not factored in. We provide back-of-the-envelope calculations based on estimates of average SO_2 emissions per tonne-km (tkm) shipped applied to international shipments in 1990 and 2000. As illustrated by the upper part of table 4, our calculations of the average transport emission intensity are based on three transport modes (rail, road and ships), and on a range of estimates to account for the diversity of available sources.

Table 4: Emissions from international shipments

A. Transport Mode		**SO_2 Emission coefficient [g/tkm] Lower**	**SO_2 Emission coefficient [g/tkm] Upper**	**Share in world shipments (% of tkm)**
Rail[a]		0.07	0.18	12
Road[a]		0.10	0.43	14
Ship[b]		0.19	0.52	74
				100
Average emission coefficient [g/tkm]		0.16	0.47	
B. Shipments [c]		**1990**	**2000**	
Shipment volume (billion tonnes)		0.37	0.46	
Shipment (trillion tkm)		1.68	1.40	
Shipment value (trillion current USD)		2.22	4.31	
C. Transport related emissions [%] [d]	Lower	1.43	1.32	
	Upper	4.19	3.85	
	Average	**2.81**	**2.58**	
Trade-related emissions[%] [e]		9.75	3.35	

Note:
[a] from OECD (1995)
[b] Network of Transport and Environment (NTM calc, 2003)
[c] Distance data comes from cepii (2006), mode shares for 1995 from the EC (1999)
[d] % of world wide production-related emissions
[e] reports first line of table 3

The middle part of table 4 is devoted to international shipment estimates.[15] Results show an increase in tonnage and value but a fall in tkm tonnage. This decline reflects surely a combination of factors ranging from the effects or preferential trade agreements (e.g. NAFTA and the extension of the EU to the East) to the more general phenomenon of cost-minimization in trade leading producers to select trade destinations with lower transport costs (see Carrère and Schiff (2005) for more disaggregated times-series evidence). The fall in tkm translates into a similar decrease in transport-related emissions. As a result, the share of transport-related emissions in total production-related emissions slightly decreases over the period (see bottom part of table 4). Taking the average estimates, international trade-related transport emissions have accounted for about 3% of world wide manufacturing-related production emissions of SO_2. Comparing these figures with those of table 3 suggests that transport-related emissions have gone from accounting for nearly one third to close to 80% of trade-related emissions across the 1990-2000 period.

5 How Environmentally Friendly is the Global Allocation of Production?

Ultimately, we would also like to know whether the present global allocation of production is environmentally friendly or not. Subject to the uncertainty on the precision of emission coefficients, γ_{kit}, we carry out a final exercise 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:

$$\begin{aligned} \underset{L_{kit}}{Min}\left(\underset{L_{kit}}{Max}\right)E_t &= \sum_k \sum_i \gamma_{kit} L_{kit} \\ s.t.\ \overline{L}_{it} &= \sum_k L_{kit} \ \ \forall\ i = 1, ..., 62 \\ \overline{Q}_{kt} &= \sum_i \ell_{kit} L_{kit} \ \ \forall\ k = 1, ..., 7 \end{aligned} \tag{9}$$

[15] Note that international distance between the most important agglomerations has been corrected by the average distance between producers and consumers for each country. This takes into account the fact that, if there were no trade, goods would be shipped anyway within each country from producers to consumers.

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.

Table 5 : Two simulations of world-wide SO_2 emissions, 1990-2000

Period	Minimal emissions (Tg)		Effective emissions (Tg)		Maximal emissions (Tg)
1990	7.55	← -80%	37.73	828% →	350.13
2000	5.30	← -84%	34.01	794% →	304.05

Results in table 5 suggest that we could have reduced world-wide emissions in both periods considered by 80% if dirty production was assigned to the lowest emission producers. Likewise, under the opposite scenario, global emissions would have increased by roughly 800% if dirty production was assigned to the highest emission producers. This is a huge range of potential emission levels reflecting the disparities in emission intensities across the world, with maximum emissions 46 (58) times larger than minimum emissions 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 hardly changes. 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.

6 Conclusions

Combining data from different sources to obtain country, sector and year specific pollution coefficients and 'taking the data seriously', this paper decomposes world-wide SO_2 emissions directly into the well-known scale, composition and technique effects for the period 1990-2000. The decomposition exercise highlights the drivers of the decline in SO_2 emissions over the period. First, the increase in emissions associated with the increase in manufacturing activities is roughly compensated by a decline in (per unit of labor) emissions due to the adoption of cleaner production techniques. Second, about one-fifth of what was previously attributable to a within-country effect (i.e. when sector-level data were not available) is due to a shift towards cleaner industries (the rest corresponding to the technique effect). Third, the different decompositions suggest that "Pollution-haven" effects, that have been the subject of debate in the trade and environment literature, have only had a limited impact.

We then extend these decomposition-based estimates in two directions. First, we build a simple no-trade benchmark to get a first-order estimate of trade-related emissions. Compared to the constructed autarky benchmark, international trade increased emissions by 10% in 1990, but only by 3.5% in 2000. Thus large net importers tend to be clean countries in 1990 but this pollution-haven pattern looses its importance over time. Since trade, by promoting growth, would also increase emissions, these first order effects may represent a lower bound. Adding back-of-the-envelope estimates of emissions related to transport activities suggest that these would have stayed constant over the period because of a shift towards trade in ligther products and that by the end of the period transport-related emissions could be almost as important as trade-related emissions.

Second, we construct two worldwide benchmark emission levels which would be achieved if within each country, labor were allocated to minimize or maximize world emissions. Comparing 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.

Clearly, these estimates ought to be refined in a variety of directions. Although particular care has been given to the use of disaggregated data for the largest panel of countries, the correspondence between trade and production categories is only approximate, the number of dirty sectors limited to six and countries constituting the former USSR are out of the sample. Improvements on these fronts are desirable but conditioned by data availability. Then one could seek out improvements on the methodological side. Our first-order estimates do not control for price effects, input-output relationships or the endogeneity of trade and environmental policies, all of which are probably of practical importance. However, taking duly into account those factors would require a multi-country general equilibrium setting which is out of the scope of the present paper.

Although perfectible, the orders of magnitude established above deserve interest *per se*. They help to weigh the relative importance of the scale effect *vis-à-vis* the other effects, which work in the opposite direction and are often neglected in the public debate. The by-sector and by-country estimates could be used to identify "pollution havens" vs. "green havens", or to guide policy-making targeting at reducing SO_2 emissions via Pigovian taxation (i.e. maximizing emission-reductions per unit of taxation). Finally the very large range of estimates regarding the emission spectrum suggests that emission intensities across countries vary considerably for a given sector. Although partly attributable to data limitations, this result calls for further investigation and brings some hope regarding the potential gains from future reductions in emissions.

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Appendix to
Trade, Technique and Composition Effects: What is Behind the Fall in World-Wide SO2 Emissions 1990-2000?

by Jean-Marie Grether, Nicole A. Mathys, Jaime de Melo

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 (Hettige et al., 1995) shares in emissions, see Grether et al (2007b) for further details.
Source: Edgar 3.2 (Olivier et Berdowski, 2001).

Table A4: Growth decomposition by country

Country	Total effect			Decomposition of total effect			
	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: Net	% of gross total [a]	Cumul.% of gross total [a]	Decomposition of total effect: 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: Net	% of gross total [a]	Cumul.% of gross total [a]	Decomposition of total effect: 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 effects

Table A6: Growth decomposition by country and sector

Country	Sector	Total Effect			Decomposition of total effect			
		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 effect

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

Country	Emission intensities [a] (g/USD)		Shares (%) [b]		Changes in emissions with respect to autarky [c]	
	Exports	Imports	Exports	Imports	Level (Gg)	Share in autarky emissions (%)
Chile	231.3	8.74	0.25	0.24	1258.6	3.59
South Africa	101.42	n.a.	0.45	0.00	1010.22	2.88
Indonesia	148.52	51.78	0.47	0.79	655.02	1.87
Canada	5.72	2.18	4.37	4.48	338.68	0.97
Peru	118.18	6	0.11	0.09	271.42	0.77
Australia	16.16	2.24	0.87	1.51	237.66	0.68
Poland	41.3	61.94	0.29	0.04	204.22	0.58
Korea, Rep.	2.7	6.76	2.29	2.26	-201.42	-0.57
Kuwait	61.78	5.8	0.13	0.09	161.14	0.46
Venezuela	28.94	3.78	0.29	0.31	160.56	0.46
China	11.42	18.56	2.90	2.14	-147.04	-0.42
Brazil	9.66	6.38	1.08	0.61	145.76	0.42
United States	1.46	1.42	13.68	17.50	-105.92	-0.30
Italy	1.06	1.84	5.52	5.52	-96	-0.27
Pakistan	5.24	20.76	0.15	0.24	-92.88	-0.26
Germany	1.6	2.22	12.97	11.15	-88.98	-0.25
Spain	4.42	4.16	1.81	2.87	-87.84	-0.25
Philippines	26	10.64	0.30	0.37	85.06	0.24
Turkey	11.5	11.6	0.26	0.56	-79.9	-0.23
Netherlands	2.8	2.38	4.54	4.10	65.28	0.19
Hong Kong, China	0.6	1.18	1.74	3.31	-63.58	-0.18
France	1.38	1.6	6.94	7.62	-58.06	-0.17
Belgium-Luxembourg	3.24	2.98	4.24	3.76	57.18	0.16
Denmark	2.56	4.48	1.10	1.08	-45	-0.13
Singapore	4.76	2.54	1.50	2.04	43.94	0.13
Taiwan, China	0.52	1.68	2.83	1.95	-40.24	-0.11
Hungary	7.78	n.a.	0.22	0.00	37.56	0.11
India	7	13.1	0.47	0.38	-35.72	-0.10
Portugal	2.9	3.8	0.53	0.82	-35.26	-0.10
Mexico	16.24	19.72	1.17	1.04	-33.38	-0.10
Finland	2.94	1.6	0.92	0.82	30.4	0.09
Malaysia	1.18	2.08	0.98	1.16	-28.2	-0.08
Tunesia	29.48	17.28	0.06	0.17	-24.42	-0.07
Greece	6.42	3.48	0.22	0.68	-20.66	-0.06
Japan	0.16	0.5	12.25	5.56	-18.5	-0.05
Argentina	4.16	3.1	0.33	0.20	16.54	0.05
Bangladesh	4.72	9.32	0.04	0.09	-14.9	-0.04
Sweden	0.94	0.76	2.17	1.84	13.68	0.04
Marocco	15.26	9.84	0.09	0.19	-10.52	-0.03
United Kingdom	1.96	1.58	5.53	7.17	-9.58	-0.03
Costa Rica	1.54	7.66	0.03	0.05	-7.32	-0.02
Egypt, Arab. Rep.	27.4	8.34	0.05	0.22	-6.88	-0.02
Israel	2.3	2.5	0.39	0.47	-6.34	-0.02
Norway	0.94	0.34	0.62	0.92	6.3	0.02
Cyprus	2.28	2.58	0.02	0.09	-4	-0.01
Honduras	3.72	7.86	0.01	0.02	-3.22	-0.01
Kenya	3.1	2.6	0.01	0.06	-2.98	-0.01
Uruguay	5.02	5.28	0.07	0.04	2.84	0.01
Iceland	5	3.74	0.02	0.06	-2.62	-0.01
Ireland	1.44	1.48	0.86	0.75	2.34	0.01
Jordan	7.6	3.58	0.02	0.06	-1.78	-0.01

Ecuador	13.7	4.2	0.02	0.08	-1.66	0.00
Senegal	2.22	2.8	0.01	0.04	-1.6	0.00
Austria	0.52	0.46	1.29	1.65	-1.52	0.00
Mauritius	0.46	1.62	0.03	0.05	-1.4	0.00
Colombia	13.32	6.08	0.08	0.19	-0.8	0.00
Panama	1.9	2.7	0.06	0.03	0.78	0.00
Bolivia	1.54	1.7	0.01	0.03	-0.7	0.00
Malawi	0.9	1.04	0.00	0.02	-0.44	0.00
Nepal	0.04	0.58	0.01	0.02	-0.2	0.00
New Zealand	1.86	1.6	0.30	0.35	0.18	0.00
Macao	0.06	0.16	0.05	0.06	-0.14	0.00
Total	**4.76**	**3.22**	**100.00**	**100.00**	3423.7	**9.76**

Notes: [a] Average emission intensities by country and trade flow. [b] Country share in world imports or exports. [c] Change in national emission levels when going from autarky to free trade. The change in emissions corresponds to the emissions trade balance, expressed in equations (6) and (8a) in section 4 of the paper.

Table A7(b): Impact of trade on total emissions, by country, 2000

	Emission intensities [a] (g/USD)		**Shares (%) [b]**		**Changes in emissions with respect to autarky [c]**	
Country	**Exports**	**Imports**	**Exports**	**Imports**	**Level (Gg)**	**Share in autarky emissions (%)**
Chile	222.76	12.44	0.26	0.28	2304.68	6.74
Indonesia	33.96	107.96	0.83	0.50	-1107.92	-3.24
South Africa	55.22	4.44	0.47	0.41	1044.18	3.06
Mexico	4.82	7.94	2.88	3.41	-569.26	-1.67
Peru	144.94	6.78	0.10	0.13	557.22	1.63
China	3.92	10.74	7.61	3.82	-482.38	-1.41
Australia	17.84	3.08	0.70	1.28	370.24	1.08
Honduras	8	197.28	0.06	0.04	-313.2	-0.92
United States	0.68	0.76	15.17	21.16	-255.66	-0.75
Canada	1.74	0.92	4.78	4.55	176.58	0.52
India	5.28	12.52	0.71	0.61	-168.58	-0.49
Korea, Rep.	1.24	3.04	3.24	2.24	-119.72	-0.35
Spain	2.64	2.82	2.00	2.75	-105.5	-0.31
Pakistan	4.54	20.24	0.16	0.14	-95.14	-0.28
Venezuela	11.8	2	0.22	0.30	84.3	0.25
Turkey	6.7	6.68	0.43	0.70	-76.78	-0.22
Portugal	3.26	4.1	0.48	0.75	-65.02	-0.19
Hong Kong, China	0.22	0.36	1.04	4.15	-54.7	-0.16
Greece	4.64	3.32	0.13	0.51	-47.04	-0.14
France	0.76	0.92	5.43	5.46	-41.18	-0.12
Poland	10.62	5.32	0.50	0.83	39.68	0.12
Italy	0.4	0.66	4.09	3.91	-38.62	-0.11
Philippines	4.8	5.64	0.87	0.60	33.32	0.10
Tunesia	13.9	12.94	0.10	0.16	-32.72	-0.10
Kuwait	9.8	4.16	0.12	0.12	32.16	0.09
Netherlands	1	0.86	3.34	3.01	31.78	0.09
Bolivia	2.5	16.78	0.01	0.04	-25.82	-0.08
Brazil	4.88	3.78	0.92	1.03	25.8	0.08
Ireland	0.62	0.46	1.60	0.99	23.02	0.07
Bangladesh	0.66	4.34	0.10	0.13	-22.08	-0.06
United Kingdom	0.66	0.46	4.90	6.03	20.36	0.06
Germany	0.42	0.48	9.99	7.87	19.74	0.06
Singapore	0.8	0.44	1.82	2.26	19.56	0.06

Finland	0.8	0.54	0.83	0.54	16.24	0.05
Argentina	3.04	1.62	0.34	0.47	11.8	0.03
Malaysia	0.7	1.18	2.09	1.45	-10.12	-0.03
Sweden	0.44	0.44	1.68	1.19	9.32	0.03
Belgium-Luxembourg	1	0.78	2.84	3.40	9.24	0.03
Taiwan, China	0.24	0.42	3.19	2.21	-7.46	-0.02
Egypt, Arab. Rep.	13.62	5.48	0.07	0.19	-6.18	-0.02
Cyprus	2	2.38	0.01	0.07	-5.98	-0.02
Panama	7.32	6.84	0.03	0.05	-5.96	-0.02
Jordan	4.14	3.04	0.01	0.06	-5.22	-0.02
Costa Rica	0.1	1	0.09	0.12	-4.6	-0.01
Marocco	7.52	5.46	0.11	0.17	-4.3	-0.01
Japan	0.14	0.26	9.80	5.11	4.24	0.01
New Zealand	1.14	1.34	0.24	0.27	-3.96	-0.01
Senegal	3.36	4	0.01	0.02	-3.48	-0.01
Kenya	1.78	1.58	0.01	0.05	-2.9	-0.01
Ecuador	11.46	5.52	0.03	0.08	-2.42	-0.01
Mauritius	0.42	1.68	0.03	0.04	-2.34	-0.01
Uruguay	1.26	1.54	0.04	0.06	-1.68	0.00
Denmark	0.16	0.18	0.75	0.84	-1.64	0.00
Norway	0.18	0.06	0.41	0.67	1.32	0.00
Austria	0.2	0.18	1.01	1.24	-1.16	0.00
Iceland	4.48	1.58	0.02	0.05	1.06	0.00
Hungary	0.38	0.4	0.55	0.58	-0.86	0.00
Colombia	5.88	3	0.11	0.23	-0.86	0.00
Nepal	1.12	n.a.	0.01	0.00	0.68	0.00
Malawi	0.98	1.26	0.00	0.01	-0.54	0.00
Israel	1.36	1.3	0.58	0.60	0.48	0.00
Macao	0.08	0.14	0.04	0.04	-0.12	0.00
Total	2.72	2.44	**100.00**	**100.00**	1143.88	**3.35**

Notes: [a] Average emission intensities by country and trade flow. [b] Country share in world imports or exports. [c] Change in national emission levels when going from autarky to free trade. The change in emissions corresponds to the emissions trade balance, expressed in equations (6) and (8a) in section 4 of the paper.

Table A8(a): Impact of trade on total emissions, by sector 1990

Sector	**Covariance [a]**	**Import Shares**	**Changes in emissions with respect to autarky [b]: Level (Gg)**	**Changes in emissions with respect to autarky [b]: Share in autarky emissions (%)**
Petroleum and Coal Products	0.22	2.77	911.3	2.60
Iron and Steel	-0.02	4.01	-135.78	-0.39
Non-Ferrous Metals	0.60	3.49	2904.02	8.28
Chemicals	-0.02	11.36	-320.64	-0.91
Other Non-Metallic Mineral Products	0.02	0.84	26.02	0.07
Paper and Products	0.00	3.16	34.88	0.10
All Other Sectors	0.00	74.38	3.9	0.01
Total		100.00	3423.7	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 (7) and (8b).

Table A8(b): Impact of trade on total emissions, by sector 2000

Sector	Covariance [a]	Import Shares	Changes in emissions with respect to autarky [b] Level (Gg)	Share in autarky emissions (%)
Petroleum and Coal Products	-0.30	2.26	-1889.26	-5.53
Iron and Steel	-0.02	2.55	-74.48	-0.22
Non-Ferrous Metals	0.52	2.48	3472	10.16
Chemicals	-0.02	11.71	-525.62	-1.54
Other Non-Metallic Mineral Products	0.04	0.64	74	0.22
Paper and Products	0.00	2.37	-23.92	-0.07
All Other Sectors	0.00	77.98	111.2	0.33
Total		100.00	1143.88	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 (7) and (8b).

Table A9: Percentage changes in total emissions when opening up to trade with respect to autarky

Country	Sector	Share in autarky emissions (%) 1990	2000
Chile	**Non-Ferrous Metals**	3.63	6.86
Indonesia	**Petroleum and Coal Products**	1.91	-3.38
South Africa	**Non-Ferrous Metals**	2.74	3.04
Peru	**Non-Ferrous Metals**	0.78	1.67
Australia	**Non-Ferrous Metals**	0.76	1.18
Mexico	**Petroleum and Coal Products**	-0.41	-0.99
China	**Chemicals**	-0.46	-0.67
Korea	**Non-Ferrous Metals**	-0.52	-0.42
Canada	**Non-Ferrous Metals**	0.62	0.31
Mexico	**Non-Ferrous Metals**	0.32	-0.62
Poland	**Non-Ferrous Metals**	0.53	0.25
Venezuela	**Petroleum and Coal Products**	0.48	0.27
China	**All other Sectors**	0.21	0.74
Kuwait	**Petroleum and Coal Products**	0.49	0.13
Canada	**Paper and Products**	0.33	0.18
USA	**Petroleum and Coal Products**	-0.16	-0.34
Spain	**Non-Ferrous Metals**	-0.16	-0.23
China	**Iron and Steel**	-0.28	-0.17
Italy	**Non-Ferrous Metals**	-0.28	-0.13
China	**Petroleum and Coal Products**	0.13	-0.30
Sum over 20 most important shares		10.66	7.37
Residual Effect		-0.91	-4.03
Total Effect		**9.76**	**3.35**

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