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THE EFFECT OF GLOBAL TRADE LIBERALIZATION ON TOXIC EMISSIONS IN INDUSTRY

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COMMENTS WELCOME

ABSTRACT: Estimates of the output effects of the Uruguay Round and of a hypothetical subsequent agreement for free trade in manufactures are constructed using a computable-general-equilibrium model These estimates are combined with estimates of the toxic intensity of industrial activities to generate estimated changes in pollution associated with trade liberalization Liberalization reduces global pollution moderately, by eliminating overproduction in protected "dirty" activities, and by reallocating "dirty" production from developing to developed countries Parts of Asia, and the economies in transition, may become more polluted as a result of liberalization Improvements in emissions technology due to liberalization-induced income increases are estimated to be of second-order importance

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I. Introduction

In general, the effects of trade liberalization on environmental quality are ambiguous, moves toward free trade can either increase or reduce pollution [1] This can be seen in the simplest 2x2 model of trade under incomplete specialization. Suppose that good 1 is initially protected by a tariff, and that the tariff-ridden outputs of the two goods are Q_1 and Q_2 Further, let emissions of pollution per unit of output of each good be represented by a_1 and a_2 respectively Now remove the tariff, so that the free-trade outputs are $Q_1^* < Q_1$ and $Q_2^* > Q_2$ The change in pollution then amounts to

$$a_1 (Q_1^* - Q_1) + a_2 (Q_2^* - Q_2),$$

which is ambiguous in sign even if the ranking of a_1 and a_2 are known To assess the likely impact, it is necessary to know which of the goods is dirtier (and to what extent) and the elasticity of production of each good with respect to the tariff To know the latter requires knowledge, in turn, of the height of the protective barrier and the degree of substitution among goods Thus, the simultaneous consideration of trade policy and environmental policy takes on aspects of the classic problem of the second-best [2]

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[1] Explorations in the pure theory of international trade with environmental pollution date back at least to Walter (1975) See Anderson and Blackhurst (1992), Copeland and Taylor (1994, 1995), and Bhagwati and Srinivasan (1996) for more recent expositions

[2] Consideration of whether there are appropriate environmental policies in place does not resolve the ambiguity Even if the tradeoff between emissions and output is optimal in the tariff-ridden equilibrium, the same environmental policies are unlikely to be optimal in the free-trade equilibrium except under fairly restrictive assumptions

Although we cannot in principle know whether trade liberalization is likely to improve environmental quality, in practice one can make a case for the following propositions (1) trade liberalization might, in fact, improve environmental quality on balance, (2) such improvements are likely to be modest, and (3) not all regions will share equally in those improvements [3] The first conclusion arises from the stylized fact that many developing countries have historically protected heavy industries from imports, and these industries are relatively pollution-intensive Trade liberalization thus reallocates production from the South to the North, where better emissions-control technologies and tighter regulatory regimes are in place Furthermore, improvements in income due to trade liberalization may lead to greater political demand for environmental regulation and/or greater investments in clean technology. The second conclusion is due to the relationship between emissions and output Since the likely output effects of trade liberalization are usually estimated to be small, so too would be the likely pollution effects The final conclusion comes from the fact that *some* countries or regions in fact have a comparative advantage in the production of "dirty" products [4] Under free trade, these comparative advantages are expressed in increases in production, which, in the absence of any change in environmental policy, lead to increases in pollution

Of course, the above optimistic scenario may not hold if trade liberalization leads to increases in the production of most goods in most places The "scale effect" of liberalization-induced expansion of production tends in general to increase pollution. In principle, this effect

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[3] See Ferrantino (forthcoming) for a more detailed discussion

[4] Again, this is true whether or not some or all countries appropriately internalize the costs of environmental damage in market prices The argument should be understood to refer to the degree of comparative advantage under the *status quo* environmental regulatory regime, as reflected in regulation-inclusive market prices

can offset the "composition effect" of shifts from one industry to another and the "technology effect" of income-induced reductions in emissions per unit of output [5]

This paper presents estimates of the potential changes in toxic industrial emissions arising from two trade liberalization experiments conducted using a computable-general-equilibrium (CGE) model First, estimates of the output changes in specific sectors and regions arising from the Uruguay Round, and from a subsequent hypothetical "zero-for-zero" agreement to eliminate all tariffs in manufactures, are generated using standard CGE techniques These estimates are then matched with estimates of the toxic intensity of manufacturing arising from the widely used Toxic Release Inventory (TRI) of the U S Environmental Protection Agency to generate estimates of the changes in toxic emissions under the assumption that emissions coefficients are constant across regions This yields useful information about local emissions changes, since in any given country (e g) chemical production is likely to have higher emissions per unit output than apparel production for pure technological reasons However, the TRI is not directly very helpful in estimating global changes, since emissions coefficients likely vary widely across regions Unfortunately, there is very little data on the extent of this variation. Thus, estimates of the likely range of pollution coefficients at different levels of per capita income are generated based on estimates in Grossman and Krueger (1995), exploiting additional information on the variation of manufacturing output as a share of GDP with respect to per capita income. These estimates are, in turn, used to generate estimates of global pollution change as well as possible

[5] See Grossman and Krueger (1991), which brought the use of this terminology into widespread discourse and produced a pessimistic estimate of pollution increases under NAFTA due largely to scale effects

technology effects

The broad results confirm the intuition described above. Trade liberalization does tend to reduce pollution globally while increasing it in some regions Thus, beneficial composition effects turn out to outweigh scale effects, and technology effects are seen to be of second-order magnitude (subject to a caveat to be raised later) The results have several important limitations First, they apply only to toxic emissions from manufacturing and reveal nothing about other important environmental problems (such as deforestation, biodiversity, agricultural chemicals, and the effects of vehicle use) Second, the projections are based on varying emissions coefficients that, in turn, rely on heroic assumptions (although we do perform a sensitivity analysis and do some crude reality checking) Finally, the traditional criticisms of CGE model specification may be brought to bear Still, we consider the results sufficiently plausible to be of interest, particularly as there are relatively few studies of environmental problems in a general-equilibrium context [6]

II. Data on Toxic Intensity and Protection

The base year used to calibrate the model used in this research is 1992. Production, trade and protection data are from the Global Trade Analysis Project (GTAP) database.[7] The

[6] Though see Beghin et al (1995, 1996A, 1996B) on Mexico and Chile, and Tsigas (1994) on agricultural environmental issues under NAFTA

[7] For complete documentation, see McDougall (1997)

fully disaggregated database consists of 30 countries/regions and 37 production sectors The data are aggregated into 10 regions, with 25 traded-goods sectors for each region, and an aggregate services sector

Table 1 presents data on the ratio of toxic emissions to value output for various industrial sectors These are based on data reported in Hansen (1994), which are, in turn, based on the Toxic Release Inventory (TRI) of the U S. Environmental Protection Agency and are reported by six-digit sector of the U S input-output table These data reflect the total weight of toxic emissions to air, water, land, and offsite disposal as reported to the EPA, regardless of the substance being emitted The World Bank's Industrial Pollution Projection System (IPPS) has weighted the U S data by toxic intensity of specific compounds and established that toxic intensity-weighted emissions are very highly correlated with raw emissions Thus, little is lost by using the raw data as we do here [8] The coefficients in Table 1 have been aggregated to the sectors used in the CGE model described in Part III below. Negligible amounts of emissions reported in the TRI for some of the services sectors and for extraction of oil/natural gas are disregarded in our model Also, no emissions are associated with agricultural production

The TRI data have several well-known shortcomings. Reports are required for only a fraction of chemicals that may be toxic More importantly, company data systems are often not sufficiently sophisticated to successfully track emissions and related production, estimation techniques used by firms vary across firms and across time for the same firm (GAO 1994).

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[8] Lucas, Wheeler and Hettige (1994) The IPPS homepage, at http //www worldbank org/html/prdei/ippshome html, gives substantial detail on the IPPS data

Unfortunately, there is no readily available alternative. Some measure of comfort can be gained from the fact that measured toxic emissions by industry are highly correlated with pollution abatement and control expenditures as reported to the U S Department of Commerce (Lucas, Wheeler and Hettige 1992)

The highest toxic emissions coefficients for our model sectors are for (in descending order) non-ferrous metals, chemicals, rubber, and plastics, iron and steel, leather products, and pulp, paper, and printing For convenience we will refer to these five as the "dirty" industries, although emissions from all of the industries are used in the estimates below Thus, while (e g) the textiles industry is substantially cleaner than any of the five industries mentioned above, a trade liberalization which shifts resources from the dirty industries into textiles will not necessarily decrease pollution, pollution could increase if the textiles expansion is sufficiently large relative to the contraction in "dirty" industries

Table 2 describes the sectors used in the model aggregation For purposes of analysis, the "developed regions" consist of Australia, New Zealand and EFTA (ANE), Japan (JPN), North America (NAM), and the European Union (EU) Together these regions roughly approximate the old OECD The "developing regions" consist of. Korea,Singapore, and Taiwan (KST); Southeast Asia (SEA), China-Hong Kong (CHK), Latin America (LAM); the economies in transition (EIT); and the rest of the world (ROW).

Tables 3A and 3B describe the levels of protection for the most relevant sectors, the five "dirty" sectors, and textiles and apparel, which are relatively clean but also highly protected Levels of protection in the "dirty" sectors are particularly high in the developing regions For example, the average pre-Uruguay Round tariff for chemicals, rubber and plastics was 17 7% in SEA, 15 2% in CHK, 15 4% in LAM, and 26 3% in ROW, the poorest region. The comparable tariffs in the developed regions are 5.0% in NAM, 6 1% in the EU, 3 9% in JPN (plus a voluntary export restraint in the base data estimated to have a 5 0% tariff equivalent), and 6 5% in ANE The chemicals tariff in the KST region is at an intermediate value of 8 0% [9,10] The pattern in other dirty industries is similar, and the Uruguay Round provided relatively little liberalization in these industries Thus, on balance, total tariff elimination in these industries would be expected to shift output from the developing to the developed regions.

In textiles and apparel, the developing.countries also report substantially higher tariffs than the developed countries Most countries protect textiles and apparel more heavily than other manufacturing sectors Trade in textiles and apparel has also been heavily influenced by the Multi-Fiber Arrangement (MFA), under which most developed countries have imposed country- and product-specific quotas. The tariff equivalents of these quotas appearing in the base data are reported in Table 3B [11] Technically, the MFA quotas are modeled as export

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[9] The reported ad valorem tariffs represent import-weighted regional averages and consequently mask existing cross-country differences within a given region For example, the average tariff reported for China/Hong Kong represents a weighted average between the zero Hong Kong tariff and the much higher Chinese tariff. Moreover, the usual caveats regarding import-weighted averages apply here

[10] 1992 tariffs appearing in the GTAP base data for the "Economies in Transition" region are relatively low across sectors Historically, imports in these regions were managed by state trading companies, and tariffed trade is a more recent development Thus, the results of tariff experiments reported for EIT here should be interpreted with caution

[11] In 1992, Japan was the principal "developed" country that did not make use of these quotas The quotas also were limited to imports of textile and apparel products from selected "developing" countries, as reflected in Table 3B and did not directly affect bilateral trade between the developed countries

restraints, with the assumption that any associated rents accrue to the exporting region [12] The Agreement on Textiles and Clothing under the Uruguay Round Agreements replaced the MFA and provides for the phase out of the bilateral quotas applied to textiles and apparel by the year 2005. The removal of the textile and apparel quotas, and the relatively large size of the developed-country importing markets, means that trade liberalization tends to shift this relatively "clean" activity from developed to developing countries. Again, the "cleanliness" of textiles and apparel is relative. Apparel production has very low emissions, as it involves primarily the application of labor to pre-manufactured components Textiles manufacture has relatively low (by manufacturing standards) but non-trivial emissions arising from chemicals used in fulling, bleaching, dyeing, etc.

[12] There are substantial complexities involved in estimating the tariff equivalent associated with MFA quotas See Linkins and Arce (1994) and USITC (1995), particularly chapters 3 and 7

III. Framework of the Liberalization Experiments

Two simulations were conducted using the GTAP CGE model The comparative static analysis performed here assumes constant returns to scale and perfect competition Production inputs include domestic factors (land, labor, and capital) and intermediate inputs from foreign and domestic sources Although labor and capital are mobile across sectors, there is no international mobility. At the firm level, constant elasticity of substitution (CES) functions are assumed for the value-added and composite nests [13] The allocation of intermediate input and value added in final production is assumed to be fixed (Leontief). Final regional demand is represented by a single, representative household for each region and a Cobb-Douglas utility function is specified across three types of final demand: private household expenditures, government expenditures,and savings The model utilizes a constant difference of elasticities (CDE) functional form to represent private household demands.[14]

The first simulation includes changes in trade protection agreed to by signatories of the Uruguay Round.[15] Although the experiment abstracts from many features of the agreements, such as the services and intellectual property agreements, it does capture changes in the levels of import tariffs affecting the other traded sectors as well as the elimination of VERs and the

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[13] Imports and domestically-produced goods are assumed to be imperfect substitutes following the Armington assumption.

[14] See Hertel (1996) for a complete description of the model's structure

[15] Information regarding the Uruguay Round tariff reductions applied to non-agricultural products is based primarily on information contained in the WTO's Integrated Data Base (IDB) and reflects changes in the MFN rates (Reincke, 1997) Additional information related to changes in the level of protection resulting from the tariffication of agricultural import quotas under the Uruguay Round is discussed in Ingco (1997)

bilateral quotas imposed under the MFA Moreover, since a static model is employed, the liberalization shocks are not phased in Rather, the scenario represents what the effects of liberalization would have been if the full implementation had occured in 1992

The second simulation includes identical changes to VERs and the MFA However, rather than partial liberalization of tariffs across all traded sectors, import tariffs applied to manufacturing and selected primary commodity sectors are eliminated.

IV. Principal Results

Changes In Output

Table 4 shows the simulated changes in real output for the two experiments for the sectors of greatest interest. In the high emissions ("dirty") sectors, the changes in output range from very small to substantial (an estimated drop in leather goods production of 18 6% for CHK) In general, the most substantial shifts are observed in the developing regions. Shifts in the developed regions are generally less than 1% of previous output, with the exception of the fairly small leather-goods sector. CHK loses output in all of the high emissions sectors, while for others there are gains in some high-emissions sectors and losses in others Non-ferrous metals, the dirtiest sector, experiences contractions ranging from 2-12% in KST, SEA, and CHK In contrast, the sector expands in the four developed regions, but by no more than 0.4% (in NAM). The chemicals compex expands the most (in percentage terms) in KST and SEA but contracts in CHK Iron and steel are reallocated away from KST, SEA and CHK towards LAM. Pulp and paper decline most markedly in SEA and CHK with very small increases elsewhere Leather goods production, with the highest rates of prior protection, shows the most marked proportional shifts in output when that protection is removed, away from ANE, SEA and CHK and towards JPN, KST, and ROW. In some of these sectors aggregate global output (not shown) declines as resources are allocated towards textiles/apparel and services (also not shown). The results for the manufacturing zero-for-zero are broadly similar 36 of the 50 region-sector pairs in the high-emissions sectors exhibit the same direction of change, including all 14 of the largest effects (those exceeding 2% in absolute value in the first experiment) In general, the magnitude of the effects is larger, in keeping with the deeper tariff cuts in the second experiment.

The large shifts in textile and apparel production that occurs in both simulations reflects the substantial degree of protection in the status quo Both sectors contract in ANE, NAM, and EU as the result of the elimination of the textile and apparel quotas in the Uruguay Round simulation and expand in all of the developing sectors except EIT. The additional elimination of tariffs in the manufacturing zero-for-zero experiment results in even larger changes in output of the same sign for all but two regions Both sectors in LAM contract under the full liberalization EIT experiences little change under the Uruguay Round but experiences expansion in textiles and contraction in apparel under full liberalization.

Local Changes In Emissions

Table 5 reports estimated changes in emissions for each region and model experiment under the assumption that U.S emissions coefficients apply to all regions In the aggregate, this assumption is of course highly implausible as there is substantial evidence that industrial technologies are cleaner in the wealthier countries The world emissions results (zero effect for the Uruguay Round and a 0 2% decline for the manufacturing zero-for-zero) are thus highly questionable However, the region-by-region results are still useful, as they rely only on the assumption that the difference in toxic intensities across industries is similar across regions and not on the assumption that average toxic intensity is the same across regions.

It is far more plausible that production of chemicals, iron and steel, etc , are dirtier than food processing or services in any given country than that U S and Chinese emissions controls are equally effective

The limited available evidence tends to confirm the assumption of fairly similar rankings of sectoral pollution intensities across countries For example, in an analysis of biological oxygen depletion (a measure of water pollution) for 250 Indonesian factories, Hettige et al (1995) find that leather tanning establishments and pulp and paper mills have clearly higher emissions than factories producing textiles or wood products This result is consistent with the U S. data.[16] Lucas *et al* also present evidence that the ratio of new plant and equipment expenditures on pollution control to output is highly correlated across the United States and West Germany. In particular, there is a sharp break between the relatively "dirty" industries (nonferrous metals, paper, iron/steel, petroleum refining, and chemicals) and other industrial activities, indicating that changes in output for these sectors are probably well-

[16] Although Hettige *et al* did find that food processing establishments also have high emissions, this is probably due to the particular type of pollution being measured and would unlikely be true for an aggregate comparable to the TRI data, including e g air pollutants and heavy metals

correlated with total emissions from manufacturing in any country.

In the Uruguay Round experiment, the primary effect of liberalization is to reduce emissions in CHK (by 3 4 percent) and to increase emissions in SEA (by 1.8%) and KST (by 1 0%) The CHK reduction in emissions arises directly from the contraction in output in all polluting sectors. Increased emissions in the latter two regions result from the expansion in chemicals production (a large high-emissions sector) and from even stronger growth in textiles production (a moderate-emissions sector) The EIT also experiences an increase of 0 6% in emissions because of the expansion of several dirty sectors. Changes in emissions in the developed countries are negligible

In the manufacturing zero-for-zero experiment there are deeper emissions reductions in the developing regions, ranging from 2-3% in SEA and ROW to 7 7% in CHK SEA experiences a a decline in chemicals production and more significant reductions in other high-emissions sectors in comparison to the Uruguay Round experiment. ANE also experiences substantial emissions reductions due to decreasing output in all high-emissions sectors. Emissions increases in KST and EIT are moderately larger than in the Uruguay Round experiment. JPN experiences a 0 5% increase in emissions as a result of growth in iron and steel and in leather goods production In contrast, the effects of total liberalization on environmental quality in NAM, the EU, and LAM are negligible

In summary, trade liberalization tends to reduce the environmental pressure in poorer economies while causing small to negligible effects in the richer economies. Some developing economies with comparative advantages in high-emissions goods may suffer environmental deterioration as a result of liberalization, particulary the Asian Tigers (KST), the EIT and (in some liberalization paths but not others) SEA

Projecting Emissions Coefficients in Poorer Countries

If data on emissions coefficients by country as well as industry were available, it would be possible to estimate changes in global emissions as a result of the liberalization experiments One can argue that global emissions are not particularly interesting for environmental policy, as pollutants tend to accumulate in local "sinks" of air, water, and land Since the regions in the model are fairly large geographically, this would imply that the local emissions changes are reasonable indicators of changes in local environmental quality, with transboundary emissions across model regions being a second-order effect The counterargument is that relatively little is known about long-distance migration of pollutants, particularly in the oceans and upper atmosphere For example, volatile compounds such as pesticides may routinely migrate from tropical to temparate regions through the global cycle of evaporation and condensation (Raloff 1996). Thus, the global level of emissions is also of interest to policymakers

Internationally comparable data on emissions are not generally available, as explained above, and research in this field has leaned heavily on use of the TRI data for the United States However, there is a substantial body of literature establishing that many measures of environmental quality tend to worsen as countries pass from low-income to middle-income status, and then to improve as per capita income increases, the so-called "inverted U hypothesis " (Shafik and Bandhyopadhyay 1992; Selden and Song 1994, Grossman and Krueger 1995) The inverted-U hypothesis is a fairly broad generalization; some measures of environmental quality (such as access to safe drinking water) decline throughout the range of per capita income, while others (such as solid wastes and lead emissions) tend to increase monotonically As a stylized fact, the inverted-U hypothesis is a useful starting point.

Measures of environmental quality are not quite the same as emissions coefficients Emissions per unit of output is a flow concept Measures of environmental quality (frequently concentrations of a substance in air or water) are stocks, they accumulate with additional emissions and decumulate due to natural dispersion

The share of national economic activity devoted to manufacturing and industrial activity[17] tends to be substantially higher for middle-income than poor-income countries, then gradually level off with the move to service-based economies at higher income levels (Chenery 1979). This "Chenery curve" accounts for at least a portion of the deterioration in environmental quality measures as income rises from low- to middle-income level. Indeed, the inverted-U relationship between environmental quality and per capita income is consistent with emissions coefficients that monotonically decline with per capita income and a Chenery curve of the usual shape The inverse is not true, monotonically declining emissions coefficients and a Chenery curve do not necessarily imply an inverted-U for environmental quality. Nonetheless, this insight leads to a procedure by which estimates of the inverted-U and of the Chenery curve can be combined to infer the elasticity of the emissions coefficient with respect to per capita income

Focus attention on manufacturing emissions, i e assume that agriculture and services are "clean" at least with respect to the particular pollutants being studied Define

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[17] "Industry" generally refers to manufacturing plus mining and utilities In practice, the share of manufacturing in GDP is only slightly less than the share of industry in most countries.

$y = Y/N$ as per capita income (the ratio of income to population)

$m = M/N$ as per capita manufacturing (or industrial) output

$P(y)$ as the relationship between pollution concentrations and per capita income (e.g the inverted-U relationship)

$m(y)$ as the Chenery curve for manufacturing

$E = \beta M$ as the emissions function (with β representing the emissions coefficient)

and $P = \alpha E$ as the relationship between the pollution stock P and the emissions flow E The flow/stock multiplier α could in turn be derived from the rate of growth of manufacturing, the rate of natural dispersion, and the length of time since polluting activity began, α will be constant for given values of these variables.

It is then straightforward to show that

$$\beta(Y) = \frac{P(Y)}{M(Y) * \alpha N}$$

that is, the emissions coefficient as a function of per capita income is the ratio of the inverted-U curve and the Chenery curve, multiplied by $1/\alpha N$ Evaluating N at the population mean, αN becomes a constant of proportionality which is invariant with respect to per capita income.

We generated estimates of $\beta(y)$ by the following procedure First, we used data from the World Bank *World Tables* diskette for per capita income and the share of manufacturing in GDP to estimate the manufacturing Chenery curve $m(y)$ for 1985. The choice of manufacturing rather than industry is due to the fact that the vast bulk of the emissions picked up in the TRI are in fact for manufacturing, the year 1985 was chosen for comparability with the environmental quality data used in Grossman and Krueger (1995), which span about a decade The Grossman and Krueger regressions were used as the source of estimates of P(y) for various pollutants The estimated Chenery curve was (t-statistics in parentheses)

$$m = 7\ 39 + 0\ 00430\, y - 2\ 77*10^{-7}\, y^2 + 3\ 12*10^{-12} y^3 \qquad R^2 = \ 389$$
$$(4\ 06) \quad (3.67) \quad (1\ 76) \quad (0\ 54)$$

This generates a curve with low levels of manufacturing at low levels of per capita income, a minimum at around \$800, a maximum at about \$9000, and then a modest decline, so that high-income countries still have a relatively high share of manufacturing Estimates of $\beta(y)$ were then generated as P(y)/m(y)

The estimates of $\beta(y)$ are higher-order polynomials displaying a variety of curvatures, but when graphed, they generally show declining emissions coefficients over a broad range of low and middle incomes The sole exception is for lead pollution, which gets worse with rising per capita income To summarize the behavior of the emissions coefficients, we approximated $\beta(y)$ by selecting the two points of $\beta(y)$ corresponding to y = \$2,000 and y = \$12,000, adopting the simple functional form $\beta = y^{\epsilon}$ over the range from and calculating the value of the elasticity of the emissions coefficient per unit output, ϵ, between the two points. The two end-points chosen span most of the relevant variation in $\beta(y)$ and the polynomials estimated tend to be monotonic or near-monotonic over that range. The results are presented in Table 6.

For eleven of the twelve pollutants examined (again excepting lead), the implied income elasticity of emissions per unit output is in fact negative, implying improved technology with increasing economic development We present elasticities for eight of the pollutants. For the other four (nickel, dissolved oxygen, chemical oxygen depletion, and nitrates), the curve drops rapidly enough that the estimate of β at $y = \$12,000$ is in fact negative, which is impossible, and we disregard these Since a fairly high share of lead emissions is generated from automobile use in countries using leaded gasoline, and our present focus is on estimating changes in emissions arising from manufacturing, it is not unreasonable to ignore lead for the purposes of the present calculation

This leaves seven pollutants for which we calculate an implied income elasticity of emissions per unit output which is negative These elasticities all fall in the range from 0 to 1, from - 15 for arsenic to - 72 for smoke We consider that income elasticities in this range are most plausible for purposes of projecting possible developing-country pollution coefficients from the TRI data, and proceed on this basis below

Global Changes In Emissions

We now generate estimates of the change in global toxic industrial emissions due to trade liberalization, allowing poorer regions to be systematically dirtier than richer ones. We begin by assuming that the four developed regions (ANE, JPN, NAM, EU) all have emissions coefficients equal to the U S values, and use the difference between regional per capita income and U.S per capita income to generate higher pollution coefficients for the six developing regions. Since the values of ϵ calculated above are speculative, we perform sensitivity analyses, allowing ϵ to vary gradually from 0 (everybody in the world has U.S. emission coefficients) to -2 (environmental improvements with per capita income substantially exceeding those implied above.)

Table 7 presents estimates of the global change in emissions for differing values of the elasticity Emissions coefficients in each region are held constant before and after liberalization, thus, there is no technology effect induced by changes in income The estimates represent the combined impact of scale effects and composition effects on emissions. The results clearly show complementarity at the global level between trade liberalization and reduction in manufacturing emissions. The more pessimistic the assumption about how dirty manufacturing is in the poorer countries, the more optimistic is the conclusion about the positive environmental effects of trade liberalization This is because of the protection of heavy industries in developing countries in the status quo Trade liberalization moves polluting output from regions with weak environmental controls to ones with stronger environmental controls A "best estimate" (with ϵ falling somewhere between -0 25 and -0 5) would suggest a comparative-static reduction of toxic emissions of between 0 08 percent and 0 23 percent for the Uruguay Round, and between 0 5 percent and 0.7 percent for the broader manufacturing liberalization

As a reality check, we calculated the global share of emissions arising in developing regions for each value of ϵ If all countries had the same emissions-control technology, then about three-quarters of emissions would arise in the developed countries (this is just the emissions-weighted share of output in those regions). For elasticities in the most plausible range, between about 46 and 63 percent of toxic emissions arise in the developed countries. But for $\epsilon = -1$ only 16 percent of emissions arise in developed countries, and for higher values of ϵ this percentage becomes vanishingly small It seems implausible that a very high share of toxic emissions from manufacturing arise from the developing countries, and this implausiblity places an upper bound on credible values of the difference between Northern and Southern manufacturing technology. Furthermore, this reasoning does not depend on acceptance of the CGE model or its results, since it is apparent that a very similar outcome would be obtained from the base manufacturing output data and emissions data themselves To see this, observe that the developed-country share of emissions under U S technology in the base data is very close to the comparable share in the two liberalization experiments.

Income-Induced Technological Improvements

Trade liberalization in general induces improvements in living standards. If higher living standards are associated with reductions in the emissions coefficient, then trade liberalization may improve environmental quality through a second channel - liberalization raises incomes, and higher incomes lead to improved technology and reduced emissions This channel could be operating because higher household incomes lead to greater political pressure for environmental cleanup, or because higher income permits more rapid investment in newer capital goods, which are likely to be cleaner The "technology effect" just described is ignored in the estimates in Table 7, emissions coefficients in each region were held constant before and after liberalization. Here, we generate alternate estimates in which the emissions coefficient is allowed to vary with liberalization-induced improvements in standards of living We assume (plausibly, but perhaps optimistically) that technological improvement is unidirectional, that is, small increases in incomes or living standards lead to small improvements in technology, but small decreases do not lead to technological deterioration. We also assume, conservatively, that all technological improvements take place in the developing regions, taking the developed regions to be already at the long-run state of the art

The model experiments generate several measures of income (or welfare) effects. the change in GDP, the change in regional income, and the change in utility of aggregate "household" expenditures (measured on a per capita basis) [18] Changes in two of the measures for the model experiments are presented in Table 8 (the behavior of regional income is very similar to the behavior of GDP). There are some differences between the two In particular, gains in the utility measure are more widespread across regions than gains in GDP As a first pass, we have used changes in utility as our metric of income changes, reserving technical issues as to the appropriate selection of metric for further examination. Under either choice, however, we would estimate favorable technology effects for KST, SEA, and CHK in the Uruguay Round experiment, differing somewhat in magnitude, and for KST and SEA also in the manufacturing zero-for-zero experiment. The choice of aggregate utility as a metric means we also estimate a technology effect for EIT, which turns out to be very small

Table 9 presents the estimated change in emissions taking technology effects into account, again with sensitivity analysis with respect to the income elasticity of the emissions coefficient Technology effects lead to a modest reduction in emissions. They are insufficient, however, to reverse the conclusion that liberalization likely induces increasesd emissions in KST and EIT (and that the Uruguay Round indices increased emissions in SEA), except under values of ϵ which we have ruled out as being implausibly high. Looking at the estimates of global emissions with technology effects, the most plausible estimates in the range of elasticity

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[18] These utility measures do not take account of the effect of toxic emissions on household utility. The consequences of this are discussed in the Conclusion

from -0 25 to -0.5 suggest that the combined scale/composition effect outweighs the technology effect.

Strikingly different outcomes might be obtained if one allowed for dynamic effects of trade liberalization, such as those posited by endogenous growth theory. If trade liberalization permanently increases the growth rate of standards of living or per capita GDP, rather than simply its level, then the role of technology effects would be substantially greater, as would the environmental benefits of trade liberalization The environmental risks of trade liberalization for those regions with comparative advantage in high-emissions production might be greater or less This is a potential avenue for future research

V. Conclusions

In theory, trade liberalization and environmental protection may be either complementary or at odds For the specific case of toxic emissions in manufacturing, we find that trade liberalization and environmental protection are compementary on the global scale. This is primarily because of the historical practice of granting high protection to high-emissions industries in developing countries, and the shift of dirty production from developing to developed countries following from liberalization This shift ensures that a higher share of output is produced under conditions of stringent emissions controls. Improvements in emissions control technology arising from the higher incomes generated in trade liberalization may produce modest additional benefits.

For some regions, there is a tradeoff between environmental protection and trade liberalization This is particularly true for the three Asian Tigers (KST) It is presumably true for Hong Kong as well, although this is not apparent from our model simulations.[19] Under the current path of Uruguay Round liberalization, SEA faces a similar tradeoff, though it would enjoy environmental improvements under a broader liberalization. These two regions also enjoy some of the largest income gains from trade liberalization, by any measure The increase in emissions under liberalization does not necessarily imply that liberalization is a bad deal for these regions Such a conclusion rests on the weight which households in the regions place on environmental quality versus consumption of goods Furthermore, the increase in emissions which is taking place under current growth rates and the current trade policy is substantially larger than the marginal further increase in emissions which would be attributed specifically to trade liberalization Rather, the results highlight the more general tensions between rapid growth and environmental quality in East Asia which have been widely discussed elsewhere [20] The degree to which the gains from trade liberalization are static or dynamic in nature is clearly relevant to the prospects for resolving this tension.

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[19] We have aggregated China and Hong Kong due to the peculiarities of bilateral trade data between the two

[20] In, e g , Brandon and Ramankutty (1993)

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Table 1
Toxic Emissions Coefficients by CGE Model Sector

Sector	Pounds of 1990 toxic releases per 1987 $1000 of output
Non-ferrous metals	9 11927
Chemicals, rubber, plastics	7 42506
Iron and steel	5 91537
Leather products	2 55945
Pulp, paper, and printing	2 18834
Fabricated metal products	1 46956
Other manufactured goods	1 03236
Lumber and wood products	0 99331
Petroleum and coal products	0 91785
Transportation equipment	0 76708
Non-metallic minerals	0.74238
Textiles	0.58584
Other machinery and equipment	0 55365
Meat	0 35139
Other processed food	0.32130
Milk	0.22194
Beverages and tobacco	0 09665
Other mineral mining	0 06999
Wearing apparel	0 03949
Electrical, gas, water utilities	0 02338
Processed rice	0.00740
Coal mining	0.00343

Table 2
Regional Aggregation of CGE Model

ANE	Australia, New Zealand, residual EFTA (i.e Norway, Iceland, Switzerland)
EU	European Union (EU-15)
JPN	Japan
NAM	North America (Canada and United States)
CHK	China, Hong Kong
EIT	Economies in transition (former Soviet Union and Eastern Europe)
KST	Korea (South), Singapore, Taiwan
SEA	Southeast Asia (Indonesia, Malaysia, Philippines, Thailand)
LAM	Latin America
ROW	Rest of world (mainly Africa, Middle East, South Asia)

Table 3A

Baseline and Post-Uruguay Round Levels of Protection
Ad Valorem Import Rates By Sector And Region

Sector		Region:									
		ANE	JPN	KST	SEA	CHK	ROW	NAM	LAM	EU	EIT
Textiles											
	Pre UR	0.173	0.052	0.095	0.360	0.318	0.462	0.103	0.192	0.073	0.056
	Post UR	0.098	0.041	0.069	0.226	0.318	0.422	0.072	0.173	0.053	0.043
Apparel											
	Pre UR	0.195	0.104	0.107	0.461	0.443	0.403	0.166	0.326	0.107	0.069
	Post UR	0.128	0.080	0.093	0.288	0.443	0.403	0.142	0.312	0.090	0.058
Leather											
	Pre UR	0.124	0.138	0.092	0.330	0.340	0.499	0.080	0.225	0.049	0.037
	Post UR	0.085	0.123	0.051	0.246	0.340	0.499	0.070	0.217	0.037	0.031
Pulp, Paper, etc.											
	Pre UR	0.075	0.009	0.040	0.142	0.125	0.263	0.016	0.103	0.033	0.041
	Post UR	0.047	0.009	0.040	0.126	0.125	0.246	0.016	0.101	0.033	0.032
Chemicals, etc.											
	Pre UR	0.065	0.039	0.080	0.177	0.152	0.263	0.050	0.154	0.061	0.043
	Post UR	0.042	0.020	0.040	0.161	0.152	0.214	0.029	0.131	0.040	0.033
Iron and Steel											
	Pre UR	0.054	0.030	0.057	0.111	0.092	0.210	0.042	0.143	0.034	0.033
	Post UR	0.030	0.019	0.035	0.110	0.092	0.182	0.031	0.138	0.015	0.030
Non-ferrous Metals											
	Pre UR	0.030	0.013	0.067	0.115	0.090	0.291	0.012	0.160	0.016	0.029
	Post UR	0.017	0.008	0.035	0.094	0.090	0.277	0.009	0.146	0.012	0.022

Note: The model experiments also remove some VERs. For the above sectors, these are valued as follows: Japan, chemical products, 0.050; EU, Iron and Steel, between 0.045 and 0.050 depending on source of imports.

Table 3B
Baseline and Post-Uruguay Round Levels of Protection
Ad Valorem Tariff Equivalents of the MFA Quotas

Importing Region	Exporting Region:						
and Commodity							
	KST	SEA	CHK	ROW	LAM	EIT	
ANE							
Textiles	0.005	0.004	0.024	0.035	0.040	0.024	
Apparel	0.071	0.077	0.082	0.077	0.068	0.057	
NAM							
Textiles	0.083	0.096	0.137	0.114	0.085	0.061	
Apparel	0.181	0.272	0.209	0.181	0.168	0.119	
EU							
Textiles	0.096	0.132	0.201	0.116	0.112	0.080	
Apparel	0.177	0.267	0.197	0.104	0.149	0.103	

Table 4
Model Results on Output-Key Sectors

Sector	UR Experiment									
	Percent change in output									
	ANE	JPN	KST	SEA	CHK	ROW	NAM	LAM	E_U	EIT
MFA sectors										
Textiles	-9.8	0.8	20	49.5	6.3	2.6	-9.4	1.5	-3.3	-0.1
Apparel	-20.3	-1.6	26.6	137.3	23.2	7.2	-27.3	3.3	-20.2	0
High-emissions sectors										
Leather	-2.9	11.1	17.7	-7.4	-18.6	1.4	-0.9	-0.6	0.3	-0.6
Pulp, paper	-0.2	-0.1	0.3	-1.2	-2.2	-0.6	0.3	-0.2	0.2	-0.1
Chemicals, etc.	0.1	-0.8	1.7	4	-2.5	-0.3	0.2	-0.3	0.3	0.6
Iron/steel	0.3	0.1	-3	-6.5	-3.2	-1.5	-0.2	1.3	-0.2	2.5
Non-ferrous metals	0.2	0.2	-2.5	-10.8	-6.5	-0.4	0.4	-0.1	0.2	0.3
Sector	Post-UR Manufacturing Zero-for-Zero									
	Percent change in output									
	ANE	JPN	KST	SEA	CHK	ROW	NAM	LAM	E_U	EIT
MFA sectors										
Textiles	-21.4	4.4	39	56.8	7.3	-3.2	-15.3	-5.6	-1.3	1.8
Apparel	-53.3	-9.6	16.7	196.1	85.5	49.3	-46.9	-9.5	-36.8	-4.9
High-emissions sectors										
Leather	-6.9	28.9	15.6	-2.8	-11.7	17.8	-11.1	-3.6	-1.9	8.9
Pulp, paper	-0.5	-0.2	-1.5	-4.8	-3.9	-6.1	0.7	0.6	0.5	0.4
Chemicals, etc.	-1.6	-0.4	4.9	-1.5	-8.6	-1.9	0.4	-0.4	0.2	0.9
Iron/steel	-3	1.1	-7.2	-21.2	-12.5	-6.7	-0.3	0.8	0.5	4.3
Non-ferrous metals	-4.1	0.2	-5	-19.9	-15.7	1.5	-0.1	4.4	-0.2	-1.9

Table 5

Local Percentage Changes In Toxic Emissions
(without technology effects)

Region	Uruguay Round	Post-UR Manuf. Zero-for-Zero
ANE	-0.2	-2.3
JPN	0 0	0 5
KST	1 0	1 4
SEA	1.8	-2 5
CHK	-3 4	-7.7
ROW	-0.4	-2 9
NAM	0.0	-0 1
LAM	0 0	0.1
EU	0 1	0 2
EIT	0 6	0 7
World (assuming US technology)	0.0	-0 2

Table 6
Implied Income Elasticity of
Emissions per Unit Output

Sulfur dioxide	- 21
Smoke	- 72
Heavy particles	- 23
Lead	59
Cadmium	-.50
Arsenic	-.15
Mercury	- 21
Biological oxygen depletion	- 40
Nickel	Negative*
Dissolved oxygen	Negative
Chemical oxygen depletion	Negative
Nitrates	Negative

For discussion of methodology see text Implied elasticity calculated between PPP per capita income of 1985 $2,000 and 1985 $12,000 "Negative" indicates that the fitted value of the coefficient is positive in the range of $2,000 and negative in the range of $12,000, thus, the implied elasticity is also negative but was not assigned a specific value

Table 7
Results on Global Emissions
(technology differences but no technology effects)

Percentage change in emissions

Elasticity of emissions per unit output	Uruguay Round	Post-Uruguay Round Manufacturing Zero-for-Zero
0 (U S technology)	-0 003	-0 182
-0 1	-0.027	-0.302
-0 25	-0.081	-0.546
-0 5	-0.227	-0.657
-1 0	-0 657	-2 609
-2 0	-1 320	-4 317

Share of emissions from developed regions
(ANE, JPN, NAM, EU)

Elasticity of emissions per unit output	Uruguay Round	Post-Uruguay Round Manufacturing Zero-for-Zero
0 (U.S technology)	7638	.7659
-0 1	7156	.7159
-0 25	6297	6303
-0 5	4597	.4608
-1 0	1582	.1593
-2.0	0067	0068

Memo. Under 1992 trade policies and U S technology, the share of emissions from developed regions = 7637.

Table 8
Percentage Changes in Per Capita Income

Region	Uruguay Round: Value of GDP	Uruguay Round: Utility of Aggregate Household Expenditures	Post-UR Manufacturing Zero-for-Zero: Value of GDP	Post-UR Manufacturing Zero-for-Zero: Utility of Aggregate Household Expenditures
ANE	-1 00	-0 02	-0 46	0.50
JPN	1 91	0 85	4 84	2 04
KST	0.93	1 04	4 10	1 82
SEA	1 49	1 91	1 62	1 49
CHK	2 44	0.45	-0 91	-0 71
ROW	-0 64	-0 003	-6 28	-0.76
NAM	-1 12	0 10	-1.81	0 07
LAM	-0 49	-0 03	-3.24	-0 29
EU	-1 21	0 11	-0.92	0 29
EIT	-0 56	-0 03	-0 08	0.21

Table 9
Changes in Emissions With Technology Effects

Region		**Elasticity of emissions coefficient**				
		0	-0 1	-0 25	-0 5	-1 0
KST						
	UR	1 0	0.9	0 7	0 5	0 0
	Man Zero	1 4	1.2	0 9	0 5	-0 4
SEA						
	UR	1.8	1.6	1 4	0 9	-0 1
	Man Zero	-2.5	-2 6	-2 9	-3 2	-3 9
CHK						
	UR	-3.4	-3 5	-3 5	-3 6	-3 8
	Man Zero	-7 7	-7 7	-7 7	-7 7	-7 7
EIT						
	UR	0 6	0.6	0.6	0 6	0 6
	Man Zero	0 7	0 6	0 6	0.6	0.6

Percentage Change in Global Emissions

Elasticity of emissions per unit output		**Uruguay Round**	**Post-Uruguay Round Manufacturing Zero-for-Zero**
0 (U S technology)		-0.003	-0 182
-0 1	(no tech effect)	-0.027	-0.302
	(tech. effect)	-0 036	-0.312
-0.25	(no tech effect)	-0 081	-0.546
	(tech. effect)	-0 110	-0.572
-0.5	(no tech effect)	-0 227	-1 132
	(tech effect)	-0 302	-1 179
-1 0	(no tech effect)	-0 657	-2 609
	(tech. effect)	-0 876	-2 629

Figure 1 - Mean Emissions and Income

SO2, Smoke, Heavy Particles, As, Hg

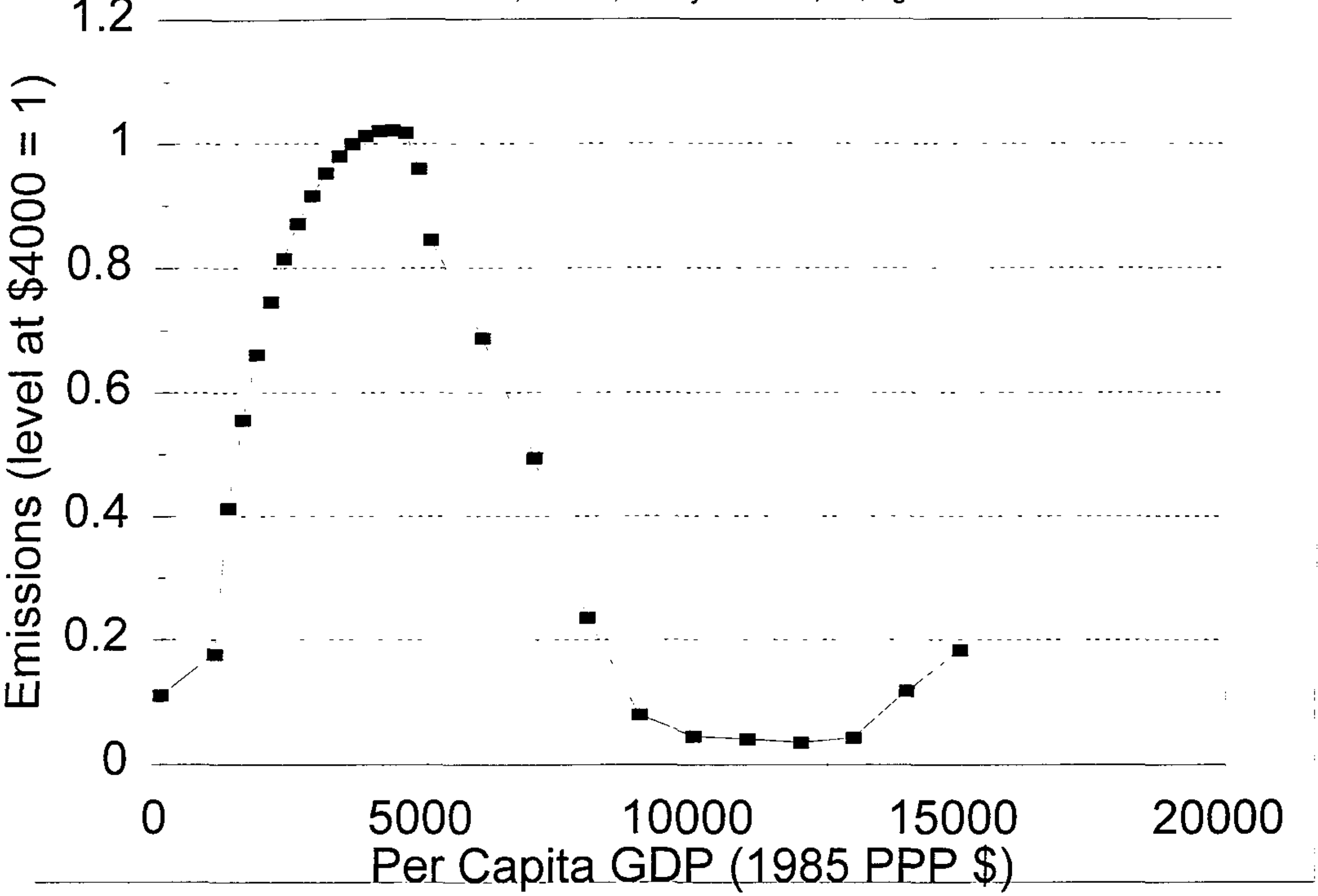

Figure 2

Chenery Curve for Manufacturing

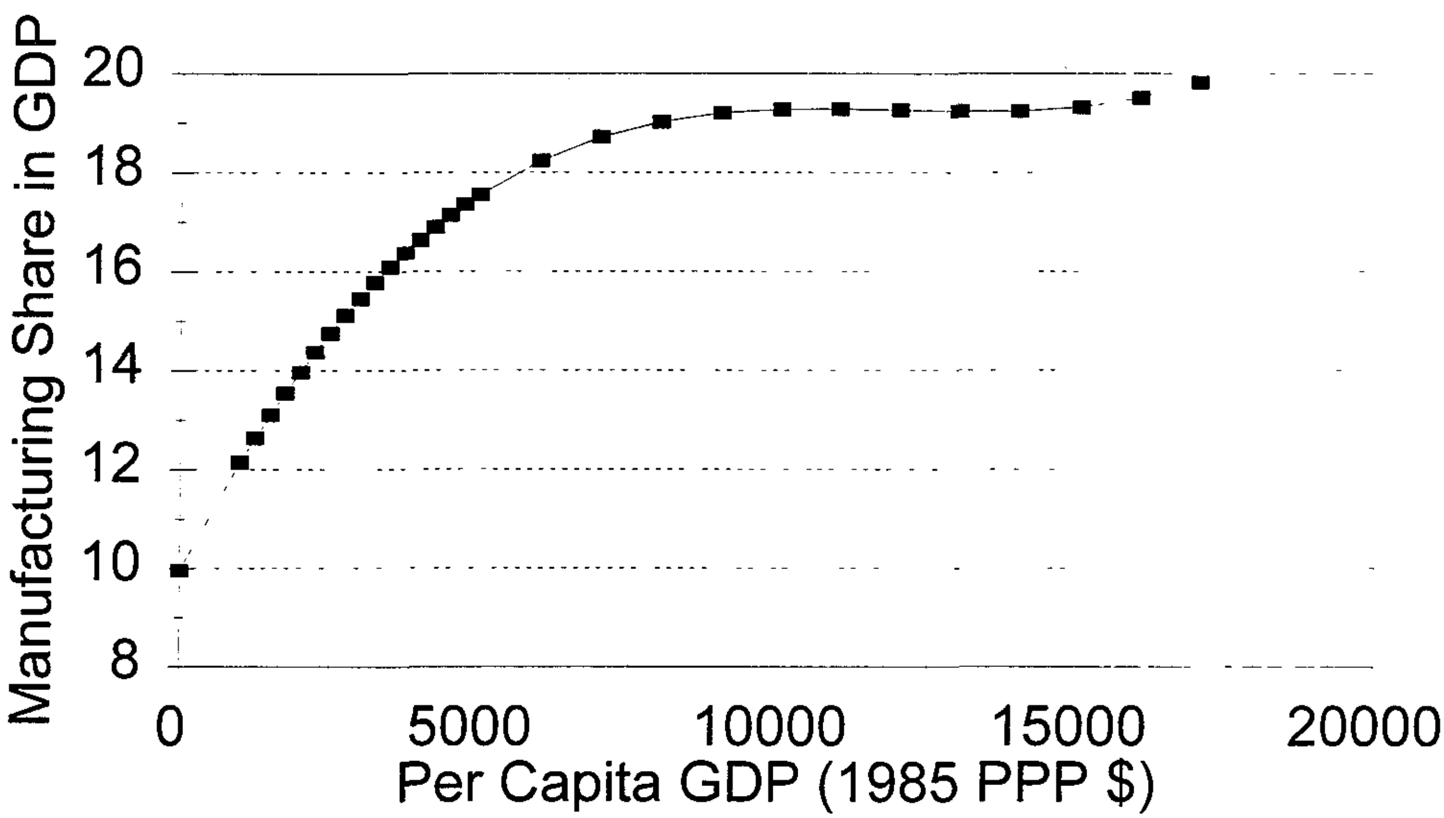

Figure 3

Emissions per unit of manufacturing