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Globalisation's Direct and Indirect Effects on the Environment

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FOREWORD

This paper was prepared by Prof. Carol McAusland of the University of Maryland in the United States, as a contribution to the OECD/ITF *Global Forum on Transport and Environment in a Globalising World* that will be held 10-12 November 2008 in Guadalajara, Mexico. It discusses the direct and indirect effects of globalization on the environment. It is meant to “set the stage” for subsequent discussions of the impacts of globalization on the activity levels of various transport modes and/or the environmental impacts of the changes in activity levels.

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GLOBALIZATION'S DIRECT AND INDIRECT EFFECTS ON THE ENVIRONMENT

1. Introduction

1. For over a quarter century researchers have been cognizant of the potential for the rise in trade to negatively impact the environment. Highly publicized events such as the fate of the Khian Sea,[1] the leak of an internal World Bank memo signed by Chief Economist Lawrence Summers (in which Summers appeared to urge World Bank economists to *encourage* pollution intensive industry migrate to developing countries[2]), and riots at the 1999 World Trade Organization meetings in Seattle, brought the question of whether the surge in international trade is good or bad for the environment onto the world stage.

2. Over this quarter century, research into the net effect of globalization on the environment has matured, although there remain many outstanding questions. Moreover, there has been little (to no) effort exerted at linking up the two broad literatures concerning the direct and indirect effects of globalization on our natural environment. The direct effects include emissions and environmental damage associated with the physical movement of goods between exporters and importers. This includes emissions from fossil fuel use, oil spills, and introductions of exotic species. At the same time, growth in trade and foreign direct investment has numerous indirect effects. These indirect effects are often classified as falling under one of three categories: the scale, composition and technique effects. I begin this chapter with a summary of patterns and rates of growth in international trade and foreign direct investment (FDI), followed by an overview of early research into the relationship between globalization and the environment. I then offer a summary of extant knowledge of globalization's *indirect* effects, focusing largely on current estimates of the size of the scale, composition and technique effects. I conclude the chapter with a brief discussion of the various *direct* effects of globalization, notably transport related emissions and biological invasions, and attempt, however modestly, to put these into the broader context of overall effects.

2. Growth of Trade and FDI

3. Trade has grown substantially over the past 50 years, both in value and volume. Between 1951 and 2004, the average annual growth rate of world trade (by tonnage) was 5.7%; when measured by present value, the average growth rate was 7.4% (Hummels, 2007, p. 133).[3] Projections are for continued

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1 The Khian Sea was a ship flying a Liberian flag that was hired to take incinerator ash from Philadelphia, USA to dump at a (manmade) island in the Bahamas. The local government refused dumping permission and the ship began a 16 month journey which included requests to unload the ash in the Dominican Republic, Honduras, Panama, Bermuda, Guinea Bissau, the Dutch Antilles, Senegal, Morocco, Yugoslavia, Sri Lanka, and Singapore, all of which were denied. Some ash was unloaded in the Bahamas under a false label (as topsoil) and the rest was later admitted to have been dumped into the Atlantic and Indian Oceans. (Sinha 2004 and Wikipedia.)

2 Although Summers took responsibility for the memo, it was originally written by staff economist Lant Pritchett who claimed editing of the memo prior to its leak changed its tenor. See *Harvard Magazine*, May-June 2001 for an interview with Pritchett.

3 Growth rates vary considerably by country. According to the World Bank Trade Indicators (http://info.worldbank.org/etools/tradeindicators/) in the 2005-2006 period, the countries experiencing the fastest real growth in total trade in goods and services were Mauritania (42.3%), Iran (38.0%), Azerbaijan

strong growth. Using a gravity model of trade, based on measures of economic, geographical, political and cultural variables over the 1948 to 1999 period, Hamburg Institute of International Economics (HWWI) forecasts trade value among industrialized countries to grow at 5.7% per annum until 2030, while trade within South Asia, East Asia and Pacific, and Latin America is projected to grow at 10.9%, 12.6%, and 8.5% per annum respectively (Berenburg Bank & HWWI, 2006).

4. Foreign Direct Investment (FDI) has also been growing at a rapid pace. Between 1986 and 2000, 65 countries saw inward FDI grow by 30% or more; the growth rates in 29 other countries ranged between 20 and 29% (UNCTAD, 2003). FDI has increased most quickly for industrialized countries. Regarding inward FDI, during the 1998-2000 period just three regions accounted for over three-quarters of global inward FDI and 85% of global outward FDI: the European Union, the United States and Japan; as a whole, developed countries account for more than 75% of global inward FDI (UNCTAD, 2003).

5. There are a number of causal factors behind the growth of trade and FDI. Bilateral and multilateral negotiations have reduced average tariff rates on manufactured goods to 1.8% in high income countries, 5.5% in middle income countries and 14.2% in low income countries [4] (World Bank, 2007). At the same time, technological improvements have lowered shipping and communication costs.

3. Globalization's impact on the environment – Early Research

6. The earliest empirical research on how globalization impacts the environment tended to ask the reverse question: how does environmental regulation impact trade? The prevailing wisdom was that, if trade impacts the environment, it must be the case that environmental regulation affects trade flows; only then would the argument that trade worsens the environment by shifting pollution intensive production to low-regulation (and often low-income) countries make sense. This proposition—that globalization facilitates the relocation of dirty industry to poor countries—is known as the Pollution Haven Hypothesis (PHH).

7. The earliest empirical work found little evidence in support of a PHH. In fact, by the time of Levinson's 1997 survey, the general consensus was that, while the PHH was theoretically persuasive, the data just didn't support it.

8. Nevertheless, subsequent empirical research has found evidence of a weaker relationship between regulatory stringency and trade patterns and volumes, known as the Pollution Haven Effect (PHE). The PHE is the hypothesis that stringent environmental regulation impacts comparative advantage *at the margin*, but that it does not necessarily lead to a wholesale migration of industry to regions with weaker regulation. This research has focused on providing econometric solutions to problems plaguing the early studies, most notably the endogeneity of regulation, trade flows, and investment in the first place. For example, Levinson and Taylor (2008) examine the relationship between industry spending on abatement and pollution control and import penetration (measured as the sum of imports and exports as a ratio to total domestic output) in the United States. Amongst other things they find "industries whose abatement costs increased most experienced the largest increases in net imports," and that for the 20 industries facing the largest relative pollution control costs, more than half of the increase in trade volume can be attributed to

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(29.3%), Vietnam (22.1%) and China (20.9%).The countries with slowest trade growth are New Zealand (-10.4%), Chad (-4. 8%), Benin (-0.2%), Senegal (0.0%), Tunisia (0.2%) and Syrian Arab Republic (0.4%). Trade growth rates for the United States, Canada and Mexico were 6.9%, 2.8%, and 11.7%.

4 Rates given are weighted mean tariffs for manufactured products. For countries reporting, the lowest mean tariff rate on manufactures is 0.0% (Singapore), the highest 76.7% (Bangladesh). Other rates are as follows: Canada (1.0%), China (5.3%), the European Union (1.8%), Japan (1.4%), Mexico (3.1%), USA (1.8%). (World Bank, 2007)

changes in domestic regulation. Similarly, Ederington *et al.* (2005) use panel data on import penetration and find that import penetration is higher for industries with high pollution abatement and control expenditures (PACE) (relative to total costs), and that this correlation is stronger for industries protected by import tariffs. They also find that the pro-import effect of tariff reductions is stronger for clean industries than for dirty ones. They conclude that “if anything, trade liberalization has shifted U.S. industrial composition toward dirtier industries, by increasing imports of polluting goods by less than clean goods” (p. 14), a result at odds with the popular sentiment that trade liberalization has shifted dirty industry out of the US and into its less developed trading partners, but consistent with the proposition that the United States has a comparative advantage in dirty goods (to be discussed further below).

4. Globalization’s indirect effects

9. In their excellent review of the literature on the PHH and PHE, Copeland and Taylor (2004) credit some of the recent success in uncovering impacts of globalization on the environment to the pairing of theory and empirics. In the early 1990s, researchers identified that globalization is likely to impact the environment through three principle channels: the composition, scale, and technique effects.

10. The composition effect measures changes in emissions arising from the change in a country’s industrial composition following trade liberalization.[5] If, for example, liberalization induces an economy’s service sector to expand and its heavy industry to contract, the country’s total emissions will likely fall since the expanding sector is less emission intensive.

11. Following resource reallocation within countries, a second indirect environmental effect from liberalization is the scale effect: more efficient allocation of resources within countries shifts out the global production possibilities frontier, raising the size of the industrial pollution base, resulting in greater global emissions other things being equal.

12. Finally, the technique effect refers to the plethora of channels through which trade liberalization impacts the rate at which industry and households pollute. These channels include changes in the stringency of environmental regulation in response to income growth or the political climate surrounding regulation; the technique effect also includes technology transfer facilitated by trade.

5. The Composition Effect

13. Trade liberalization changes relative prices: eliminating tariffs and non-tariff barriers lowers the relative price of import-competing goods. Suppose this leads to an increase in the output of sector E (for Expanding) and a reduction in the output of sector C (for Contracting)—changes resulting from, say, capital and labor moving from the contracting sector to the expanding sector in response to a change in relative goods prices. This resource allocation will lower a country’s total emissions if the expanding sector is less pollution intensive than the contracting sector. Specifically, holding the scale of economic activity and production techniques constant, the composition effect can be summarized as the following change in the country’s total emissions Z: $\Delta Z = e_E \Delta Q_E + e_C \Delta Q_C$ where Δ indicates changes, e_i indicates emission intensity in sector i and Q_i is output. If, for example, prices were equal across sectors, then an income- and scale-preserving reallocation of resources across sectors would require $\Delta Q_E = -\Delta Q_C$, such that the change in emissions can be written as $\Delta Z = [e_E - e_C]\Delta Q_E$. That is, trade will lower national emissions if and only if the expanding sector is relatively less pollution intensive.

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5 As much of the econometric evidence concerning globalization’s environmental effects has concentrated on the growth in international trade in goods (as opposed to services), my discussion will similarly focus on goods trade.

14. This begs the question of which sectors will expand as a result of liberalizing trade. The Heckscher-Ohlin theory of trade suggests that the industries most likely to face competition from imports (and so to contract following tariff liberalization) are those that depend relatively heavily on the country's scarce factor. A case in point: textiles and clothing are amongst the most heavily protected sectors in the United States, a country whose endowment of unskilled labor is small relative to its capital and land endowments (when compared to international averages). Moreover, for some pollutants at least, there is a strong correlation between an industry's emissions and its capital intensity. Using the OECD's Environmental Data Compendium (1999), Cole and Elliot (2003) calculate a .42 correlation between SO_2 intensity and capital intensity; the correlation for NO_x is .44; both correlations are statistically significant.[6] Similarly, Cole and Elliot (2005) calculate a correlation between pollution abatement and operating costs (per dollar of value added) and physical capital per worker of 0.69 and 0.53 at the 2- and 3-digit SIC code levels respectively.

15. Because of the often strong correlation between emission intensity and capital intensity, Antweiler *et al.* (2001) postulate a Factor Endowments Hypothesis (FEH), which predicts that trade liberalization will lead to an increase in emissions in capital-abundant countries, and a reduction in capital-scarce countries. They test this hypothesis, as well as several other hypotheses maintained in the literature, using panel data on city-level ambient SO_2 concentrations, and find evidence that concentrations of SO_2 are increasing in a country's capital to labor ratio. They calculate the "composition elasticity", and find that, for most specifications, "a 1-percent increase in a nation's capital-to-labor ratio—holding scale, income and other determinants constant—leads to perhaps a 1-percent-point increase in pollution." (pp. 893-4). Cole and Elliot (2003) replicate Antweiler *et al.*'s (2001) study for SO_2 and extend the analysis to consider CO_2, NO_x, and Biological Oxygen Demand (BOD) as well; their estimated composition elasticities are 2.3 and 0.45 for SO_2 and CO_2, and statistically indistinguishable from zero for NO_x and BOD. Using Chinese data, Shen (2007) calculates composition effects for SO_2, Dust fall, Chemical Oxygen Demand (COD), Arsenic and Cadmium, in each case finding that higher capital/labor abundance corresponds to more pollution (with elasticities of 3.025, 1.079, .788, 1.325 and 2.416 respectively).

16. Another source of comparative advantage is regulatory stringency itself. The preponderance of micro-level studies of the relationship between income and willingness to pay for environmental amenities suggests that *demand* for environmental quality increases with income. This is consistent with the logic that environmental amenities are "normal" goods: as we get richer, we want more of them. To the extent that demand for environmental amenities influences environmental regulation, high-income countries are likely to set stricter environmental regulation than do low-income countries, giving rich countries a comparative advantage in relatively clean industries. Accordingly, trade liberalization that drives each country's industry to restructure along the lines of its comparative advantage should lead clean industries (*e.g.* services) to expand in rich countries; similarly, dirty industries will expand in poor countries. This can generate a Pollution Haven Effect (PHE) as discussed above, whereby strict regulation gives countries a comparative disadvantage in dirty goods. As I will present below, there is evidence that income and regulatory stringency are highly correlated. Thus one interpretation of the PHE is that poor countries have a comparative advantage in dirty goods, other things (specifically capital abundance) being equal.

17. Because there is a strong correlation between per capita income and capital abundance per capita—Welsch (2002) calculates a raw correlation of .95—in theory we expect the PHE and FEH to offset each other in empirical tests that only control for either national income or factor abundance but not both. Recognizing this, Antweiler *et al.* (2001) and Cole and Elliot (2003) each construct indices of "comparative advantage", where the comparative advantage index is the sum of quadratic functions of per

6 For other indicators of resource use the correlation is weaker. Cole and Elliot (2003) calculate a correlation between Biological Oxygen Demand (BOD) and capital intensity of only 0.12. They speculate this correlation is weak because the major contributor to BOD is agriculture.

capita gross domestic product (GDP) and capital-labor ratios each measured relative to a global average. They then interact these comparative advantage indices with measures of openness to calculate trade-induced composition elasticities. In the Antweiler *et al.* (2001) sample, the statistically average country has a comparative advantage in clean goods, with a corresponding trade-induced composition elasticity between -0.4 and -0.9; stated alternately, for the mean city in their sample, Antweiler *et al.* (2001) calculate that a 1% increase in openness reduces SO_2 concentrations by between .4 and .9 percent, holding income and scale constant. Santos-Pinto (2002) similarly estimates a trade-induced composition elasticity, focusing exclusively on CO_2 emissions (as imputed using United Nations data on fossil fuel use); for the average country in his sample, Santos-Pinto (2002) estimates that a 1% increase in the trade ratio (X+M/GNP) leads to a 0.1 % reduction in CO_2 emissions, holding income and scale constant. Santos-Pinto points out that this trade-induced composition effect, although favorable to the environment for the average country in his sample, is only about 1/5th as large as the (negative) scale and pure composition effects. In contrast, in the Cole and Elliot (2003) sample, the median observation has a comparative advantage in dirty goods; specifically, for the statistically median country in their sample, a 1% increase in trade (holding income and scale constant) *raises* SO_2, CO_2 and BOD levels by 0.3%, 0.049% and 0.05% respectively.[7] Shen (2007) uses concentration data from China and finds mixed effects. Shen's (2007) estimates of the trade-induced composition elasticity are as follows: 1.556, 1.962, -2.148, -0.236 and -3.884 for SO_2, Dust fall, COD, Arsenic and Cadmium respectively, such that, holding income/scale and composition fixed, an increase in trade intensity leads to higher SO_2 and Dust concentrations, but lower COD, Arsenic and Cadmium for the average province in China.

18. Frankel and Rose (2002, 2005) similarly test whether the impacts of openness on the environment are stronger when a country has a capital-labor ratio that is above the global average, or per capita income that is below average. They test the impact of openness on concentrations of NO_2, SO_2 and Particulate Matter (PM), CO_2 emissions, deforestation, energy depletion and rural clean water access. Their approach is distinct from earlier assessments in that they use instrumental variables to account for the endogeneity of trade volumes and income levels; because there is little variation in their instrument for trade volumes, they restrict their attention to cross-sectional data. They include an interaction term between relative capital abundance and openness to see whether capital-abundant countries have a comparative advantage in dirty goods, and find the signs are mixed and the large standard errors render the interaction term statistically insignificant.

19. To test the PHE, Frankel and Rose (2002, 2005) run separate regressions that include an interaction between income and openness; their results are statistically insignificant except for PM and SO_2, for which they find income has a deleterious effect on concentrations in more open economies. They conclude "there is no evidence that poor…or capital-abundant countries use trade to exploit a "comparative advantage" in pollution" (2005, p. 90). Although the Frankel and Rose (2002, 2005) evidence is informative, I hesitate to conclude it refutes the FEH and PHE. As noted above, income and capital abundance are highly correlated. If only one variable is included in the interaction, the fitted coefficient may well reflect the influence of the excluded variable. Since the FEH and PHE work in opposite directions on pollution levels, a statistically insignificant interaction between capital abundance and openness, for example, may simply reflect two counteracting effects, rather than absence of a factor endowment effect.

20. In my assessment, the majority of the empirical evidence suggests there is an economically and statistically significant interaction between measures of trade intensity and relative capital abundance for local air pollutants. Whether this interaction favors or harms the environment should vary across countries depending on whether they are capital rich or poor relative to the rest of the global economy.

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7 The trade elasticity for NO_X is statistically insignificant.

21. Of course measures of aggregate capital and labor supplies are crude measures of comparative advantage. Other industry characteristics, such as the importance of transport costs and timeliness, may be equally important. Hummels (2007) argues that transport costs and times are currently a larger barrier to trade than tariffs[8] in industrialized countries: "[f]or the median individual shipment in U.S. imports in 2004, exporters paid $9 in transportation costs for every $1 they paid in tariff duties." (Hummels, 2007 p.136) Reduced transport times favor industries with time-sensitive products disproportionately; to the best of my knowledge, there has been no empirical investigation into the relative pollution-intensity of time-sensitive and insensitive products. Reduced transport costs will similarly favor industries for which transport costs make up a large portion of delivered costs (Hummels, 2007). Investigating the relationship between import penetration and abatement costs at the industry level in the United States, Ederington *et al.* (2005) find evidence that industries facing substantial transport costs are relatively insensitive to changes in environmental regulation.

22. Another dimension along which empirical evidence into the composition effects of trade is lacking concerns consumers and agriculture. For example, Costello and McAusland (2003) argue that an increase in the volume of trade expands the platform for biological invasions (more goods coming in on more ships translates to more material in which an exotic species can stowaway), but that crop-related damages from exotic species may nevertheless decline with trade if the agricultural sector contracts as a result of the trade liberalization. They point to the protection of the US sugar industry as an example of how protectionism can therefore *raise* damages from invasive species. The price of sugar in the US is roughly twice that on international markets. This has led land area in the US planted with sugar to expand even though land planted for all crops has been contracting. The accidental introduction of Mexican Rice Borer now leads to damages of between $10 million and $20 million from the sugar sector in Texas alone, compared to annual revenue from the Texas sugarcane crop of $64 million (Costello and McAusland, 2003).

23. Regarding consumers, trade liberalization also alters prices facing households, inducing consumers to change the mix of goods consumed. To the extent that consumers generate emissions or deplete resources when goods are *consumed*, trade liberalization should have an impact on the emission intensity of a dollar's worth of goods consumed. For example, most countries subsidize (at least implicitly) fossil fuel consumption. Some countries do this through implicit export taxes on energy, or implicit subsidies to consumption. Venezuela is an extreme example, where the 2005 price per gallon of gasoline was only USD$0.12 (CNN 2007). If Venezuela were to allow its gasoline price to rise to approx $2.60 (the US price in 2005, less average US taxes of $.40/gallon), fuel use and associated emissions would drop considerably.[9]

6. Global Net Composition Effect

24. The discussion above focuses on the impact of trade liberalization on industrial composition at a national level. There I argued that, holding the scale and techniques of production constant, trade liberalization will lead to a reduction in national emissions if the contracting sector is more pollution intensive than the expanding sector, *i.e.* if $e_E < e_C$. A similar analysis holds for changes in global emissions. Suppose reductions in output of sector C in one country are exactly matched by increased output in that

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8 This analysis does not include non-tariff barriers to trade such as quotas and Voluntary Export Restraints (VERs).

9 There is ample empirical research establishing long-run responses to fuel price increases. Reviewing this literature, Graham and Glaister's (2002) conclude that typical long run price elasticity of household demand for gasoline is between -0.6 and -0.8. However it would be inappropriate to use these measures to predict the impact of a Venezuelan price liberalization, since the size of the price adjustment (a 2000% increase) would require out-of-sample prediction.

sector abroad. Then whether a scale- and income-neutral trade liberalization raises or lowers global emissions depends on the relative emission intensity in each trading partner. Specifically, using asterisks to indicate changes in the rest of the world, the change in global emissions Z^G will be $\Delta Z^G=[e_E-e_C-(e_E^*-e_C^*)+2e_T]\Delta Q_E$ where e_T are emissions per unit traded.[10] Thus we see that total emissions will rise unless production techniques in the rest of the world are relatively clean by a non-negligible margin. But there is evidence that, for some products at least, countries with a natural comparative advantage in production of agricultural goods, for example, use less energy-intensive production techniques. A case in point is the distinction between food-miles and carbon-footprints. Since the 1990s it has been increasingly common for retailers in the UK and Europe to label food products indicating the number of miles a food item was transported. The presumption has been that food shipped smaller distances is less pollution intensive. However, Saunders, Barber and Taylor (2006) show that importing dairy and meat into the UK from New Zealand would lead to fewer, not more, carbon releases than producing the same goods locally, even accounting for emissions associated with transport. For example, Saunders *et al.* (2006) calculate that raising (and transporting to the UK) one tonne carcass of lamb in New Zealand results in 688 kilograms of CO_2 emissions, while producing that same amount of lamb in the UK and foregoing transportation would result in 2,849 kilograms of CO_2 emissions.[11] Similar carbon savings are associated with importing dairy and (out of season) apples into the UK: 1422.5 vs 2902.7 per tonne of milk solids, and 185 vs 271.8 per tonne of apples (Saunders *et al.,* 2006). In some cases the differences in emission-intensity stem from something as simple as differences in energy sources. Based on estimates of total primary energy supply, the International Energy Agency (2007) estimates that carbon emissions per Million Tonnes of Oil Equivalent (MTOE) vary by as much as 100 times across countries: CO_2 emissions per MTOE are 0.13 and 0.15 for Democratic Republic of Congo and Mozambique, compared to 3.46 and 3.75 for North Korea and Mongolia.[12]

7. Technique Effect

25. How much a country emits per unit of a particular good produced or consumed depends on the "techniques" of production or consumption. To the extent that globalization changes these techniques, either through policy channels or technological changes, globalization impacts the environment itself. Most attention to technique effects has focused on changes in environmental policy associated with income gains from trade. Accordingly, I allocate much of my discussion to empirical estimates of income effects. However I will also discuss evidence concerning additional channels through which globalization impacts "techniques", such as changes in the political environment shaping regulation, regulators' ability to assess abatement potential, and producers' ability to abate in the first place.

8. Technique Effect—Income

26. The most widely studied channel through which liberalization affects emission intensities is the income growth associated with trade liberalization. Estimates indicate the impacts of trade on income may be substantial. Using cross-country data on per capita incomes, instrumented measures of trade shares (specifically, the value of a country's imports plus exports, divided by the value of its national output) and other control variables, Frankel and Romer (1999) conclude that "a one percentage point increase in the

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10 This formulation assumes all production reallocated to/from the rest of the world is subsequently traded.

11 Of course producing agricultural goods abroad is not always more carbon efficient; Saunders *et al.* (2006) calculate that the CO_2 footprint of a tonne of NZ onions shipped to the UK is 184.6 kg, while the comparable emissions from UK production are only 170 kg.

12 For comparison, CO_2/MTOE for other major countries are 1.57 (Brazil), 2.02 (Canada), 2.95 (P.R. China), 1.41 (France), 2.36 (Germany), 3.09 (Greece), 3.07 (Israel), 2.21 (Mexico), 2.99 (Morocco), Russia (2.39), 3.02 (Serbia and Montenegro), 2.27 (UK), 2.49 (US).

trade share raises income per person by 2.0 percent." (p. 387)[13,14] Frankel and Rose (2002, 2005) similarly estimate per capita income as a function of (instrumented) trade shares, population (levels and growth rates), per capita income (measured at a 20 year lag), investment/capita and school enrollment rates; they do not, however, test for interactions between trade and any measures of factor abundance. Frankel and Rose find that a one percentage point increase in the ratio of (instrumented) trade to GDP leads to a 1.6 percent increase in income (2002, p. 17).[15]

27. Any trade-generated income growth is important for the environment as there is general consensus from micro-level studies that raising incomes fuels demand for environmental amenities. In fact, even though there are a handful of studies finding a negative relationship between income and environmental demand, the debate instead is whether demand rises more or less than proportionately with income;[16] this is equivalent to asking whether the income elasticity of demand for environmental quality is above or below unity. Examining parkland and forestation, Antle and Heidebrink (1995) find "the income elasticity of demand for environmental services...[for high income countries is] positive and generally greater than one" (p. 618). Shafik (1994) uses international panel data and finds an income elasticity of demand greater than one for a variety of environmental amenities, including access to clean water and sanitation as well as ambient air quality. Boercherding and Deacon (1972) and Bergstrom and Goodman (1973) find evidence that willingness to pay (WTP) for environmental improvements increases more than proportionately with income. However McFadden and Leonard (1992) and Kriström and Riera (1996), find WTP as a fraction of income declines with income (suggesting an income elasticity of WTP of less than unity).

28. There is a separate body of evidence using macro-level data and environmental outcomes that posits an inverted U-shape relationship between pollution concentrations (on the vertical axis) and per capita income (on the horizontal axis); this inverted-U is known as an Environmental Kuznets Curve (EKC). In one of the earliest papers on the subject, Grossman and Krueger (1995) used GEMS data to estimate the cubic relationship between growth (as proxied by per-capita income) and concentrations of urban air pollutants and other contaminants. They found that the negative relationship between growth and pollution reversed itself at "turning points." For example, for SO_2, Smoke, BOD, Arsenic and Mercury, concentrations fall with income when per-capita income exceeds $4053, $6151, $7263, $4900 and $5247 respectively. Subsequent authors raised several concerns with the EKC estimation exercise. Holtz-Eakin and Selden (1995) use panel data on CO_2 emissions and finds that, even though the marginal propensity to

13 This is just a point estimate; the 95% confidence interval for the elasticity of per capita income with respect to trade share is [0.03, 3.9104].

14 They also estimate what are the channels for this income growth. They decompose output into contributions from capital and labor stocks, education, and productivity. "The estimates imply that a one-percentage point increase in the trade share raises the contributions of both physical capital depth and schooling to output by about one-half of a percentage point, and the contribution of productivity to output by about two percentage points." (p. 390).

15 Gains in per capita income may underestimate the actual consumption benefits from trade. Much of the trade between developed countries is *intra*-industry (*i.e.* a country imports goods in the same product class as it exports), which is often explained by trade in distinct varieties of otherwise similar goods. Some economists believe the variety gains from trade may be as large as the gains in nominal income. Broda and Weinstein (2006) estimate that "US welfare is 2.6 percent higher due to gains accruing from the import of new varieties" (p. 582). Klenow and Rodriguez-Clare (1997) estimate that ignoring the benefits from increased variety can underestimate the benefits from trade liberalization anywhere from 33 to 80%.

16 For example, Kahn and Matsusaka (1997) find that high-income voters are less likely to support certain environmental initiatives in California referenda. However, as McAusland (2003) points out, many of the initiatives in question were to be funded by bond measures, so the no-vote by high-income voters may be explained by Ricardian Equivalence.

emit ultimately declines with income, rapid growth in developing countries dominates such that global CO_2 emissions are projected to rise at roughly 1.8% per year for the foreseeable future.

29. Theoretically, the EKC can be explained using Engel curves or changes in the types of factor accumulation (see Copeland and Taylor, 2003). However, a decomposition of emissions into emission-intensities and input (*e.g.* energy) use suggest that regulation likely plays an important role. Hilton and Levinson (1998) examine the relationship between automotive lead emissions and income, for which they do find an EKC. However, they decompose lead emissions into emissions-intensity and energy use. Because energy use is consistently increasing in per-capita income, any emission reductions must come through declining emission intensity, for which regulation is necessary. They also point out that emissions-intensity was declining, even holding income constant, for countries on the upward sloping portion of the EKC; they take this as evidence that, during their study period, there were technological changes that cannot be explained by income.

30. Others have raised issue with the econometrics underlying research finding evidence of an EKC. Harbaugh *et al.* (2002) showed that the evidence for an inverted U in the GEMS data "is much less robust than previously thought. ...[T]he locations of the turning points, as well as their very existence, are sensitive both to slight variations in the data and to reasonable permutations of the econometric specification. Merely cleaning up the data, or including newly available observations, makes the inverse-U shape disappear." (p. 541).

31. Another problem with interpreting results from the EKC literature as measuring a causal relationship between income growth and environmental quality is that most of these analyses do not investigate the underlying causes of income growth. Frankel and Rose (2002, 2005) provide an exception. Using instrumental variables to account for the endogeneity of income and trade intensity, Frankel and Rose (2002, 2005) test the relationship between predicted per capita income and pollution concentrations. Their point estimates confirm an inverted U-shape relationship between (instrumented) per capita income and concentrations of air pollutants; based on the point estimates from their IV estimation, PM peaks at an income level of $3,217 per capita, SO_2 at $5,710 per capita, and NO_2 at $8,134 per capita.[17] For CO_2, however, Frankel and Rose find no evidence of a turning point.[18]

32. In light of the micro- and (controversial) macro-level evidence that incomes and environmental quality are positively correlated, it seems logical then that income gains from trade will translate into increased demand for environmental quality; one channel through which consumers express this demand is through calls for tighter environmental regulation. Using panel data on SO_2 concentrations in 108 cities from 43 countries, Antweiler, Copeland and Taylor (2001) obtain point estimates of the "technique elasticity" between -1.577 and -0.905; accordingly, they argue that if trade raises incomes by 1%, the technique effect will lead to a reduction of SO_2 concentrations of approximately 0.9 to 1.6 percent. Looking at the relationship between trade restrictions, income growth, and COD in China, Dean (2002) similarly finds evidence of a technique effect: a "1 per cent reduction in the level of trade restrictiveness produces an increase of 0.09 per cent in the growth rate of income…[which] causes a decline in the growth rate of emissions by …-0.03 per cent." (p. 834).

33. Needless to say, growth in trade is not the only channel through which globalization may raise incomes. FDI has also increased substantially over the past quarter century. FDI now accounts for "over 60 percent of private capital flows" (Carkovic and Levine, 2005, p. 195) and is four times as large as

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17 Based on author's own calculations using point estimates reported in Frankel and Rose (2005, Table 1).

18 Frankel and Rose (2002, 2005) conclude that *for a given level of income*, on average trade has a beneficial impact on the environment. Moreover, because there is evidence that trade raises incomes, trade also has an indirect effect on the environment, which is beneficial for high income levels but negative for low levels.

commercial lending was to developing countries in the 1970s. Although inward FDI should have many of the same composition, income and scale effects as trade, researchers have instead focused on the reverse question: do strict environmental regulations attract or repel inward FDI? As with early research on the pollution haven effect, the evidence is mixed. Some of the earliest complaints about FDI (in an environmental context at least) have concerned the Pollution Haven Hypothesis, the supposition that freeing-up trade and investment rules will lead multinational corporations (MNCs) to relocate their production activities to low-income (and inadequately regulated) developing countries. There has, however, been little evidence that such capital flight has occurred. Explanations include the substantial disparity between pollution abatement and control costs relative to capital and labor costs. For example, in the United States, the ratio of pollution abatement and operating costs (PAOC) to value added is 9.9% in the US Petroleum and Coal Products sector, but no more than 3.5% in any other sector (Primary metal industries: 3.5%, Paper and Allied Products: 2.7%, Chemicals and Allied Products: 2.4%, Tobacco Products: 2.3%); see Cole and Elliot (2005). At a country level, Jaffe *et al.* (1995) calculated pollution abatement and control expenditures (PACE) as a percentage of GDP in the 1980s, finding highs of 1.6% in West Germany and 1.5% in the US,[19] the Netherlands and the United Kingdom. Instead, the lion's share of payments go to labor and capital. In the United States, labor's share of national income is consistently about two-thirds (Pakko, 2004).

34. Subsequent research asked whether differences across countries, provinces or states might influence the pattern of inward or outward FDI. See, for example, Becker and Henderson (2000),[20] List and Co (2000),[21] Keller and Levinson (2002),[22] and Fredriksson, List and Millimet (2003).[23] An excellent review of this literature can be found in Brunnermeier and Levinson (2004). By and large these studies take environmental outcomes as given and ask how variation in regulations impact investment flows. In this chapter we are interested in the flip side of this question: how does FDI affect environmental outcomes? To the best of my knowledge this question has not been answered empirically.[24] However, it is reasonable to expect that lowering barriers to international investment may raise GDP in recipient countries, largely through the technology transfer imbedded in FDI. Borensztein, De Gregorio and Lee (1998) examine the impact of inward FDI on per-capita income in developing countries, concluding that, for the statically average country in their sample, "an increase of 0.005 in the FDI-to-GDP ratio (equivalent to one standard deviation) raises the growth rate of the host economy by 0.3 percentage points per year "

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19 Using EPA data, Jaffe *et al.* (1995) arrive at a higher 2.6% figure for the United States.

20 "Becker and Henderson (2000) examined the effect of air quality regulations on plant births in U.S. counties between 1963-1992. They estimated a conditional poisson model and found that at the county level, NAAQS nonattainment status reduced the births of new plants belonging to four heavily polluting industries by 26% to 45% during this period." (Brunnermeier and Levinson 2004, p. 21).

21 List and Co (2000) use cross-sectional data to examine the impact of state regulatory spending on inward FDI. They find the environmental regulation has a negative and statistically significant impact on planned new foreign-owned manufacturing plants, but that the effects are stronger for *cleaner* industries.

22 Keller and Levinson (2002) use panel data to look at inward FDI into the United States. Based on their calculations, "a doubling of their industry-adjusted index of abatement cost is associated with a less than 10% decrease in foreign direct investment." (Brunnermeier and Levinson 2004, p. 30).

23 Fredriksson, List and Millimet (2003) use measures of per-capita Gross State Product (GSP) and the share of legal services in GSP to create an instrument for environmental policy. They find evidence of a U-shaped relationship between regulatory stringency and inward FDI. They point out that, for California, a one-standard deviation increase in regulatory stringency "reduces employment by over 2500 jobs, or about 6% of foreign affiliates' employment in the chemicals sector." (p. 1424).

24 Although some authors have used Instrumental Variables (IV) to control for the endogeneity of pollution abatement policy—see Xing and Kolstad (2002), Ederington and Minier (2003) and Levinson and Taylor (2008)—none have estimated the elasticity of emissions with respect to FDI.

(p. 125). Should this causal relationship bear scrutiny, we would expect the income boost associated with inward FDI to have beneficial impacts on the environment akin to trade. In the same vein, some FDI advocates suggest that outward FDI may also raise incomes in the source country (for example, by increasing demand for white collar employment at a multinational's home office), with potential impacts on the environment via the income effect. To the best of my knowledge, no one has tested these hypotheses empirically. Similarly, the environmental scale and composition effects of inward and outward FDI have gone without scrutiny.

9. Scale Effect

35. Although they are quite different in theory, in many empirical applications the scale and technique effects are difficult to separate. Using GDP/km^2 as a proxy for scale, Antweiler *et al.* (2001) estimate a scale elasticity of between 0.112 and 0.398 for SO_2; *i.e.*, holding income and capital per capita constant, a 1% increase in the density of economic activity corresponds to a increase in SO_2 of between 0.1 and 0.4 percent. Because they use country-level data, Cole and Elliot (2003) are unable to measure scale and technique effects independently of one another. Using per-capita national income as the independent variable, Cole and Elliot (2003) find that, for a statistically median country in their sample, a 1% increase in national output/income through trade lowers SO_2 and BOD by 1.7% and 0.06%, respectively; in short, for SO_2 and BOD, the technique effect appears to dominate. However their results suggest that for NO_X and CO_2 the scale effect dominates: a 1% increase in national output/income corresponds to 1% and 0.46% increases in NO_X and CO_2 through the combined scale and technique effects. (In comparison, Antweiler *et al.*'s combined scale and technique elasticity is approximately 1.0.) Using Chinese data, Shen (2007) calculates net scale and technique elasticities, finding a negative net environmental effect of income/scale for SO_2 and Dust fall, while for COD, Arsenic and Cadmium, the net effect is beneficial to the environment (with elasticities of 4.0, 2.4, -0.982, -1.659 and -3.039).

10. Technique Effect – Environmental Politics

36. Much of the research on income effects assumes that households are effective at translating their preferences to policy. The usual presumption is that regulators and politicians are sensitive to the tastes of their constituents, and so will tighten environmental regulations in response to increased demand. In practice, of course, voters are only one input in the political process; industry and factor owners may be similarly interested in influencing policy in their favor. Moreover, trade liberalization can *alter* the political economy surrounding regulation. McAusland (2003) shows that opening a country to trade changes the incidence associated with regulating industrial emissions: in a closed economy, the burden of regulation is shared by dirty good producers and consumers through price changes. However, in an open economy, consumers are insulated from the price effects of local industrial regulation since consumers are able to buy substitutes from unregulated competitors. McAusland (2003) argues that, even if trade liberalization leaves the price of dirty goods unaffected (so composition, income, and scale effects are absent), this incidence-shifting will lead to stronger industry opposition to regulation and weaker environmental policy if industry has undue influence over regulators. Conversely, if the regulation in question concerns *consumer-generated pollution*, openness shifts incidence in the opposite direction: producers will be the ones whose payoffs are insulated in the open economy, *reducing* industry opposition to environmentally motivated product standards (McAusland 2008). Gulati and Roy (2007) similarly argue that trade liberalization can lead an import-competing industry to prefer stricter environmental regulations when exposed to international competition. They show this "greening" of domestic industry can occur whenever domestic firms have a cost advantage in complying with regulation, such that strict product standards have a "raising rival's cost" effect. McAusland (2004) similarly argues industry may want strict local product standards governing the intermediate products they use (even if these standards are not legally binding on overseas competitors) if there is a "California effect" via international input markets.

37. Aside from changes in regulatory incidence, trade liberalization also changes the stakes associated with lobbying. Fredriksson (1999) argues that an increase in the price of dirty goods (as per trade liberalization in a country with a comparative advantage in pollution intensive industrial goods) raises the stakes for industry and environmental lobbyists alike, with ambiguous effects on environmental regulation.

38. Another concern surrounding trade liberalization is that it will facilitate inter-jurisdictional competition: if footloose firms can serve their markets from any number of locations, this may give governments an incentive to bid down their environmental regulation so as to attract industry. Oates and Schwab (1998) argue that governments may set inefficiently weak environmental regulation so as to attract capital that complements local fixed factors. Markusen *et al.* (1995) argue that governments attempting to attract lumpy investment might similarly bid down environmental regulations. Levinson (2003) provides some evidence that governments do indeed "compete" in environmental regulation. Using the 1992 US Supreme Court decision prohibiting discriminatory taxation as a turning-point, Levinson (2003) finds that the slope of state government's reaction functions (mapping local regulation to that of geographic neighbors) is statistically insignificant before the 1992 decision but statistically significant and positive in the post-1992 era.

11. Technique Effect – Technology Transfer

39. There are several channels through which globalization may facilitate technology transfer between countries. Trade is one obvious channel: engineering firms that develop clean technologies engage in the direct sale (and support) of their technologies to firms overseas. Alternately, technology may be embodied in traded capital equipment; additionally, these products may be reverse engineered, allowing competitors in the importing country to incorporate the new technology into domestically produced capital goods.

40. Another channel is through subsidiaries of multinationals. There is substantive evidence that the technology embodied in inward FDI is greener than local technology. Eskeland and Harrison (2003) look at plant-level energy use in Mexico, Venezuela, and Côte d'Ivoire. Using the ratio of energy inputs to output (both measured in value), Eskeland and Harrison (2003) conclude "foreign ownership is associated with lower levels of energy use in all three countries. To the extent that energy use is a good proxy for air pollution emissions, this suggests that foreign-owned plants have lower levels of emissions than comparable domestically owned plants. The results are robust to the inclusion of plant age, number of employees, and capital intensity—suggesting that foreign plants are more fuel efficient even if we control for the fact that foreign plants tend to be younger, larger, and more capital-intensive" (pp. 17-18). Blackman and Wu (1998) similarly point to embodied technology as an explanation for the high fuel efficiency of foreign-owned (relative to domestically owned) energy-generation plants in China, noting that 52% of the generating capital used in the foreign-owned generating plants in their sample is foreign produced, while in domestic plants only 24% of equipment is foreign produced. Observations that inward FDI tends to be more energy efficient than domestic enterprises is consistent with a 1990 survey of 169 MNCs; most of these firms indicated their overseas health, safety and environmental practices reflect regulations in their home country (Brunnermeier and Levinson 2004, UNCTAD 1993).

41. *If* inward FDI displaces local producers, this embodied technological transfer can reduce domestic emissions. Alternately, even if inward FDI does *not* displace local production, there may be spillovers to local producers. Research on the strength of technology spillovers usually focuses on wages and output. Most early research on this topic found positive spillovers—see, for example, Caves (1974), Globerman (1979), Blomström and Persson (1983) and Blomström (1986)—however subsequent work using plant-level data (and which controlled for the endogeneity of the siting and sectoral allocation of inward FDI) found evidence of negative spillovers. For example, Aitken and Harrison (1999) look at

productivity spillovers in Venezuela and find a negative impact of inward FDI on domestic productivity. They calculate that an increase in a sector's foreign ownership from 0 to 10% can lower overall productivity in that sector by as much as 3%. Görg and Strobl (2001) provide an excellent survey of the FDI spillover literature.

42. Even if the technology accompanying inward FDI isn't shared with domestic firms, there may still be a spillover via yardstick competition: *i.e.* regulator's set standards for one region or firm based on what its neighbors are doing. Fredriksson and Millimet (2002) examine the relationship between the stringency of a US state's environmental regulation and that of its neighbors. They find that, in the Northeast US, "a 10% increase in (income-weighted) neighboring relative abatement costs increases own state environmental stringency by over 30%." (p. 116). Moreover, the pull is asymmetric: while stricter standards next-door pull up local standards, Fredriksson and Millimet (2002) find relatively weak standards in a neighboring state have no statistically significant impact on local regulation. Although there is evidence that regulators use yardstick competition at the firm level—Bhaskar *et al.* (2001) find evidence that local governments use yardstick competition between firms to restrict rents accruing to public sector managers (Bangladesh), while Estache *et al.* (2002) find evidence that yardstick competition in regulation of port infrastructure operators in Mexico would enhance efficiency—to the best of my knowledge yardstick competition at the firm level has not yet been studied in an *environmental* context.

12. Technique Effect – trade induced innovation

43. The final channel through which globalization may affect the environment is through globalization-induced technological change. An example is containerization. Containerization reduces the amount of time ships must spend in port loading and unloading, raising the rate-of-return on capital investments, leading to investment in larger, faster ships (Hummels, 2007). One of the by-products of containerization has been the emergence of a hub-spoke system, which has two potential impacts on the environment. Firstly, the hub-spoke system may increase the effective distance between a given exporter-importer pair, potentially increasing the amount of ship-related emissions associated with 1$ worth of trade. The hub-spoke system also creates stepping stones for biological invasions: if exports from region A to region B are routed through a hub in region C, the pool of species region B is exposed to is the set of all species in region A *and in every other region whose exported goods travel through the hub in region C.* Simulating a network-flows model, Drake and Lodge (2004) find that 7 key ports serve as bottlenecks for pathways for marine invasions: Chiba (Japan), Durban (South Africa), Las Palmas de Gran Cana (Spain), Long Beach (USA), Piraeus (Greece), Singapore (Singapore) and Tubarao (Brazil). Nevertheless, they conclude that changes in technology that reduce the per-ship propogule pressure would be a more effective means of reducing marine invasions worldwide than would rerouting shipping traffic away from these seven hotspots. Fernandez (2007) collects data on marine transport and biological invasions at ports along the pacific coast of Mexico, the US, and Canada and argues that cooperative prevention strategies dominate reactive strategies for all parties.

13. Globalization and the Environment – Direct Effects

44. The scale, composition and technique effects considered above are best described as the *indirect* effects of globalization. They all stem from changes in relative prices that stem from integration with the global economy. Surprisingly, much of the economics literature has ignored the *direct* effects of increased trade, specifically increases in emissions and other externalities from the transport sector responsible for moving goods and embodied services (personnel and tourists) between countries. The following section provides a very brief overview of environmental damages and other spillovers from the transport sector.

14. Surface Transport

45. Just under one quarter of global trade (measured by value) is between countries sharing a land border, although this average largely reflects the trade patterns within North America and Europe, where between-neighbor trade accounts for between 25 and 35 percent of trade. In Africa, Asia and the Middle East, in contrast, between-neighbor trade accounts for between 1 and 5 percent of trade. For Latin America, between 10 and 20 percent of trade is between land neighbors. (Hummels, 2007) Data concerning the mode of neighbor trade is not available at the global level, however Hummels (2007) reports that "U.S. and Latin American data suggest that trade with land neighbors is dominated by surface modes like truck, rail, and pipeline, with perhaps 10 percent of trade going via air or ocean" (p. 132). Fernandez (2008) calculates that 90% of US-Mexico trade and 66% of US-Canada trade is by truck.

46. Environmental damages arising from land transport vary considerably depending on, amongst other things, the density of the area through which traded goods are routed. Forkenbrock (2001) estimates of the costs associated with one ton-mile of rail transport in *rural* counties (based on volatile organic compound (VOC), NO_X and PM10 emission intensity estimates): Heavy unit train: 0.009, Mixed freight train: 0.011, Intermodal train: 0.020, Double-stack train: 0.013; all numbers are 1994 cents per ton-mile. Forkenbrock (2001) compares these with estimates of the damages from transport via truck: 0.23 cents per ton-mile. Notably, these are estimates of *average* damage from transport within the United States.[25] For comparison, Parry and Small (2002, 2005) conclude that environmental damage per passenger-vehicle mile *within* urban areas is approximately 2.0 cents per mile. For Europe, Bickel *et al.* (2005) calculate the *marginal* damage from transport, paying particular attention to how it can vary across mode, energy source, and location. They find that damages from air pollution associated with inter-urban transport via heavy goods vehicles (HGV) ranges from 2.09 to 7.46 €cents per vehicle-km (see Bickel *et al.* 2005 Table 4, p. 196), while the damages from global warming (associated with exhaust greenhouse gas emissions) for HGV ranges from 2.03 to 3.28 €cents per vehicle-km. We hesitate to draw conclusions from a comparison of these estimates as their units—vehicle distance, passenger miles and weight-distance—are not comparable.

47. As with other modes of transport, the fuel efficiency of surface transport continues to improve. For example, the US Department of Energy reports average fuel economy improved by 3.2% for light trucks, 9.6% for medium trucks, and 3.6% for heavy trucks over the 1992-2002 period (Davis and Diegel, 2007).

48. One issue often overlooked in analyses of trade related transport emissions concerns wait times at borders. Fernandez (2008) reports that wait times are often twice as long for northbound commercial traffic at US-Mexico border crossings as for southbound. In the El Paso-Ciudad Juarez area, as much as 22% of emissions may be attributable to vehicles idling at border crossings (Fernandez 2008).

15. Shipping Related Emissions

49. For trade between countries that do not share a land border, the vast majority of goods are moved by ocean or air. Ton-miles transported by ship dominate shipments by air by a factor of 100. For example, in 2004, 8335 billion ton miles of non-bulk cargoes were transported internationally by ocean vessel, compared to only 79.2 billion ton-miles by air. However growth rates are higher for air: for non-bulk cargoes, the annual growth rate of ton-miles was 11.7% for air shipments and 4.4% for ocean shipments (Hummels, 2007 p. 133). Of course an increase in the volume of trade need not imply an increase in

25 These estimates are based on damage estimates obtained from Cambridge Systematics Incorporated, who assess the costs per ton of VOC, NO_X, SO_X and PM10 emissions in US rural counties at $385, $213, $263, $3943 1994 dollars, respectively.

emissions if the emission intensity of a ton-mile may falls; this is plausible given that vessels have become more fuel efficient (as well as faster) over the past half century, in large part due to containerization (Hummels 2007).

50. Some projections for the future, though, suggest emissions will rise faster than fuel use. The International Maritime Organization projects fuel use by marine transport will increase by approximately one third over the 2007-2020 period, with corresponding increases in marine CO_2, NO_X and PM_{10} by approximately one third, and a 40% increase in SO_x emissions. (International Maritime Organization 2007) Corbett *et al.* (2007) predict that the number of deaths attributable to shipping related PM_{10} emissions will rise by 40% by 2012,[26] with most of the deaths occurring in coastal Europe and East and South Asia; the majority of these deaths will arise from cardiopulmonary disease and lung cancer.

51. Another negative externality from ocean transport is the risk of oil spills. In the 1970's total oil spilled averaged at 314,200 tons per year; in the 1980s and 1990s the average annual spill rate was 117,600 and 113,800 respectively; for the first 7 years of the 2000's, the average spill rate is only 25,143 tons. The number of spills similarly declined: 25.2, 9.3, 7.8 and 3.6 spills per year for the periods 1970-79, 1980-89, 1990-99, and 2000-2006 respectively (ITOPF (no date)).

15. Aviation

52. The global transport sector accounts for approximately 14% of anthropogenic greenhouse gas emissions. Of this 14%, freight trucks account for 23%, ships 10%, and international aviation 7%. (Stern, 2007, Chapter 7, Annex C). Although aviation's direct greenhouse gas emissions are the smallest of the group, greenhouse gas emissions from aviation under-represent their actual contribution to climate change. "For example, water vapour emitted at high altitude often triggers the formation of condensation trails, which tend to warm the earth's surface. There is also a highly uncertain global warming effect from cirrus clouds (clouds of ice crystals) that can be created by aircraft." (Stern, 2007, p. 342) Although there is no agreed-upon conversion rate, the warming ratio is thought to be between 2 and 4 (Stern, 2007, Annex 7.c) raising aviation's contribution to global greenhouse emissions from 1.7% to over 3%.

53. Moreover, the growth rate of air transport is nearly twice that of ocean transport. Over the 1975-2004 period, the annualized growth rate for ocean transport was 3.8%, while for air transport the growth rate was 8.4% (Hummels, 2007). Consistent with the disparity between growth rates of aviation and other modes of transport, the Stern report (2007) projects that "between 2005 and 2050, emissions are expected to grow fastest from aviation (tripling over the period, compared to a doubling of road transport emissions)." (Stern 2007 Annex 7.c)

16. Biological invasions

54. Another direct channel through which trade and transport impact the environment is through the introduction of non-native, or exotic, species (loosely defined as species that have traveled outside their native range with the direct or indirect assistance of humans). The costs of dealing with past invasive species can be considerable: Pimental *et al.* (2005) estimate that the annual cost of dealing with invasive species currently present in the United States is $120 billion per year.[27] Some species are introduced intentionally and subsequently escape, while others are introduced accidentally. Notable channels for unintentional introductions are as contaminants of traded products (particularly food products and nursery stock), packing materials, and modes of transport, particularly contaminated ballast water. Invasive species

26 Corbett *et al.* (2007) estimate that current shipping PM10 emissions lead to 60,000 deaths per year.

27 Of course some of the 50,000 alien species present in the United States are beneficial, including corn, wheat, rice, cattle, poultry. (See Pimental *et al.*, 2005 and USBC, 2001.)

are implicated in 458 of the 900 species currently listed as either threatened or endangered in the United States. This has led some to go so far as to suggest broad trade restrictions should be pursued (see, *e.g.* Jenkins, 1996), while others have argued that the rate at which trade fosters exotic species introductions is *increasing.* However, as Levine and D'Antonio, show, although the number of non-native species is positively correlated with trade, because the number of potential invaders is finite, invasions will attenuate with time rendering the relationship between invasions and trade concave. Moreover, Costello and Solow (2003) point out that there is a lag in the discovery process, such that the number of exotic species observed at any point in time underestimates the number actually present. Costello *et al.* (2007) estimate the rate at which new introductions arise as a result of trade. They use data on invasions in San Francisco bay to calculate the marginal invasion risk (MIR) from imports from different regions. They find that imports from historic trade partners—specifically those in the Atlantic & Mediterranean (ATM) and West Pacific (WPC) region—have been responsible for the lion's share of exotic species in SF bay, with invasions from ATM nearly double those from the WPC (74 and 43 respectively). However, the MIR from *future* WPC imports (0.38 additional introductions per additional million short tons imported) are triple that from future ATM imports (0.11). They project that business-as-usual imports from ATM and WPC will lead to 1.4 and 52.4 introductions of new exotic species into SF bay by 2020; they offer no forecasts of introductions into other ports.

55. In a related vein, Kasperski (2008) uses cross-sectional data and instruments for trade intensity and income levels to test whether the generally beneficial effect of openness on environmental indicators extends to biotic resources. While he finds no statistically significant impact of trade intensity on the number of endemic species, he finds a positive and statistically significant effect on the number of non-endemic species; he calculates elasticities of non-endemic species counts with respect to trade intensity of -1.045, -0.830, -1.080 and -1.071 for birds, mammals, plants and total biodiversity respectively. Although some might view this result as positive, given that exotic species are included in counts of non-endemic species, this result is consistent with the presumption that trade facilitates introduction of invasive species.

17. Conclusions

56. As with any body of research, there are always exceptions to the general rule. The general rule concerning the indirect effects of trade on the environment seems to be that increased openness has a benign to beneficial effect on the local environment. Antweiler *et al.* (2001) conclude that, for the statistically average country in their sample, a 1% increase in trade leads to an approximately 1% lower concentration of SO_2. One concern regarding the Antweiler *et al.* (2001) approach is that the potential endogeniety of trade volumes is not accounted for. Frankel and Rose (2002, 2005) use instruments for trade volume and find that openness nevertheless appears to have a beneficial impact (*i.e.* lower concentrations) on SO_2 and NO_2, but no statistically significant impact on PM. Chintrakarn and Millimet (2006) similarly use instrumental variables to control for endogeneity, focusing instead on the relationship between sub-national trade and toxic releases. They find trade intensity *increases* land releases, but either reduces or has no statistically significant effect on air, water and underground releases. One advantage of the Chintrakarn and Millimet (2006) approach is that the instruments employed control for endogeneity, while the use of data from a single federal jurisdiction entails (some) comparability of data across units; the drawback is that there's no reason a prior to expect that inter-national and sub-national trade flows impact the environment similarity. McAusland and Millimet (2008) build a theoretical model arguing that the pro-environment effects of sub-national trade should in fact be smaller than those of international trade; they find that increasing the inter-national trade intensity of the statistically average province/state by 10% lowers its total toxic releases by roughly 9%, while changes in sub-national trade intensity, ceteris paribus, do not have a statistically meaningful effect on total toxic releases.

57. Although the recent evidence concerning trade and local pollution is encouraging, the evidence concerning carbon and other greenhouse gas emissions is less so. Using a cross-section of 63 countries and instruments for trade intensity and income, Magani (2004) calculates the scale, technique and composition effects of trade and concludes that the combined effect of a 1% increase in trade leads to a 0.58% increase in CO_2 emissions for the average country in her sample. Frankel and Rose (2002, 2005) similarly find openness raises CO_2 emissions when estimating using Ordinary Least Squares (OLS), but finds the detrimental impact disappears when instruments are employed. In the EKC context, Neumayer (2004), Holtz-Eakin and Selden (1995) and Schmalensee *et al.* (1998) similarly observe a positive relationship between income and carbon emissions. One of the most likely explanations for the consistently pessimistic assessments of trade's impact on greenhouse gas emissions is their global nature. Not only are the costs of CO_2 emissions shared with citizens abroad (who have no political voice outside their own country), but many greenhouse emissions are associated with fossil fuel use, for which few economically viable substitutes have emerged to date (again, arguably as a result of the international free-rider problem). The income and other technique effects that are largely responsible for reductions in local air pollutants do not seem to have the same force when the pollutant in question burdens the global population—and requires global solutions—rather than just the citizens residing within any one government's jurisdiction.

58. I am unaware of any studies that have looked at how the income gains from trade, amongst other things, will impact demand for, and ultimately regulation of, transport related externalities. On the one hand, it seems hard to imagine that citizens suffering from transport related damage such as PM_{10}-related deaths along shipping corridors will not demand stricter regulation as they become richer. But, as noted above, transport emissions associated with ocean and air travel are global and/or transboundary in nature, and so may suffer the same fate as CO_2 emissions absent global action. Moreover, unlike emissions by point sources (like power plants and factories), international transport-related emissions often involve third parties, *i.e.* many goods are moved via vessels not bound by operational regulations in either the importing or exporting country. This is a particular issue for ocean shipping. Although open registry fleets—ships registered under flags of convenience—accounted for only 5 percent of ocean trade (by weight) in 1950, by 2000 its share had expanded to 48.5%. (Hummels, 2007 p. 140) Thus, even if voters in high-income countries want stringent environmental regulations attached to the transport of traded goods they consume, shipping emissions may be outside their government's jurisdiction. It is possible that applying carbon footprint taxes on all goods (with discounts for taxes imposed at the source) can play a role in arriving at an efficient outcome in this case, but this has yet to be shown either theoretically or empirically.

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