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Is Free Trade Good or Bad for the Environment? New Empirical Evidence

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1. Introduction

One of the most important debates in trade policy concerns the impact of trade liberalization on the environment and, hence, on climate change. “Increased trade liberalization, increased trade, increased production, increased energy use and climate change,” while treated as separate issues until the early nineties, have become the focus of scholars researching trade and the environment (Stoessel, 2001). In particular, the debate originated in the early 1990s, following negotiations over the North American Free Trade Agreement (NAFTA) and the Uruguay round of the General Agreement on Tariffs and Trade (GATT), both of which emerged during a time of rising environmental awareness. Environmentalists argued that the creation of NAFTA would result in an environmental disaster for Mexico and pointed to the Maquiladora zone, where trade with the United States caused a concentration of industry that had detrimental effects on the local environment.

Moreover, trade is related to numerous environmental problems. The Handbook on Trade and Environment emphasizes that trade acts as facilitator of the “international movement of goods that, from an environmental perspective, would best never be traded. With hazardous wastes and toxic materials, the environmental risks increase the further the goods are transported, since spillage is always possible. Equally, such ‘goods’ may end up being dumped in countries without the technical or administrative capacity to properly dispose of them, or even assess whether they should be accepted. Trade also makes possible the over-exploitation of species to the point of extinction – there is rarely enough domestic demand to create such pressure.” Examples include the threats to species such as elephants, due to trade in ivory, the deterioration of air quality in parts of China attributed to export-led growth, and unsustainable harvest rates in tropical rainforests due to trade in timber (Copeland and Taylor, 2003).

A major concern is that the increasing competition between companies induced by further trade liberalizations causes a “race to the bottom” in environmental standards, because countries might weaken their environmental policy in order to shelter their industry from

international competition or to attract foreign firms due to low costs of environmental protection as a similar incentive as low labor costs.

In contrast, advocates of free trade point out the potential “gains from trade,” in particular, the increases in income generated by trade. These have likely contributed to major improvements in air and water quality in developed countries over the last decades because the citizens’ demand for environmental quality is likely to increase with income. Another possible benefit of trade is the increased transfer of modern (and thus cleaner) technologies to developing countries, as multinational corporations might find it simpler and more effective to apply the same technology in all of their locations. Similarly, the Porter hypothesis (Porter and van der Linde, 1995) states that a tightening of environmental regulations stimulates technological innovation and thus has a positive effect on both the economy and the environment.

Furthermore, supporters of free trade emphasize that trade restrictions are an ineffective way to protect the environment and that environmental problems are better dealt with by adopting effective environmental controls. Recently, the debate has been further intensified by the creation of the World Trade Organization (WTO) and by new rounds of trade negotiations that include several trade and environment issues, such as the Doha Declaration.

At the heart of the debate over how trade affects the environment are the questions as to whether environmental goals are being threatened by free trade and the WTO, and whether trade liberalization will cause pollution-intensive industries to locate in countries with relatively weak environmental regulations. Furthermore, since different countries undertake different levels of climate-change mitigations, significant concern has arisen that carbon-intensive goods or production processes from high income and stringent environmental regulation countries could potentially migrate to low income and lax environmental regulation countries (e.g., countries that do not regulate greenhouse gas {GHG} emissions). This is known as the pollution haven hypothesis (PHH). Although two distinct hypotheses concerning pollution havens have sometimes been blurred together by the subject literature, it is crucial to distinguish between them (we follow the definition of Taylor, 2004).

First, a “pollution haven effect” (PHE) occurs when tightening of environmental regulation leads to a decline in net exports (or increase in net imports) of pollution-intensive goods. In terms of capital mobility, a PHE exists if tightened environmental stringency causes a capital outflow in the affected industries. The existence of a pollution haven effect simply indicates that environmental regulations have an influence on trade volumes, capital flows and plant location decisions. Second, according to the PHH, the pollution haven effect is the main determinant of trade and investment flows. It predicts that trade liberalization will cause pollution-intensive industries to migrate from countries with stringent environmental regulations to countries with lax environmental regulations. The latter countries will have a comparative advantage in “dirty” goods and will attract foreign investment in their polluting sectors.¹ Simply put, a PHE takes trade policy as given and asks what happens if a country tightens environmental regulations. The PHH, however, takes differences in environmental policy as given and asks what happens if a country liberalizes trade. Although these two concepts are different, there is a clear link between them. The predictions of the PHH can only be true if there is a strong PHE. While the existence of a pollution haven effect is necessary, it is not sufficient, however, for the PHH to hold.²

¹ The production shift might occur as a consequence of either trade or foreign direct investments.

² Additionally, this implies an alternative test for the pollution haven hypothesis: The finding of a small pollution haven effect is evidence against the pollution haven hypothesis.

This chapter aims to answer the following questions: Placed in the context of the PHH, is free trade good or bad for the environment? Do developed countries export their pollution-intensive production to developing countries? Is trade liberalization responsible for increased greenhouse gas (GHG) emissions (e.g., CO₂) and/or sources of GHG emissions (e.g., SO₂) contributing to climate change? Our investigation uses panel data for 95 countries during the period 1980-2004 and regresses three measures of pollution, namely per capita emissions of sulfur dioxide (SO₂), emissions of carbon dioxide (CO₂), and energy consumption on trade intensity (the sum of exports and imports divided by GDP), thereby controlling for income per capita, year and country-specific effects. We carry out the analysis as follows. First, we perform the estimation for the full sample of countries. Second, we divide the countries into three categories according to their income levels: low, middle and high income. Based on our analysis, we argue that it is not possible to find any implications for the PHH in regressions over the full sample, but, rather, over distinct income groups. Our results show moderate support for the PHH for CO₂ emissions and energy consumption, but no significant effect could be obtained for SO₂ emissions. Concerning the impact of trade liberalization on climate change, its indirect effect on anthropogenic climate change has been present through an increase in transport activities and an increase in the use of fossil fuel energy. However, trade alone is certainly not the root cause for anthropogenic climate change.

This chapter is organized as follows. Section 2 provides a summary of the theoretical and empirical background for purposes of our empirical application. The section also summarizes briefly the literature pertaining to the impact of trade liberalization on climate change. Section 3 discusses methodological issues related to this research. Section 4 describes the data and the empirical analysis and presents the results. Section 5 summarizes the main findings and concludes.

2. The effects of trade and trade liberalization on the environment and climate change: theory and empirics

2.1 Theory

2.1.1 How does trade in general affect the environment?

There is a close and complex relationship between the effects of trade on the environment. This typically led scholars to decompose the environmental impact of trade liberalization into scale, technique and composition effects³. Furthermore, when trade is liberalized all these effects interact with each other.

Scale effect

Trade liberalization expands economic activity and fuels economic growth. As the scale of global economic activity increases due, in part, to international trade, Environmental change/damage will occur. In addition, the literature suggests that, when the composition of trade and the production techniques are held constant, the total amount of pollution must increase. Thus, the scale effect has a negative impact on the environment. Simply put, "if the scale effect dominates technology and composition effects and if externalities are not internalized, economic growth will always be harmful to the environment" (Stoessel, 2001).

³ Antweiler et All (2001), Grossman & Krueger (1991), Lopez & Islam (2008), Cole (2003), Stoessel (2001),

Trade is also credited with raising national incomes. The literature reports a great deal of evidence that higher incomes affect environmental quality in positive ways (Grossman & Krueger, 1993; Copeland and Taylor, 2004). This suggests that, when assessing the effects of growth and trade on the environment, we cannot automatically hold trade responsible for environmental damage (Copeland and Taylor, 2004). Since beneficial changes in environmental policy are likely to follow, the net impact on the environment remains unclear. Within the scale effect the income effect is subject to controversy. The less controversial part regards the fact that extreme poverty tends to lead to people exploiting the environment in order to survive. The more controversial part concerns the “hump-shaped” or the inverted U-shaped relationship between per capita income and pollution, also known as the Environmental Kuznets Curve (EKC). The essence of the EKC is that raising incomes per capita are not linearly correlated with environmental deterioration. Rather, pollution increases in its early development stages until it reaches a turning point, and then declines since concern with environmental quality increases and long-term issues start to prevail (Stoessel, 2001; Copeland, 2005; Copland and Gulati, 2006).⁴

Technique effect

Researchers widely agree that trade is responsible for more than 75% of technology transfers. New technology is thought to benefit the environment if pollution per output is reduced. Furthermore, if the scale of the economy and the mix of goods produced are held constant, a reduction in the emission intensity results in a decline in pollution. Hence, the technique effect is thought to have a positive impact on the environment (Stoessel, 2001; Mathys, 2002).

Composition effect

Trade based on comparative advantage results in countries specializing in the production and trade of those goods that the country is relatively efficient at producing. If comparative advantage lies in lax environmental regulations, developing countries will benefit and environmental damage might result. If, instead, factor endowments (e.g., labor or capital) are the source of comparative advantage, the effects on the environment are not straightforward. Therefore, the impact of the composition effect of trade on the environment is ambiguous (Mathys, 2002; Stoessel, 2001).

2.1.2 How does trade liberalization affect the environment?

The impact of trade liberalization on the environment has been studied by many scholars over time and is the main focus of environmentalists.

The PHH states that differences in environmental regulations are the main motivation for trade. The hypothesis predicts that trade liberalization in goods will lead to the relocation of pollution intensive production from countries with high income and tight environmental regulations to countries with low income and lax environmental regulations. Developing countries therefore will be expected to develop a comparative advantage in pollution intensive industries, thus becoming pollution havens. In this scenario developed countries will gain (clean environment) while developing countries will lose (polluted environment). Table 1 below summarizes these ideas.

⁴ The name of the environmental Kuznets curve relates to the work by Kuznets (1955), who found a similar inverted U-shaped relationship between income inequality and GDP per capita (Kuznets, 1955).

The “factor endowment hypothesis” (FEH) claims that pollution policy has no significant effect on trade patterns but, rather, differences in factor endowments determine trade. This implies that countries where capital is relatively abundant will export capital intensive (dirty) goods. This stimulates production while increasing pollution in the capital rich country. Countries where capital is scarce will see a fall in pollution given the contraction of the pollution generating industries. Thus, the effects of liberalized trade on the environment depend on the distribution of comparative advantages across countries. A summary of the FEH is presented in Table 2 below.

Country	Environmental Policy	Comparative Advantage	Environmental Quality
Developed (high income)	Strict environmental regulations	“Clean” industries	“Clean”
Developing (low income)	Lax environmental regulations	“Dirty” industries	“Dirty”

Table 1. Overview of the pollution haven hypothesis.

The race-to-the-bottom hypothesis asserts that developed countries refrain from adopting more stringent environmental regulations due to competition with countries that have lax environmental regulation (Stoessel, 2001; Esty and Geradin, 1998).

Country	Comparative Advantage	Effects on pollution
Developed (capital abundant)	Pollution intensive goods	Pollution increases
Developing (capital scarce)	Non-pollution intensive goods	Pollution decreases

Table 2. Overview of the factor endowment hypothesis.

The “Porter hypothesis” assumes a race-to-the-top, meaning that strict environmental regulations have the potential to induce efficiency while encouraging innovation that helps to improve competitiveness (Porter and van der Linde, 1995; Stoessel, 2001).

In summary, the literature identifies the existence of both positive and negative effects of trade on the environment. The positive effects include increased growth accompanied by the distribution of environmentally safe, high quality goods, services and technology. The negative effects stem from the expansion of scale of production and consumption that could potentially threaten the regenerative capabilities of ecosystems while increasing the danger of depletion of natural resources.

2.1.3 How do trade and trade liberalization affect climate change?

The literature presented in this section focuses on sectors where trade liberalization has consequences on the emission of GHGs, which, in turn, affect climate change.

Trade and trade liberalization increase global production and consumption of goods and services, generate increases in countries’ incomes, and fuel economic growth. Higher trade volumes and increased trade in general are directly correlated with increased transport activities and increased demand for energy. How can these affect climate change?

According to the Center for International Climate and Environmental Research in Oslo, Norway, “The transport sector is responsible for a large share of gas and particle emissions

that affect the climate. These emissions also threaten human health, crops, and the material infrastructure. Higher standards of living and increased travel are largely to blame." Current means of transportation use fossil fuels whose burning generates around 21.2 billion tons of CO₂ per year, a GHG that enhances radiative forcing, thus contributing to climate change. McConnell (1999) points out that emissions of carbon monoxide (70 percent of which are produced by the transport sector) and carbon dioxide (25 percent of which are also produced by the transport sector) are destabilizing the earth's climate. Landis Gabel (1994) notes that transport is one of the major causes of environmental erosion in industrial countries. This is attributed to the depletion of non-renewable energy resources, noise and the development of infrastructure.

Road traffic is seen as the main contributor to climate change (mainly, warming) given its large emissions of CO₂ as well as significant emissions of ozone and soot. Road transportation is credited with generating more GHG than rail, and significantly more than sea-based freight transport (Stoessel, 2001).

Ships and planes regarded in a climate context are a special category. They are not covered by the Kyoto Protocol⁵, and emissions consist of components with short lifetimes and specific local effects. Ship emissions of NO_x in unpolluted areas have a big impact on ozone formation. According to Stoessel (2001), ships have the advantage of carrying 90 percent of world's trade while being responsible for around 2 percent of global CO₂ emissions. Air traffic, however, shows the most rapid and quantitatively significant increase in emissions. Its emissions of NO_x in areas that are rather clean have a large impact on ozone formation.

Without overlooking the environmental degradation caused by the increase in transport services as a result of trade liberalization, one should note several positive effects of trade liberalization in the transport sector. First, trade liberalization in the transport sector results in productive and allocative efficiency in the use of transportation services. Second, the existence of a larger market for more efficient transportation has the potential to generate technological developments in that area. Third, energy-intensive travel may be avoided by using electronic communication (Horrihan and Cook, 1998). Teleconferencing and telecommuting also reduce and even eliminate travel by offering people the possibility to work from home. All these advances in electronics and communication technologies will eventually contribute to GHG abatement. Policy is also seen as a key factor in reducing GHG emissions. Reducing mobility, improving energy and changing transport fuel's mix are only a few of the policy options that countries can adopt in an effort to reduce GHG emissions.

As with transportation, increased trade liberalization resulting in higher per capita incomes also raises the demand for energy. Consumption of fossil fuels also rises in response to trade liberalization, especially in developing countries (Millstead et al, 1999). Increased CO₂ emissions due to the burning of fossil fuels and energy use contribute to the greenhouse effect which, in turn, negatively affects climate change. Moreover, coal mining contributed 13 percent of the global methane emissions in the early 1990s. According to Stoessel (2001), where lack of market reform (internal liberalization) already has adversely affected pollution, trade liberalization will further aggravate these market and policy failures. The typical example is the coal market, where the effect of trade liberalization on climate change depends on the internal deregulation of the coal sector. In order to avoid changes in patterns of trade that potentially bring more pollution, internal liberalization should precede external

⁵ The Kyoto protocol is an international agreement whose major feature is that it sets binding targets for 37 industrialized countries and the EU for reducing GHG emissions.

liberalization. It has been pointed out that internal liberalization changes the relationship between industry and the government. This will then change the instruments available to governments for mitigation of climate change. Fells and Woolhouse (1996) suggest several solutions to market failure: replacing the market, encouraging the market to operate more efficiently through an incentives and costs system, and extending the application of property rights and creating a new market. The authors note that no policy tool is considered superior to the other. Also worthwhile mentioning are subsidies that have beneficial implications on climate change, such as subsidies that support the use of nuclear energy, renewable energy sources, hydroelectric power, as well as energy efficient investments (OECD, 1997).

In conclusion, both internal (market reform) and external (trade) liberalization in the energy sector are important factors in mitigating climate change, and the implementation of one without the other is thought to be detrimental to the atmosphere. While market reform on its own is trusted to decrease GHG emissions significantly, the net effect of combined internal and external liberalization, however, seems to be ambiguous.

2.2 Empirics

In general there are two main methods to obtain empirical evidence on pollution havens. The first uses investigations contained in case studies or interviews (e.g., interviews of industry representatives on location choices).⁶ The second uses econometric analyses. The econometric studies in turn can be classified into three broad categories. The first category includes direct examinations of location choices, which mainly focus on investigating environmental factors that determine new plant births within the US as a consequence of a lack of comparable cross-country data. The other two categories are indirect examinations of output and input flow. The former group of empirical studies explores the influence of differences in environmental stringency on output measures such as emissions or net exports, whereas the latter group of studies tests whether environmental regulations have an effect on the movement of inputs, such as capital and in particular foreign direct investments (Brunnermeier and Levinson, 2004).

This section presents a survey of the empirical literature, focusing on the studies of output flows. There are two reasons that explain our focus on this literature. First, there is a high number of scholarly contributions in this area of research and, second, our own empirical analysis is conducted in this manner.

The typical strategy of early studies is to regress trade flows on a measure of environmental stringency and other relevant control variables (such as income per capita) using cross-sectional country data. An early study is Tobey's (1990) paper. The author uses a cross-sectional Heckscher-Ohlin-Vanek model of international trade to examine trade patterns in five pollution-intensive sectors. For each sector he regresses net exports on country-specific measures of factor endowments and environmental stringency for 23 countries (the index of environmental stringency is an ordinal ranking of countries, based on subjective surveys). The results show that the environmental stringency index is insignificant in all regressions, leaving the author to conclude that environmental stringency has no measurable effect on net exports of polluting industries. Furthermore, in an additional omitted variable test

⁶ For a survey on this literature, see, for example, Brunnermeier and Levinson (2004). The authors find the results of this literature group inconclusive, and moreover, because the predicted effects are solely based on survey responses, there is no way to isolate and quantify them.

consisting of a larger country sample, Tobey cannot reject the hypothesis that environmental stringency has no effect on net exports. However, the validity of his conclusions seems questionable because the vast majority of the estimated coefficients are insignificant (especially the measure of environmental stringency).

An often cited paper is the investigation of Grossman and Krueger (1991) on the environmental effects of NAFTA. This study is among the first to find an “environmental Kuznets curve” (EKC) relationship between economic growth and pollution. The first exercise uses a cross-country sample of concentrations of air pollutants in various urban areas to explore the relationship between economic growth and air quality over time (while controlling for country, site and city specific characteristics). Finding that concentrations of sulfur dioxide and dark matter increase at low levels of per capita GDP and decrease at high levels of per capita GDP, the authors argue that this occurs because the technique effect offsets the scale effect (the EKC relationship). In a second exercise, Grossman and Krueger follow the approach of Tobey (1990), using data on US imports from Mexico classified by industrial sector. They investigate whether pollution abatement costs⁷ in the US could explain the Mexican specialization and trade patterns, thereby confirming the results of Tobey (1990), according to which environmental policy seems to have no effect on trade flows. The authors find that the composition effect created by an increase in US-Mexico trade is affected by factor endowments rather than by differences in pollution abatement costs (thus giving support to the factor endowment hypothesis). The coefficient of pollution abatement costs is negative in four of their six cross-industry regressions that explain US imports from Mexico (and is statistically significant in only two of these cases). This result contradicts the initial predictions, and the authors note that the perverse sign might be due to omitted variable bias.

Lucas et al. (1992) use a pooled cross-sectional model in order to investigate whether toxic intensity of production changed with economic growth for 80 countries during the period 1960-1988. The authors calculate total toxic emission per dollar of output for different US industrial sectors and make the assumption that these emission intensities remain constant over time and across countries. They find that developing countries as a whole had greater toxic intensity growth during the 1970s and 1980s, but toxic intensity increased in closed fast-growing economies while it declined in open fast-growing economies. This implies that trade liberalization could not have caused the toxic industry flight.

Birdsall and Wheeler (1993) replicate the study of Lucas et al. (1992) for 25 Latin American countries for the period 1960 to 1988 and report similar findings: Pollution intensity growth increased as a whole in Latin America. However, this effect is not associated with more trade openness, as in closed economies toxic intensity growth increased while in open fast-growing countries toxic emission growth declined over time. The authors conclude that pollution havens exist, but not where they are supposed to be in protectionist countries. The cited studies can be criticized on multiple grounds. First they only use income levels and openness as control variables; thus, they do not account for the role of other factors such as resource endowments. Second, because the studies use pooled cross-sections over time, the

⁷ In most cases authors use pollution abatement operating costs (PAOC) rather than capital costs (see Ederington and Minier, 2003, for arguments on this matter). We try to keep a differentiation as long as it is explicitly noted by the corresponding authors. However, in general we use the term pollution abatement costs (PAC) for simplicity.

obtained result could be subject to omitted variable bias. Finally, the assumptions used in constructing the toxic emission intensities seem rather questionable (e.g., determinants of sectoral pollution intensities, such as pollution control technologies, regulations and enforcement effort, are assumed to be the same across countries). This is equal to disregarding the technique effect and leaving only the scale and composition effects (Brunnermeier and Levinson, 2004).

Van den Bergh (1997) use a trade flow equation (a gravity model of international trade) to explain the bilateral trade flows between 21 OECD countries and examined how differences in strictness of environmental regulations between countries influenced a country's imports and exports. The authors ran three regressions: for total bilateral trade flows, for an aggregation of pollution-intensive-sectors, and for an aggregation of pollution-intensive-sectors that are non-resource based. As a measure of environmental stringency they constructed an environmental index for both the exporting and importing countries from two OECD environmental indicators in 1994.⁸ Other control variables included GDP, population and land area for both countries, the distance between them and three dummy variables (contiguous countries, EFTA member, European Community member). The results are partly consistent with the PHH in that the environmental index has a significantly negative effect on exports (in the first regression on total trade flows). In the second regression (dirty trade flows only) the effect is insignificant, which is consistent with the findings of Tobey (1990) for the 1970s. The authors argue that this might be due to the fact that many trade flows from dirty sectors are from resource based industries and thus from immobile industries. This is undermined by the results of the third regression (non-resource based dirty trade flows) that again show a negative and significant coefficient. On the import side the results are counterintuitive. All three regressions indicate a negative influence of country environmental regulation on imports. This leads Van Beers and van den Bergh to speculate that strict environmental regulations may provide an excuse for many governments to introduce new import barriers.

Mani and Wheeler (1998) search for the existence of pollution havens during the period 1960-1995 by using information on industrial production, trade and environmental regulation. Their study compares the development of the polluting to non-polluting output ratio (the share of pollution-intensive products relative to total manufacturing) over time with the development of the import to export ratio of polluting industries for the OECD and for Asian and Latin American emerging countries. The authors find evidence for the PHH. In the OECD countries the polluting to non-polluting ratio declined, while at the same time the import to export ratio of polluting industries increased. This is accompanied by an increase in the polluting to non-polluting ratio and a fall in the import to export ratio in Asian and Latin American countries during the same period. The authors argue that the existence of pollution haven effects revealed by their research had no major significance for several reasons. First, most of the dirty industry development seems to be explained by domestic factors, e.g., the consumption/production ratios in developing countries remained close to unity during the whole period under study. Second, the increase in the share of dirty products in developing countries is mainly caused by a high income elasticity of

⁸ Van Beers and van den Bergh (1997) actually constructed two indices: one broad index which included indicators of protected areas, unleaded gas market share, recycling rates of paper and glass, population with sewage connection, and energy intensity; and a narrow index, which included only two indicators related to energy intensity. The results of their estimations refer only to the narrow index.

demand for basic industrial products. While income continued to grow, this elasticity declined. Third, tougher environmental regulations seem to have played a role in the shift to cleaner sectors. All these factors led the authors to conclude that the evidence found on pollution havens seemed to have been self-limiting, because economic development induces pressure on polluters to increase regulation, technical expertise and clean-sector production. Thus, the authors only regarded pollution havens as transient. The investigation conducted by Mani and Wheeler can be criticized on the grounds that their findings are based on speculations, since no comprehensive model is developed that might explain the observed structural changes.

In sum, earlier studies investigating the effects of environmental regulations on output flows provided rather mixed results. In general, the estimated coefficient of the explanatory variable is small in magnitude and therefore insignificant. This can be attributed to the fact that the studies mentioned mainly used cross-sectional models which were unable to control for unobserved heterogeneity and endogeneity of right-hand-side variables.

The recent literature attempts to correct the deficiencies of previous studies by employing panel data. The typical strategy is to regress trade flows or data of pollutants such as sulfur dioxide or carbon dioxide on a measure of environmental stringency or a measure of openness respectively and other relevant control variables (such as income per capita and factor endowments) for a given period.

A number of recent studies are closely linked to our investigation. Antweiler et al. (2001), whose work represents an extension of Grossman and Krueger's (1991) paper, develop a theoretical model based on the decomposition of the effect of trade on the environment into scale, composition and technique effects. Then they estimate and add up these effects to explore the overall effect of increased trade on the environment, thereby allowing for pollution haven and factor endowment motives. Factor endowment motives of trade seem to dominate pollution haven motives, implying that high income countries tend to have a comparative advantage in pollution-intensive goods. When the estimates of scale, technique and composition effects are added up, the results point to the fact that increased trade causes a decline in sulfur dioxide concentrations. Based on their analysis, Antweiler et al. conclude that freer trade seems to be good for the environment.

Heil & Selden (2001) present evidence on the relationship between trade intensity and global patterns of pollution using data on carbon emissions across 132 countries from 1950 to 1992. In contrast to other studies that rule out the pollution shifting across countries by not interacting trade measures with income, Heil and Selden use a more functional form and show that increased trade intensity increases carbon emissions in lower income countries while lowering carbon emissions in higher income countries. Their findings support the PHH.

Dean (2002) uses the literature on trade and growth, as well as on the environmental Kuznet's curve, to show that freer trade does not necessarily harm the environment like some might believe. The author derives a simultaneous equations system that incorporates multiple effects of trade liberalization on the environment. Using pooled Chinese water pollution data pertaining to provinces, the estimation considers the scale, composition and technique effects. The results suggest that freer trade further worsens environmental damage via the terms of trade while alleviating it via income growth. The simulations seem to suggest that the net effect on China is beneficial.

Cole's and Elliott's (2003) approach is similar to Antweiler's et al. (2001). The authors examine the compositional changes in pollution arising from trade liberalization and

investigate the cause, i.e., the FEH and/or the PHH. Similar to Antweiler et al., Cole and Elliott find evidence supporting both factor endowment and pollution haven motives for SO₂, and that these effects seem to cancel each other out (leading the authors to conclude that this is a possible reason why many studies tend to find no evidence for the PHH). The estimated net effect of trade depends on the pollutant and on the pollutant's measurement (per capita emissions or pollution intensities). A trade-induced increase in income of 1% will cause a decline in per capita SO₂ emissions of 1.7% (but the net outcome is uncertain because the trade intensity elasticity is positive). Trade reform causes a reduction in per capita BOD emissions, while for NO_x and CO₂ further trade liberalization will increase emissions. However, if pollution intensities are used instead of emissions the results change: For all four pollutants, increased trade would reduce the pollution intensity of output.

Frankel and Rose (2005) contribute to the debate over trade and the environment by asking the question: What is the effect of trade on a country's environment, for a given level of GDP? The authors use exogenous geographic determinants of trade as instrumental variables to take account of the endogeneity of trade. They find that trade tends to reduce three measures of air pollution. Statistical significance is found to be high for concentrations of SO₂, moderate for NO₂, and absent for particulate matter.

The authors find a positive impact of trade on air quality (the estimated coefficient of trade is always negative) and support for the EKC (the estimated coefficients on the income square term are negative for all air pollutants). No evidence is found for "a-race-to-the-bottom" driven by trade or support for the PHH.

Similar work to that of Antweiler's has been done by Cole (2004, 2006), who examines the relationship between trade liberalization and energy consumption, and by Abdulai and Ramcke (2009), who examine the relationship between growth, trade and the environment both theoretically and empirically.

Cole (2004) tests for pollution havens as well as factor endowment motives by controlling for lagged income per capita (scale and technique effects) and capita-labor ratio (composition effect). The author finds evidence for both factor endowment and pollution haven hypothesis. Trade liberalization increases energy use for a capital-abundant country and decreases it for a capital-scarce country. Additionally, a high income country will find energy use falling in response to liberalized trade, whereas a low income country will experience an increase in energy consumption. The author estimates elasticities to assess the impact of trade liberalization on energy consumption for the mean country. Both the estimated scale-technique and trade-composition effects are positive, which implies that the mean country will experience increasing per capita energy use in response to trade liberalization. For the regressions with energy intensities, the technique effects are negative and the trade-composition elasticities positive; thus, the net outcome is uncertain.

Abdulai and Ramcke's (2009) results indicate the existence of an EKC for most pollutants, with some reservations. The hypotheses concerning the link between trade and environmental degradation cannot be entirely confirmed. However, the results bring modest support to the PHH. The authors further mention that there is some evidence that trade liberalization benefits sustainable development in rich countries, but can be potentially harmful for poor countries.

3. Estimation issues and methodologies

In this section we discuss the different methodologies applied in the studies described in the previous section. In particular, we highlight what the crucial choices are in designing a study

whose aim it is to test the PHH. Of course, a comparison of the findings is complicated by the studies' different underlying assumptions and methods. Even when the same methods are employed, the investigations may use different samples or sets of variables.

First, different dependent variables have been used as a measure of economic activity ranging from plant births, production emissions and net imports to inward and outward foreign direct investments. One might argue that the different applied variables are the causes of the mixed results reported in the literature. Xing and Kolstad (2002) argue that capital flows will be more affected by differences in environmental regulations than good flows because a country's production mix will only change in the long run. However, the choice of the dependent variable seems to be less important in regard to the ability to find evidence on pollution haven effects. Other factors appear to be more important, in particular the applied econometric approach (panel versus cross-section).

In the discussion of the dependent variable two further issues arise if pollutants are employed as dependent variables. These will be discussed briefly because the empirical analysis in the following part will also employ data on different pollutants as the dependent variable.

3.1 Concentration versus emission data

The EKC literature illustrated that the estimated relationship between economic variables (e.g., per capita income) and pollution can vary depending on whether pollutants are measured in terms of emissions or concentrations.⁹ Overall, it is important to note that data on concentrations is directly observable, while data on emissions is not. Therefore, emission data has to be constructed, and the method of construction differs by pollutant. Further, both measurement types have advantages and disadvantages. First of all, it has to be clear that concentrations and emissions provide different information. City-level concentrations offer more information related to the human health impact of a specific pollutant due to the direct link between the health of a city's population and pollution concentrations within that city. National emissions provide more information on nationwide environmental issues (climate change or acid deposition); thus, the link to city-level concentrations might be rather weak. Some policies that aim to reduce the detrimental health impact of air pollution could reduce city-level concentrations but not national emissions (e.g., encouraging of firms to locate outside the city). Furthermore, the use of concentration data leads to some issues in estimation and therefore requires the inclusion of several dummy variables in order to capture site-specific effects. Fixed site-specific effects, such as the nature of the observation site (e.g., city, suburban or rural), or the type of measuring equipment, are easy to control for using dummy variables. On the other hand time-varying site-specific effects, such as the average temperature of the site (might affect energy consumption) or the level of rainfall at the site (rainfall typically reduces concentrations), are more complicated (Cole and Elliott, 2003).

An example of a study employing concentration data as the dependent variable is Antweiler et al. (2001). The authors include numerous dummies to allow for site-specific effects (suburban, rural, average temperature and precipitation variation). An advantage of this study through the use of data on concentrations is the separation of technique and scale

⁹ See for example Selden and Song (1994).

effects, which is not possible with national emission data.¹⁰ In sum, as these two data types offer different information, the estimated results of a study using concentration data might differ from the results of a study using emission data.

An illustrative example for this is the study by Cole and Elliott (2003), using concentrations to test if the findings of Antweiler et al. (2001) also hold for emissions. In general, they support the results of Antweiler et al., which indicate that the form of pollution measurement has little effect on the estimated results.

In contrast, Naughton (2006) closely follows the approach by Frankel and Rose (2005), but uses emission data instead of concentration data. The author argues that the correlation between concentrations and emissions is low and thus might not be a good test of the environmental impact of trade, because theoretical models find a relationship between emissions, not concentrations, and trade. This data modification has significant effects. Naughton's estimated positive effect of trade on the environment is four times larger than what Frankel and Rose found, which implies that the measurement of pollution matters.

3.2 Results differ by pollutant

We might also expect the results to depend on the particular pollutants. Antweiler et al. (2001) propose that, in order to be useful for a study of this nature, a pollutant must possess as many of the following characteristics as possible: (1) It should be a by-product from goods production; (2) It should be emitted in greater quantities per unit of output in some industries than others; (3) It should have strong local effects; (4) It should be subject to regulations because of its adverse effects on the population; (5) It should have well-known abatement technologies; and (6) It should have data available from a wide mix of countries.

Most studies employ pollutants such as SO₂, NO_x or BOD, which possess all of these characteristics. CO₂ however, does not have a local impact and has not received a great deal of regulation in the past. SO₂, NO_x and BOD have received a greater degree of regulation than CO₂ (Hettige et al., 2000). Most domestic CO₂ regulations were implemented only in the last 5 to 10 years; attempts for multilateral regulations, such as the Kyoto Protocol, have been rather weak, and progress has been slow. Furthermore, all pollutants vary in characteristics such as atmospheric lifetime or health impact.

Indeed, estimated results in the empirical literature often differ by pollutant even in the same study. Cole and Elliott (2003) find in their study on four different pollutants that the impact of trade depends on the pollutant and on whether it is measured in terms of per capita emissions or pollution intensities. For the latter, they find for all four pollutants a negative effect on output. On the contrary, the estimated effects are different in magnitude and sign for all pollutants if measured in per capita emissions. In sum, the results often differ between pollutants, and there is no reason to expect that the finding for one pollutant will be robust for other pollutants (Cole and Elliott, 2003).

¹⁰ Antweiler et al. (2001) include as a measure of the scale effect the city economic intensity which is measured by GDP per km². Cole and Elliott (2003) use national emission data, but are able to estimate technique effects as well as a combined scale-technique effect due to the use of both per capita emissions and pollution intensities as dependent variables.

3.3 Target variable

Numerous studies test for the PHH by using a measure of environmental stringency as the explanatory variable. Some measures have obvious weaknesses. For example environmental stringency indices (used in studies such as Tobey, 1990; van Beers and van den Bergh, 1997; Harris et al., 2001) might lack objectivity. On the other hand, as mentioned by Wagner and Timmins (2008), it is possible that such a measurement captures the correlation even better than objective measures. Nevertheless, it is generally still preferable to apply an objective measure in order to present unambiguous results, so that clear policy implications are applicable.

Empirical papers that aim to explain an environmental variable, such as emissions, employ an indicator of trade liberalization or openness as explanatory variable. To our knowledge, all of those studies use the trade intensity (the sum of imports and exports divided by GDP). It might be interesting to check if the results hold for other measures of trade openness as well.

3.4 Level of industry data aggregation

A common characteristic of most studies relates to the use of aggregated industry data (researchers pool together all industries) in order to examine if countries or regions with differences in environmental regulations differ in pollution-intensive activities. However, there are a number of studies that use disaggregated data (industry specific data) to examine if specific industry sectors in a country are affected differently by environmental regulations.

Some researchers (for example, Grether and de Melo, 2002; Mathys, 2002) note that an aggregate analysis hides specific patterns in each industry and, hence, may mask pollution haven effects in specific industries. They argue that, if there is indeed a PHH story in the data, it is more likely to be found at the disaggregated level. Similarly, Ederington et al. (2005) identify and test three explanations for the lack of evidence on the PHH. These reasons are that (1) most trade takes place between developed countries; (2) some industries are less geographically footloose than others; and (3) for the majority of industries environmental regulation costs represent only a small fraction of total production costs. In all these three cases, aggregated trade flows across multiple countries could conceal the effect of environmental regulation on trade for countries with distinct patterns of regulation, in the more footloose industries, or in those industries where environmental expenditures are significant, respectively. The authors find support for the first two explanations: Estimating the average effect of an increase in environmental costs over all industries understates the effect of regulatory differences on trade in more footloose industries and on trade with low-income countries. On the other hand, a study that uses disaggregated data might be problematic, too. For example, most cross-industry studies only examine dirty industry sectors (e.g., Tobey, 1990). Those industries could share some unobservable characteristics (e.g., natural resource intensiveness) that also make them immobile. Restricting the sample to pollution-intensive industries might lead to the selection of the least geographically footloose industries. Furthermore, it would be reasonable to add clean sectors for a comparison, because we would expect that the effect of pollution regulations on pollution-intensive sectors is different (or even has the opposite sign) from the effect on clean sectors (Brunnermeier and Levinson, 2004).

3.5 The role of factor endowments

Recent studies that control for the role of factor endowments in addition to environmental regulations as the source of comparative advantage find that both effects are at work and tend to cancel each other out (see, for example, Antweiler et al., 2001; Cole and Elliott, 2003; Cole, 2006). In general, these studies state that a country with a low capital-labor ratio will experience pollution to fall with trade liberalization, while it will increase for a country with a high capital-labor ratio. Furthermore, a low-income country (with lax environmental regulations) will find an increase in pollution as a result of increased trade, while pollution will fall for a high-income country.

These findings might be an explanation of the failure of the earlier literature to find support for the PHH. Furthermore, these results are consistent with the earlier indications of theoretical models that comparative advantage is determined jointly by differences in regulation policy and factor endowments.

Empirical testing of the linkages between trade and the environment is complicated by two issues: unobserved heterogeneity and endogeneity.

Unobserved heterogeneity refers to unobserved industry or country characteristics which are likely to be correlated with strict regulations and the production and export of pollution-intensive goods. Assume a country has an unobserved comparative advantage in the production of a pollution-intensive good; consequently it will export a lot of that good and also will generate a lot of pollution. *Ceteris paribus*, it will impose strict regulations to control pollution output. If these unobserved variables are omitted in a simple cross-section model, this will cause inconsistent results, which cannot be meaningfully interpreted (in this example, a simple cross-section model would find a positive relationship between strict regulations and exports). The easiest solution to this problem would be to use panel data and incorporate country or industry specific fixed effects (Brunnermeier and Levinson, 2004).

The endogeneity problem is that pollution regulations and trade may be endogenous, i.e. the causality might run in both directions (problem of simultaneous causality). Assuming trade liberalization leads to higher income, which in turn causes an increase in the demand for environmental quality, it follows that environmental regulations could be a function of trade. A possible solution to this problem is to use instrumental variables techniques. However, the instruments should possess the following characteristics: vary over time and correlate with the measure of environmental stringency (but not with the error term) (Brunnermeier and Levinson, 2004).

3.6 Cross-section versus panel data and endogeneity correction

The early literature based on cross-sectional data tends to reject the PHH, or even finds, counterintuitively, that economic activity is concentrated in regions with stricter environmental regulation. However, for the majority of these studies the estimated coefficients are statistically and economically insignificant.

In contrast, recent studies using panel data do find at least moderate pollution haven effects in general. This is notable in that it does not depend on the explained variable. Studies on plant locations (e.g., Becker and Henderson, 2000) output flow such as imports (such as Ederington and Minier, 2003; Ederington et al., 2005; Levinson and Taylor, 2008) or emissions (e.g., Cole and Elliot, 2003), and on FDI (for example, Keller and Levinson, 2002; Cole and Elliott, 2005; Cole et al., 2006; Wagner and Timmins, 2008) all estimate a significant

pollution haven effect using panel data. These results indicate that it is important to control for unobserved heterogeneity.

Empirical investigations that control for endogeneity of environmental policy tend to find more robust evidence on moderate pollution haven effects. For example, Ederington and Minier (2003) and Levinson and Taylor (2008) find no significant effect of pollution abatement costs if they are treated as exogenous. If they model these costs, however, as endogenous, the authors do find a statistically significant effect. Yet any instrument variable analysis is always an easy target for criticism, since it will be sensitive to the choice of instruments. Frankel and Rose (2005) use instruments to control for the endogeneity of income and trade and find no support for the PHH. As they use a cross-sectional approach, however, the authors cannot control for unobserved heterogeneity.

What are the crucial factors for an empirical investigation testing the PHH? We found that the essential choices are which empirical methods are applied. It does not seem to matter whether these studies examine plant location decisions, investment or trade patterns.

Early studies based on cross-sectional analyses typically tend to find an insignificant effect of environmental regulations, while recent studies using panel data to control for unobserved heterogeneity or instruments to control for endogeneity do find statistically and economically significant pollution haven effects.

Furthermore, recent studies try to incorporate the traditional sources of comparative advantage into the analysis and find that both factor endowments and environmental regulations jointly determine the trade-induced composition effect. These effects however tend to cancel each other out leading the researchers to conclude that this might be a possible explanation of the failure to find evidence on the PHH in earlier studies.

4. Empirical analysis

In this section we conduct an empirical analysis in order to test for the pollution haven hypothesis. We choose to employ a panel study with aggregated data across countries and time. Despite the potential problems of such a study that were mentioned in Section 3 and the motivation to find more robust evidence at the disaggregated level, we follow this approach for several reasons. The first reason is its simplicity. The study design is relatively simple, while still providing a comprehensive and transparent test on this hypothesis. Moreover, this approach asks an interesting question: Whether a specific country or a specific group of countries tends to become a pollution haven for other countries (and this is the question which dominates the public debate). Additionally, the high number of contributions to this type of study reflects the relevance of this approach (examples include Heil and Selden, 2001; Antweiler et al., 2001; Cole and Elliott, 2003; Cole, 2004; Cole, 2006; Abdulai and Ramcke, 2009).

The analysis uses panel data on 95 countries during the period 1980-2004 and regresses three measures of pollution on trade intensity, hence controlling for income per capita, year and country specific effects (and indirectly also for population growth by employing the dependent variables in per capita terms).

4.1 Estimation method

The empirical specification applied in this analysis follows recent studies such as Heil and Selden (2001), Cole (2004), Frankel and Rose (2005), and Abdulai and Ramcke (2009) in employing the standard EKC framework with trade as an additional explanatory variable to test for the PHH. The model specification is given as follows:

$$\ln(ED)_{it} = \beta_0 + \beta_1 \ln(GDP)_{it} + \beta_2 [\ln(GDP)]^2_{it} + \beta_3 \ln(TRADE)_{it} + \delta_t + \mu_i + \varepsilon_{it}, \quad (1)$$

where ED denotes environmental degradation for country i and year t (this term includes the pollutants that are analyzed: per capita emissions of SO_2 , per capita emissions of CO_2 , and per capita energy consumption). GDP is gross domestic product per capita, $TRADE$ is the trade intensity (the sum of exports and imports divided by GDP) and ε_{it} is the stochastic error term. δ_t are the time specific fixed effects that control for time varying omitted variables and stochastic shocks which are common to all countries but which change over time (e.g. technological progress). μ_i are the country specific fixed effects that account for effects specific to each country which do not change over time (e.g. climate and resource endowments). The notation “ln” denotes the natural logarithm.

Unobserved heterogeneity is a potential problem. It refers to omitted variables that are fixed for an individual (at least over a long period of time). If the unobserved heterogeneity is correlated with the explanatory variables, OLS is biased and inconsistent. Fixed Effects (FE) could be employed to obtain consistent results. If the unobserved heterogeneity is uncorrelated with the explanatory variables, OLS is unbiased and consistent. In this case, we might still employ Random Effects (RE) in order to overcome the serial correlation of panel data and thus improve efficiency. Both employ a different approach as the FE model treats the δ_t and μ_i as regression parameters, while the RE model treats them as components of the random disturbance. We use a Hausman test to test the null hypothesis that RE is consistent. In some cases we cannot reject this hypothesis. However, throughout our analysis we report estimation results for both fixed and random effects.

Two methodological issues arise. Some authors such as Stern et al. (1996) argue that many studies fail to test for heteroskedasticity and autocorrelation. First, heteroskedasticity might be present due to the large variations in the income and environmental variables. Therefore we apply a modified Wald statistic for groupwise heteroskedasticity (following Greene, 2000, p. 598). In all regressions we can reject the null hypothesis of homoskedasticity.

The second issue concerns serial correlation. In order to control for this, we employ a Wooldridge test for serial correlation in panel-data models (Wooldridge, 2002, p. 282) and an Arellano-Bond test (Roodman, 2006, p. 34).

In sum, we test for heteroskedasticity and autocorrelation and can confirm the presence of both conditions in all of the specifications. Therefore, we use robust standard errors in both fixed and random effects estimation. The employed FE model calculates Driscoll-Kraay (DK) standard errors (Driscoll and Kraay, 1998).¹¹ DK standard errors assume the error structure to be heteroskedastic, autocorrelated up to some lag and possibly correlated between the groups. The RE specification uses robust standard errors (see, for example, Cameron and Trivedi, 2009, p. 233).

Estimations over the full sample could mask different effects between countries, since the estimated trade coefficient only shows the average change in the pollution level over all countries, and it is not possible to derive implications for the PHH or FEH.¹² To overcome this drawback, we divided the sample into different income groups (See Table 3 below).

The results should differ for the separate income groups, if the PHH or the FEH is true and dominant. The PHH would predict that trade increases pollution for low income countries

¹¹ A two-way FE model is applied (both time and country specific effects are included, one-way FE only includes country fixed effects).

¹² A positive trade coefficient for all countries could thereby give support to the “race-to-the-bottom” hypothesis and a negative coefficient to the Porter hypothesis. However, clear implications would only be possible if one analyzes the environmental policy in the respective countries.

and decreases it for high income countries. Hence, the trade coefficient should be positive for low income countries and negative for rich countries. In contrast, the opposite should be true for the FEH under the assumption that poor countries are capital scarce and rich countries are capital abundant, and that pollution-intensive goods are also capital intensive in their production.

Low Income		Middle Income		High Income	
Angola	Madagascar ¹³	Algeria	Mauritius ¹³	Australia	Korea, Rep. of
Bangladesh	Mali ¹³	Argentina	Mexico	Austria	Malta
Benin	Mozambique	Botswana	Panama	Belgium	Netherlands
Bolivia	Malawi ¹³	Brazil	Paraguay	Canada	New Zealand
Burkina Faso ¹³	Nigeria	Bulgaria	Peru	Denmark	Norway
Cameroon	Nicaragua	Chile	South Africa	Finland	Oman
China	Nepal	Colombia	Swaziland ¹³	France	Portugal
Côte d'Ivoire	Pakistan	Costa Rica	Syrian Arab Rep.	Gabon	Saudi Arabia
Ethiopia	Philippines	Dominican Rep.	Thailand	Germany	Spain
Ghana	Rwanda ¹³	Ecuador	Trinidad and Tobago	Greece	Sweden
Haiti	Sudan	Egypt	Tunisia	Hong Kong	Switzerland
Honduras	Senegal	El Salvador	Turkey	Hungary	United Kingdom
India	Togo	Guatemala	Uruguay	Iceland	USA
Indonesia	Uganda ¹³	Iran, Islamic Rep. of	Venezuela	Ireland	
Kenya	Vietnam	Jamaica		Israel	
Sri Lanka	Zambia	Jordan		Italy	
Morocco	Zimbabwe	Malaysia		Japan	

Table 3. Income groups.

The World Bank country classification uses GNI per capita to classify every economy into four income groups (low income, lower middle income, upper middle income and high income) (World Bank, 2009). We follow this approach, but we divide the sample into three different income groups (low, middle and high income), merging the two middle income groups into one middle income group. Studies as Abdulai and Ramcke (2009) only use two income groups, low and high income groups. In our opinion such a separation is questionable. Recall that in terms of the PHH we expect to find differences between poor and rich countries. Rich countries tend to have strict environmental regulations, and therefore export their dirty good production to low income countries with lax environmental policy. It should be expected that especially middle income countries should be an attractive relocation site in this context, because they inherit laxer environmental stringency than their richer counterparts and should also provide a sufficient infrastructure for the firms' production sites. Extremely poor countries might lack this needed infrastructure and are less interesting "pollution havens," as the costs for building up the production may be too high. The division into low and high income countries means that

¹³ No data on energy consumption, thus not included in respective regressions

middle income countries such as Mexico, Turkey, Brazil or Venezuela, which are often indicated as potential pollution havens in public debates, are incorporated into the high income group. If these countries are in fact pollution havens, separate regressions over low and high income samples are likely to show no support for the PHH, as the potential effects for the pollution havens are probably offset by the rich developed countries in the high income group. For the PHH to be true we expect the trade coefficient to be negative for the high income group and positive for low and middle income groups (particularly for the latter countries as they are often indicated to be pollution havens).

4.2 The data

The sample includes 95 developed and developing countries and covers the period 1980-2004.¹⁴ A complete list of countries can be found in Table 3. Data availability is the criterion used to select the countries; those with no data on specific variables or too many missing values are not considered.¹⁵ Descriptive statistics and definitions of the variables are shown in Table 4 for the whole sample and in Table 5 for each income group.

Variable	Definition	Obs.	Mean	Std.Dev.	Min.	Max.	Source
SO2PC	SO ₂ emissions (kg per capita)	1995	1.856	1.302	-4.679	4.947	World Bank (2008)
CO2PC	CO ₂ emissions (metric tons per capita)	2375	0.454	1.631	1.631	3.205	Stern (2005)
ENERGYPC	Energy use (kg of oil equivalent per capita)	2174	7.069	1.012	4.551	9.391	World Bank (2008)
GDP	GDP per capita, PPP (constant 2005 international \$)	2362	8.554	1.241	5.762	10.749	World Bank (2008)
TRADE	Trade Intensity (the sum of exports and imports divided by GDP)	2361	4.053	0.559	1.844	5.917	World Bank (2008)

Table 4. Variable definitions and descriptive statistics.

Our study uses the following variables: one dependent variable, environmental degradation; two direct measures of air pollution, CO₂ and SO₂ emissions; and one indirect measure of pollution, the energy consumption. All of them are measured in per capita terms to control for pollution generated by population growth.¹⁶ Sulfur dioxide, or SO₂, is produced in various industrial processes, e.g., during the combustion of coal and oil, which

¹⁴ For SO₂ emissions, the data is only available for the period 1980-2000.

¹⁵ E.g., no Eastern European countries were included, as there is no data for a large part of the sample period 1980-2004.

¹⁶ An initial approach employed total emissions as the dependent variable and total population as a control variable. The estimated coefficient of total population was very close to 1 for all pollutants in all regressions, and thus we chose to calculate and use the pollutants in per capita terms (according to the rules of logarithmic calculation).

often contain sulfur compounds. SO₂ dissolves in water vapor to form acid, and interacts with other gases and particles in the air to form sulfates and other components that can be harmful to people and their environment. SO₂ contributes to the formation of acid rain and is linked with increased respiratory symptoms and disease, difficulty in breathing and premature death (EPA, 2009). Sulfur dioxide data was obtained from Stern (2005) and are measured in kg per capita.

Variable	Income Group	Obs.	Mean	Std.Dev.	Min.	Max.
SO2PC	Low Income	714	0.769	0.979	-1.976	4.849
	Middle Income	651	2.141	1.021	-0.996	4.947
	High Income	630	2.793	0.956	-4.679	4.717
CO2PC	Low Income	850	-1.282	1.077	-3.575	1.351
	Middle Income	775	0.785	0.839	-1.858	3.205
	High Income	750	2.083	0.454	-0.058	3.110
ENERGYPC	Low Income	700	6.027	0.415	4.552	7.107
	Middle Income	724	6.935	0.573	5.857	9.149
	High Income	750	8.172	0.494	6.732	9.391
GDP	Low Income	837	7.164	0.574	5.762	8.229
	Middle Income	775	8.665	0.360	7.721	9.568
	High Income	750	9.992	0.332	8.552	10.749
(GDP) ²	Low Income	837	51.652	8.225	33.206	67.717
	Middle Income	775	75.207	6.240	59.611	91.551
	High Income	775	99.956	6.553	73.134	115.553
TRADE	Low Income	837	3.861	0.485	1.844	5.187
	Middle Income	775	4.109	0.592	2.446	5.433
	High Income	749	4.212	0.538	2.779	5.917

Table 5. Descriptive statistics for income groups. All variables are in natural logarithms.

Carbon dioxide, or CO₂, emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They incorporate carbon dioxide produced during consumption of solid, liquid as well gas fuels, and gas flaring. Carbon dioxide is one of the major greenhouse gases and CO₂ emissions play a central role in the global climate change debate. The employed CO₂ emissions are measured in metric tons per capita and were obtained from the World Development Indicators 2008 (WDI 2008) (World Bank, 2008). Note that CO₂ is purely a global externality, whereas SO₂ is a local air pollutant.

Data on energy consumption was also taken from WDI 2008 and is measured in kg of oil equivalent per capita. It is an indirect source of pollution, in particular air pollution. The consumption of energy and especially the burning of fossil fuels are the major causes of most air pollutants. Therefore it is a useful approach to examine the effect of trade on energy consumption (Cole, 2006). WDI 2008 additionally provided data on income, trade and population. The income measure is given by gross domestic product (GDP) per capita in purchasing power parity (PPP) terms in constant 2005 international dollars. Trade intensity as a percentage of GDP is calculated as the sum of exports (X) and imports (M) of goods and

services measured as a share of GDP ($X + M / GDP$). Total population was used to calculate emissions per capita. All the variables are in natural logarithms in order to make the variables less sensitive to outliers.

5. Results

5.1.1 Sulfur dioxide

The results for the full sample are presented in Table 6. We estimate equation 1 for SO_2 emissions by applying a FE regression with Driscoll-Kraay standard errors and a RE regression with robust standard errors due to the presence of heteroskedasticity and autocorrelation. Following the result of the Hausman test, we cannot reject the null hypothesis that the RE estimates are consistent. The coefficients are only slightly different in magnitude in both specifications. The income terms show the expected EKC relationship.¹⁷ The coefficient of GDP is positive and statistically significant, while its square term is negative but insignificant (in the FE model). However, an F-Test showed that GDP and its square term are jointly significant (p-value: 0.000). In the RE model, both terms are highly significant. In both models, the TRADE coefficient is positive and statistically significant. This would imply that further liberalized trade would cause an increase in per capita SO_2 emissions on average. However, this increase is small in magnitude: A 1% increase in TRADE would cause on average a less than 0.1% increase in emissions *ceteris paribus* (in the RE model). As mentioned, no implications for the PHH are possible. A regression over the full sample requires the effect of TRADE to be uniform across all countries, but the signs and magnitudes of the overall effects may mask important differences between countries. If one wants to test the pollution haven hypothesis, one approach to do so is to divide the sample into income groups.

The estimates change in the income group regressions (see Table 7). The Hausman test indicates that RE is consistent. Middle and high income groups again show the EKC relationship (GDP is positive, its square term negative). This is not the case for low income countries. There the signs are reversed. All these estimates are statistically significant at the 1% level. Surprisingly, the coefficients on trade are not as expected. Only for high income countries do we find a positive relationship between trade and SO_2 emissions per capita, which is contrary to our expectations. This indicates that further trade liberalization increases SO_2 emissions for rich countries. This finding is contrary to the PHH, but could provide support for the FEH. However, no clear implications are possible as the results for middle and low income countries are insignificant.

5.1.2 Carbon dioxide

The results for CO_2 , which are presented in Table 8, are similar to those of SO_2 for the whole sample. Again, we estimate equation 1 for CO_2 emissions by applying a FE regression with Driscoll-Kraay standard errors and a RE regression with robust standard errors. The FE estimates are preferred due to the result of the Hausman test. The estimates of FE and RE specifications are nevertheless similar. The expected EKC relationship is present: GDP and its square term are positive and negative, respectively. All are statistically significant

¹⁷It is not my focus, however, to find evidence on the EKC or to discuss it extensively. The focus is to find evidence for the pollution haven hypothesis.

at 1%. TRADE is again positive and highly statistically significant, although small in magnitude, indicating that increased TRADE causes rising emissions on average ceteris paribus.

Dependent Variable	(1) SO ₂ per capita		(2) CO ₂ per capita		(3) Energy use per capita	
	FE (DK ^a)	RE ^b	FE (DK ^a)	RE ^b	FE (DK ^a)	RE ^b
GDP	2.334** (1.010)	2.315*** (0.691)	1.480*** (0.188)	1.611*** (0.271)	-0.268** (0.117)	-0.311** (0.148)
(GDP) ²	-0.092 (0.069)	-0.093** (0.043)	-0.043*** (0.011)	-0.042*** (0.015)	0.050*** (0.007)	0.055*** (0.009)
TRADE	0.092* (0.047)	0.089** (0.040)	0.080*** (0.024)	0.090*** (0.023)	-0.011 (0.012)	-0.011 (0.013)
Constant	-11.321*** (3.403)	-11.063*** (2.592)	-9.243*** (0.749)	-10.522*** (1.209)	5.545*** (0.430)	5.571*** (0.607)
Observations	1979	1979	2358	2358	2159	2159
Groups	95	95	95	95	87	87
Hausman Test (p-value)	0.91 (1.000)		81.48*** (0.000)		37.09* (0.093)	
Autocorrelation coefficient	0.880	0.839	0.810	0.873	0.905	0.925
R ² (within)	0.146	0.146	0.858	0.342	0.839	0.564
F-Test: all country effects = 0 ^c	101.69***	13635.46***	169.04***	20477.97***	290.47***	21481.41***
F-Test: all year effects = 0 ^d	130000***	321.47***	20408.55***	(19.52)	91563.29***	41.55**

Table 6. Estimation results for the full sample. Standard errors in parentheses. ***, **, *, indicate significance at 1%, 5% and 10%, respectively. All the variables are in natural logarithms. a) Fixed Effects estimation with Driscoll-Kraay standard errors. b) Random Effects estimation uses robust standard errors. c) RE estimation employs a Breusch-Pagan LM Test for individual effects. d) if year effect test- statistic is in parentheses, year effects were not significant and thus not included in estimation.

Concerning income groups, for low and high income countries the Hausman test indicates that RE are consistent. For middle income countries the null hypothesis that RE are consistent could be rejected only at the 10% level. This means that it could be kept at the 5% level, and thus a RE model is also estimated (see Table 8). Again, we find a statistically significant EKC relationship for middle and high income countries, but not for low income countries. For poor countries the GDP term is negative and insignificant, and its square term is positive (and significant). On the other hand, we do find statistically significant evidence for pollution haven consistent behavior. For low and middle income countries further trade liberalization will increase CO₂ emissions per capita, while it will decrease for high income countries. The TRADE coefficients are positive for both poorer income groups and negative for rich countries. Following the predictions of the PHH this is exactly as expected.

Dependent variable is SO ₂ per capita	Specification					
	FE (DK ^a)			RE ^b		
	Low Income	Middle Income	High Income	Low Income	Middle Income	High Income
GDP	-4.065*** (1.002)	7.948*** (1.677)	22.554*** (1.727)	-4.079*** (0.834)	7.859*** (2.381)	23.830*** (6.456)
(GDP) ²	0.328*** (0.068)	-0.410*** (0.103)	-1.084*** (0.084)	0.329*** (0.057)	-0.404*** (0.141)	-1.165*** (0.326)
TRADE	-0.015 (0.034)	0.091 (0.059)	0.444 (0.347)	-0.013 (0.033)	0.092 (0.058)	0.285** (0.145)
Constant	13.291*** (3.594)	-35.936*** (6.790)	-115.676*** (10.099)	13.334*** (3.013)	-35.602*** (10.098)	-119.71*** (31.867)
Observations	699	651	629	699	651	629
Groups	34	31	30	34	31	30
Hausman Test (p-value)	0.17 (1.000)	0.83 (1.000)	21.69 (0.539)			
Autocorrelation coefficient	0.831	0.771	0.892	0.954	0.927	0.628
R ² (within)	0.329	0.227	0.288	0.329	0.227	0.284
F-Test: all country effects = 0 ^c	350.64***	242.02***	35.22***	6254.18***	5440.84***	1981.73***
F-Test: all year effects = 0 ^d	26793.74***	1314.87***	738.61***	82.18***	63.66***	180.57**

Table 7. Estimation results for SO₂ income groups. Standard errors in parentheses. ***, **, *, indicate significance at 1%, 5% and 10%, respectively. All the variables are in natural logarithms. a) Fixed Effects estimation with Driscoll-Kraay standard errors. b) Random Effects estimation uses robust standard errors. c) RE estimation employs a Breusch-Pagan LM Test for individual effects. d) if year effect test- statistic is in parentheses, year effects were not significant and thus not included in estimation.

5.1.3 Energy consumption

For the whole sample (Table 6), we follow the same approach as before (FE with Driscoll-Kraay standard errors and RE with robust standard errors). According to the Hausman test, the null hypothesis that RE is consistent could be rejected at the 10% level (i.e., it could be kept at the 5% level). Both FE and RE are estimated and the estimated coefficients only differ slightly in size. Surprisingly, the results for the indirect measure of pollution are not at all consistent with the results for SO₂ and CO₂. All coefficients have the reversed sign. No EKC relationship is present. GDP is negative; the square term of GDP is positive. The TRADE coefficient is again small in size, but this time negative, implying that an increase in trade on average decreases energy consumption. However, the coefficients on trade are not statistically significant even at the 10% confidence level.

Next, we estimate both FE and RE for each income group. The Hausman test results suggest that for low and high income countries RE is consistent, but not for middle income countries (p-value=0.000) (see Table 9). GDP and its square term are statistically significant in all specifications. Middle and high income countries experience first increasing emissions per capita with rising income and decreasing emissions with higher income increases. The opposite is found for low income countries; the GDP term is negative and its square term positive. For energy consumption per capita we can find evidence for the PHH. The TRADE coefficients are all statistically significant and show the expected signs. Trade will cause poorer countries (low and middle income groups) to increase their energy consumption per capita. On the other hand, rich countries (high income group) will reduce their energy use following further trade liberalization.

Dependent variable is CO ₂ per capita	Specification					
	FE (DK ^a)			RE ^b		
	Low Income	Middle Income	High Income	Low Income	Middle Income	High Income
GDP	-1.241 (0.967)	3.498*** (0.733)	4.271*** (0.890)	-0.975 (0.903)	3.387*** (0.992)	4.391*** (1.281)
(GDP) ²	0.128** (0.064)	-0.146*** (0.043)	-0.159*** (0.049)	0.113* (0.062)	-0.139** (0.057)	-0.167** (0.068)
TRADE	0.105** (0.044)	0.067*** (0.014)	-0.145** (0.071)	0.098** (0.042)	0.067** (0.030)	-0.135*** (0.051)
Constant	0.614 (3.535)	-18.742*** (3.135)	-24.237*** (4.057)	-0.494 (3.248)	-18.373*** (4.307)	-24.298*** (6.064)
Observations	834	775	749	834	775	749
Groups	34	31	30	34	31	30
Hausman Test (p-value)	26.64 (0.483)	6.64* (0.084)	4.63 (0.98)			
Autocorrelation coefficient	0.740	0.793	0.886	0.883	0.927	0.779
R ² (within)	0.553	0.364	0.331	0.325	0.589	0.387
F-Test: all country effects = 0 ^c	169.67***	314.93***	81.03***	6747.91***	7240.81***	4959.66***
F-Test: all year effects = 0 ^d	1013.59***	127.91***	1844.71***	40.54**	37.13**	34.76*

Table 8. Estimation results for CO₂ income groups. Standard errors in parentheses. ***, **, *, indicate significance at 1%, 5% and 10%, respectively. All the variables are in natural logarithms. a) Fixed Effects estimation with Driscoll-Kraay standard errors. b) Random Effects estimation uses robust standard errors. c) RE estimation employs a Breusch-Pagan LM Test for individual effects. d) If year effect test- statistic is in parentheses, year effects were not significant and thus not included in estimation.

5.2 Discussion

This section summarizes our empirical findings and critically discusses them.

Econometric issues such as heteroskedasticity and autocorrelation complicated the estimations, and while we still employed methods to control for these matters (robust standard errors), these issues might have weakened the quality of our estimation. Despite this drawback, 62 of the 72 estimated coefficients (86%) are statistically significant, and we do find most results in agreement with expectations. Regressions over the whole sample indicated a positive and statistically significant effect of trade on SO₂ and CO₂ emissions per capita (the effect on energy consumption is negative but insignificant). This result seems to provide support to the “race-to-the-bottom” hypothesis (see footnote 33 for limitations). With respect to the income group estimations, we could not find statistically significant results for SO₂ concerning the trade variable; thus, no implications on the effect of trade on sulfur dioxide emissions are possible. The results for CO₂ emissions per capita and energy consumption per capita are more optimistic. In general, both dependent variables show consistent results, and the findings are as expected. We do find moderate support for the pollution haven hypothesis. Trade liberalization will cause increasing CO₂ emissions and energy consumption in low and middle income countries, while the opposite will occur in high income countries. However, this effect is marginal. The effect of a 1% increase in trade intensity on CO₂ emissions per capita is about 0.09% and 0.06% for low and middle income countries, respectively (and -0.13% for high income countries). For energy consumption per capita the effect is .05% to 0.06% for low and middle income countries (and -0.15% for high income countries).

Dependent variable is energy use per capita	Specification					
	FE (DK ^a)			RE ^b		
	Low Income	Middle Income	High Income	Low Income	Middle Income	High Income
GDP	-1.767*** (0.489)	1.953*** (0.682)	9.431*** (0.296)	-1.828*** (0.391)	2.348*** (0.905)	7.859*** (0.914)
(GDP) ²	0.145*** (0.033)	-0.071* (0.042)	-0.448*** (0.016)	0.150*** (0.027)	-0.090* (0.053)	-0.356*** (0.046)
TRADE	0.030* (0.016)	0.062*** (0.022)	-0.174*** (0.040)	0.050*** (0.012)	0.095*** (0.018)	-0.151*** (0.033)
Constant	11.053*** (1.786)	-4.964* (2.711)	-40.642*** (1.341)	11.146*** (1.411)	-7.035* (3.881)	-34.121*** (4.570)
Observations	686	724	749	686	724	749
Groups	28	29	30	28	29	30
Hausman Test (p-value)	0.57 (1.000)	0.000 (0.000)	0.71 (1.000)			
Autocorrelation coefficient	0.899	0.891	0.884	0.953	0.923	0.905
R ² (within)	0.159	0.476	0.452	0.459	0.637	0.683
F-Test: all country effects = 0 ^c	451.64***	329.05***	241.41***	7315.30***	6068.25***	6875.27***
F-Test: all year effects = 0 ^d	901.25***	1091.70***	21.80***	(17.15)	(27.98)	(32.07)

Table 9. Estimation results for energy consumption income groups. Standard errors in parentheses. ***, **, *, indicate significance at 1%, 5% and 10%, respectively. All the variables are in natural logarithms. a) Fixed Effects estimation with Driscoll-Kraay standard errors. b) Random Effects estimation uses robust standard errors. c) RE estimation employs a Breusch-Pagan LM Test for individual effects. d) If year effect test- statistic is in parentheses, year effects were not significant and thus not included in estimation.

In general, our results are consistent with the findings of other empirical studies. Abdulai and Ramcke (2009) find moderate support for the PHH in their income group regressions for energy consumption as well (however, their estimated coefficients are even smaller than our estimates in magnitude). Some support for the PHH is also found in Cole and Elliott (2003). The authors estimate that a 1% increase in trade generates a 0.05 increase in per capita carbon emissions for the mean country. Cole (2006) finds support for the PHH; according to his estimates; low income countries will increase their energy use and high income countries will decrease their energy use as a consequence of further trade liberalizations. Following his estimated trade elasticities, a 1% increase in trade would increase energy consumption per capita by 1.7% to 3.1% (for the mean country). Similarly, Heil and Selden (2001) conclude in their analysis of CO₂ emissions that increased trade intensity causes falling emissions for high income countries and rising emissions for low and middle income countries. They predict that a 1% expansion of trade would cause a 0.11% increase in CO₂ emissions for a low income country and a 0.14% decrease in carbon emissions for a high income country.

To answer the central question of this paper: Does trade liberalization cause poor countries to pollute more, while causing rich countries to become cleaner? Due to the simplicity of the empirical analysis, we do not claim to have found a clear-cut answer to this question. As mentioned earlier, the aggregated data investigation could hide specific effects, and disaggregated data should be used to find clear evidence for the PHH. Furthermore, we did not directly control for the role of factor endowments, which recent papers try to

incorporate in their analyses. Additionally, advanced panel data methods might be able to find more robust evidence. Despite these limitations, our analysis gives a fair approximation on this topic and a rough idea of the direction of the effects of trade on the environment.

6. Summary and conclusions

This investigation is an attempt to answer the following questions: 1. Is trade good or bad for the environment in the context of the pollution haven hypothesis?. 2. Do rich developed countries shift their pollution-intensive production to poor developing countries? 3. Is trade liberalization responsible for increased GHG emissions (e.g., CO₂) and/or sources of GHG emissions (e.g., SO₂) contributing to climate change?

No clear-cut and unambiguous answer to the first two questions is possible, due to the complex relationship between trade and the environment. There are many intervening forces at work. In this paper we emphasized the role that income plays in the context of the effects of trade on the environment. It is a complicated task to disentangle these forces and to identify and quantify the pure effect of trade on the environment. Air pollutants such as SO₂ and CO₂ contribute to numerous health and environmental problems, such as diseases, acid rain, or global climate change in general. Our approach to answer these questions was to examine theoretical and empirical research in this area and to conduct our own empirical analysis on this matter.

First, according to the theoretical models, the impact of trade on the environment can be decomposed into scale, technique and composition effects. The effect of interest is the composition effect that can contribute to increasing and also falling pollution. The direction of the composition effect depends on a country's comparative advantage. In this context, we examined two competing hypotheses on the determinants of comparative advantage and thus the pattern of trade: the pollution haven hypothesis and the factor endowment hypothesis. The pollution haven hypothesis states that differences in environmental regulation are the only determinant of comparative advantage, while the factor endowment hypothesis states that relative factor endowments, such as capital and labor, explain the pattern of trade. It is rather likely that both, differences in environmental policy and factor endowments, jointly determine comparative advantage and thus the pattern of trade. Econometric analyses might be able to answer the crucial question of which of these effects dominates.

We tested empirically for the pollution haven hypothesis and illustrated what potential problems are found in the estimation associated with unobserved heterogeneity and endogeneity. While the majority of early studies typically applied a cross-sectional analysis and tended to find a non-significant pollution haven effect, recent studies that used panel data to control for unobserved heterogeneity or instruments to control for endogeneity did find statistically and economically significant pollution haven effects. Recent papers additionally incorporate the role of factor endowments into their empirical models. Most of them reported similar findings in that both pollution haven and factor endowment motives were at work and they tended to cancel each other out. This offers a possible explanation why most early studies failed to find robust evidence on the pollution haven hypothesis.

We argue that estimations over the full sample would not be able to identify possible implications for the PHH (or the FEH). The estimated coefficient for trade would only show the average change in the pollution level over all countries and would not be able to illustrate differences between poor and rich countries (these differences are the central focus in the

argumentation of the pollution haven hypothesis.) Hence, we divided the sample in three income groups (low, middle and high income). Regressions over these groups should differ if the PHH (or the FEH) is true and dominant. The trade coefficient is expected to be negative for high income countries and positive for low and middle income countries. We found that for the whole sample further liberalized trade causes per capita emissions of SO₂ and CO₂ to increase on average, and these results were statistically significant. For energy consumption we found negative and insignificant trade coefficients. Concerning the results of the estimations for each income group, for CO₂ emissions and energy consumption we did find the expected signs for the trade coefficients. Indeed, for low and middle income countries the trade coefficient was positive and for high income countries negative (all statistically significant). In general, these results give support to the pollution haven hypothesis. Trade liberalization will increase emissions in poorer countries (low and middle income economies), while it will decrease emissions in rich countries (high income). Additionally, these results are consistent with findings of other empirical investigations. In contrast, these findings could not be obtained for SO₂ emissions. The estimates were mostly not significant. Only for high income countries did we find a positive effect of trade on sulfur emissions, meaning that trade causes increasing sulfur emissions in richer countries (which might implicate support for the factor endowment hypothesis). However, all the estimates are relatively small in magnitude. On average, a 1% increase in trade intensity would cause an effect of about a 0.1% increase or decrease in emissions all else being equal.

In sum, although the theory and the recent empirical work tend to find moderate support for the pollution haven hypothesis, there is still a lot of uncertainty in this field of research, and results tend to be ambiguous. Whether rich countries' dirty goods production tends to migrate to poor developing countries through further trade liberalization remains unclear. The net effect, however, is likely to be determined by a change in the trade patterns (composition effects). Further empirical research that uses data at a disaggregated level and incorporates the role of other factors such as environmental regulations is necessary to find unambiguous results.

Regarding the issue of whether trade liberalization is responsible for increased GHG emissions (e.g., CO₂) and/or sources of GHG emissions (e.g., SO₂) contributing to climate change, the answer, again, is not so straightforward. If indeed there is a relationship between increased trade and increased production of goods and services, then increased trade will impact the changes in climate a great deal. The impact of trade liberalization on climate change, however, need not be negative. Trade can certainly have both positive and negative effects. The positive effects lie in the increased efficiency of the resources used, the dissemination of environmentally friendly technology, and the creation of the much-needed income to increase environmental protection. The less desirable effects involve the increased scale of economic activity (the scale effect), that can be harmful to ecosystems since they could result in irreversible damage. Equally, existing market and policy failures are thought to be aggravated by trade liberalization (Stoessel, 2001). While trade by itself is not the main cause of anthropogenic climate change, there is evidence that trade liberalization has indirectly contributed to anthropogenic climate change through an increase in transportation activities as well as an increase in the use of fossil fuels energy (e.g., CO₂).

In conclusion, we agree that "trade liberalization is -per se- neither necessarily good nor bad for the environment. Its effects on the environment depend on the extent to which environment and trade goals can be made complementary and mutually supportive. A positive outcome requires appropriate supporting economic and environmental policies" (UNEP, 2000).

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This book shows some of the socio-economic impacts of climate change according to different estimates of the current or estimated global warming. A series of scientific and experimental research projects explore the impacts of climate change and browse the techniques to evaluate the related impacts. These 23 chapters provide a good overview of the different changes impacts that already have been detected in several regions of the world. They are part of an introduction to the researches being done around the globe in connection with this topic. However, climate change is not just an academic issue important only to scientists and environmentalists; it also has direct implications on various ecosystems and technologies.

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