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Trade, Pollution and the Environment: An Examination of Economic Growth and Greenhouse Emissions from Different Sources

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To the Graduate Council:

I am submitting herewith a dissertation written by Alejandro E. Dellachiesa entitled "Trade, Pollution and the Environment: An Examination of Economic Growth and Greenhouse Emissions from Different Sources." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Economics.

Don P. Clark, Major Professor

We have read this dissertation and recommend its acceptance:

Dr. Daniel De La Torre Ugarte, Dr. Dayton Lambert, Dr. Mohammed Moshin, and Dr. Mary F. Evans

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To the Graduate Council:

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Trade, Pollution and the Environment: An Examination of Economic Growth and Greenhouse Emissions from Different Sources

A Thesis Presented for
The Doctor of Philosophy
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Alejandro Enrique Dellachiesa
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Abstract

This dissertation investigates the relationship between greenhouse gas emissions, international trade, and economic growth as per capita incomes increase. The first chapter uses a Suits Index to illustrate the degree of pollution concentration among countries at different levels of per capita Gross Domestic Product. It also analyzes the collective progressivity of pollution and compares countries with similar levels of per capita income to monitor emissions as countries move up the income scale. Pollution is found to be concentrated among the lower income countries for all sources of greenhouse gas emissions including nitrous oxide, methane, and carbon dioxide. Emissions are more concentrated among poorer countries when the source of pollution is the agricultural sector. Poor countries account for much more pollution than would be expected from their levels of economic activity and well being.

Chapter 2 uses an Environmental Kuznets Curve model to investigate the relationship between methane and nitrous oxide emissions from industrial and agricultural sources and per capita income from 1970 to 2005 for 157 countries. A fixed effect panel regression model is used to capture technological change, economies of scale, composition effects, and trade effects on per capita pollution. Results suggest that an inverted U-shape characterizes the relationship between per capita income and both industrial and agricultural emissions, but that agricultural turning points will occur later and at a higher per capita pollution than industrial turning points in the absence of regulation.

In Chapter 3, a dynamic fixed effect panel data regression model is used to explore the relationship between pollution emissions and several related economic factors. An alternative simultaneous equation model is developed to allow for both a direct effect of trade on
environmental damage via changes in relative prices and an indirect effect of trade on income
growth via liberalization. Human capital, physical capital, labor and the catch-up term are
expected to affect the growth of the economy positively and significantly. The extent of their
economic significance will depend on the level of economic activity of the countries analyzed.
Direct and indirect effects of openness on pollution are ambiguous and enter insignificantly or
have a small effect on pollution across all country groups. Concerns about trade liberalization
on environmental degradation from GHG seem unjustified.
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Industrial and Agricultural Nitrous Oxide, Methane and Carbon Dioxide Emissions:

Different Policy Approaches
Introduction

Several empirical studies on the relationship between pollution and economic growth used different measures of environmental quality and found that environmental quality initially worsened as per capita income increased. These studies help determine whether growth steadily worsens environmental conditions or if it eventually leads to an increase in environmental quality, but they have not given adequate recognition to the extent of pollution in the poorest developing countries relative to their levels of economic activity. In this study, rather than comparing the level of emissions and per capita income, emissions are compared with the level of economic activity to understand the relationship between economic growth and environmental quality. The objective of this paper is to evaluate the relationship between nitrous oxide, methane, and carbon dioxide emissions and the level of economic activity as countries develop and increase per capita income. It also analyzes the collective progressivity of pollution and compares emissions of countries with similar per capita gross domestic product levels as they reach higher per capita incomes. Understanding these results will help develop policy recommendations to reduce pollution and achieve sustainable development in lower income countries.

Measures of economic activity such as gross domestic product, industry value added, agricultural value added, industrial exports, agricultural exports, total industrial trade, and total agricultural trade are included to investigate the relationship between economic development and pollution emissions. Most developing countries’ top policy priorities are economic development and trade liberalization. Jones and Rodolfo (1995) and Lee and Roland-Holst (1997) point out that overall trade is expected to improve environmental quality, but it has contradictory impacts on the environment, since it increases pollution but also motivates its
reduction. Grossman and Krueger (1991) identify three possible impacts of an increase in economic activity due to a reduction in trade barriers and consequently an increase in trade. The first factor adversely affects the environment through an expansion of economic activities (scale effect). The second entails a structural change of the current production (composition effect), which will not result in pollution reduction everywhere, and the third factor results in changes in the production techniques (technique effect). The composition and the technique effects have to offset the effect of the expansion of the economic activity for the possibility of an Environmental Kuznets Curve (EKC) relationship. Industrial value added and agricultural value added reflect the level of industrial-agricultural development and are key indicators of sustainable development. Both industrial value added and agricultural value added have mixed impacts on the environment. They increase pollution as they expand but are also expected to motivate its reduction through per capita income and adoption of newer, cleaner technology.

This study differs from previous studies in several aspects. First, this research compares emissions with levels of economic activity, which helps understand the relationship between economic growth and environmental quality, rather than comparing the level of emissions and per capita income. Second, this study uses a more complete dataset from the Emissions Database for Global Atmospheric Research (EDGAR 4.0), which enables disaggregation of the data by industrial and agricultural sources rather than using total pollution. This will help formulate better policies to achieve emission reductions and attain sustainable development. Third, this study focuses on the three major GHGs, but attention is focused on measures of methane and nitrous oxide, which have received less attention than carbon dioxide, from industrial and agricultural sources.
We find that pollution is concentrated among the lower income countries, which account for much more pollution than would be expected from their levels of economic activity. Economic-pollution relationships are consistent with the EKC hypothesis, but agricultural turning points will take a longer time and will occur at a higher per capita pollution than industrial emissions in the absence of regulations. Although an EKC relationship exists between per capita income and pollution, addressing environmental problems early in the process of economic development will result in a more favorable tradeoff between economic growth and environmental quality. Understanding the relationship between measures of economic activity and environmental quality will help formulate sustainable development policies in less developed countries.

**Literature review**

Grossman and Krueger (1991), World Bank (1992) and Selden and Song (1992) found an inverted U-shape relationship between per capita income and environmental quality known as the Environmental Kuznets Curve. The EKC hypothesis suggests that during the initial stages of economic growth, environmental quality will deteriorate; then, after reaching a peak, it will improve as the economy grows. It also suggests that as countries develop and increase their per capita income, the composition of their production results in cleaner technologies and service activities. Grossman and Krueger (1991) found that environment quality deteriorates with growth until middle income is attained. Roca et al. (2001) and Magnani (2001) suggested that this is true for a select set of pollutants and not for environmental quality in general.

Dijkgraaf and Vollebergh (2001 and 2005) challenged the existence of an overall EKC for CO₂ emissions. Other studies as Shafik and Bandyopadhyay (1994) and Roca et al. (2001)
found that per capita CO₂ increases monotonically with income growth.¹ Sengupta (1996) suggested peaks for CO₂ at $8,740 (1985 US dollars) but found that beyond $15,300 emissions have positive elasticities, which implies that emissions decline over a mid range of incomes and then increase with GDP growth. Friedl and Getzner (2003) found a similar N-shape relationship between GDP and CO₂ emissions for industrialized countries. Holtz-Eakin and Selden (1995) suggested a diminishing marginal effect of CO₂ emissions as income increases, but the effect is not significant. Roca et al. (2001) found that for CH₄ emissions economic growth is associated with more emissions. Giles and Mosk (2003) estimated a “double-hump” EKC curve for CH₄ in New Zealand, with a maximum of $8,000 US 1996 real dollars.

Magnani (2001), in her cross-sectional analysis, estimated the level of income at which emissions start declining for industrial nitrous oxide to be between $9,000 and $12,000 (1985 US dollars) for a panel of 152 countries. Magnani also found some evidence that CO₂ emissions increased with per capita income. Using the same data of pollution emissions from the United Nations Environmental Program (1994), Hill and Magnani (2002) estimated peaks for industrial N₂O to occur between $8,000 and $12,000 (1985 US dollars) for 156 countries. They also found that the CO₂ turning point for three cross-sectional results analyzed occurs at $9,000 in 1970, $13,000 in 1980 and $11,000 in 1990. Hill and Magnani suggested that the empirical EKC relationship is shown to be highly sensitive to the choice of pollutant, sample of countries and time period, and recommended the inclusion of education and inequality variables.

Antweiler, Copeland, and Taylor (2001) and Liddle (2001) argued that trade is not the root of the cause of environmental damage. As trade expands, there is a tendency to adopt

¹ Most studies on CO₂ use data from the Carbon Dioxide Information and Analysis Center (CDIAC) at the Oak Ridge National Laboratory.
cleaner techniques of production, since trade raises real incomes, which will create demand for
tighter environmental protection. Edwards (1997) and Zaki Eusufzai (2006) also found positive
relationships between trade expansion and income distribution. Some studies like Gallagher
and Taylor (2003) found that trade increases pollution by leading to an expansion in the size of
the economy. To that extent Batra, Beladi, and Frasca (1997) concluded that trade is the cause
of environmental degradation, ceteris paribus. Levinson and Taylor (2006) examined the effect
of environmental regulations on trade flows and found that an increase in abatement costs
the possibility that developing countries with low wages and lax environmental regulations
have been an attractive alternative for producers in dirty sectors from developed economies. In
terms of the environment it is desirable to allocate production in a country with an
“environmental” comparative advantage where it has the lowest environmental impact.

The share of agricultural and industrial activities tends to change with the development
of the economy as resources move from one sector to the other. Panayotou (1993) pointed out
that environmental degradation tends to increase as the structure of the economy changes from
rural to urban, from agricultural to industrial, but starts falling with the second structural
change from energy-intensive heavy industry to services and technology-intensive industry.
This industrial structural change is not expected to offset the upward emissions trend from the
agricultural sector for methane (CH\(_4\)) and nitrous oxide (N\(_2\)O) due to the large agricultural
contribution of CH\(_4\) and N\(_2\)O on total emissions. Trade is expected to increase environmental
degradation among countries with different levels of economic activity, but its effect is
expected to be alleviated through income growth as countries become wealthier.
Methodology

The Suits Index is used in this analysis as a measure of collective progressivity of pollution. Similar to the Gini coefficient, the Suits Index is calculated by comparing the area under the Lorenz curve to the area under a proportional line.\(^2\) For a progressive pollution the Suits Index is positive. This happen when richer countries pollute more than poor countries. A proportional pollution has a Suits Index of zero, and a regressive pollution has a negative Suits Index. In a regressive pollution lower income countries have a greater fraction of pollution. The Gini coefficient is computed as the ratio of the area from the Lorenz curve sag to the 45 degree line to the total area under the 45 degree line. If there is no pollution inequality, the Lorenz curve is simply the line of perfect equality, the 45 degree line, and thus the area between the Lorenz curve and the line of perfect equality is zero, making the Gini coefficient zero. In order to adapt this measure of income inequality to the application of estimating the progressivity of pollution, Suits envisioned a figure similar to the Lorenz curve, but one in which the cumulative percent of pollution is plotted on the vertical axis against the cumulative percent of Gross Domestic Product (GDP) on the horizontal axis. Pollution data and per capita GDP, accumulated GDP, industrial and agricultural value added, industrial and agricultural exports, and trade are taken from the WDI database. Carbon dioxide, CH\(_4\), and N\(_2\)O emissions are calculated in thousand metric tons (kt) of CO\(_2\) equivalent.

Countries are ranked in ascending order according to their per capita GDP and are grouped in deciles based on per capita GDP. Figures are converted from percentages and accumulated. For the Lorenz curve, the cumulative percent of total pollution is calculated and plotted on the vertical axis against the cumulative percent of the total GDP on the horizontal

\(^2\) Daniel B. Suits (1977).
axis. The 45 degree line from bottom left corner of the diagram to top right corner represents the line of perfect pollution equality. Along this line, pollution distribution is perfectly proportionate to the GDP. The first deciles of the population earns exactly 10 percent of the income, the first two deciles earn 20 percent, and so on. The farther above the line of perfect equality the Lorenz curve sags, the less equitable is the pollution distribution as illustrated in Figure 1.1. On the other hand, if there is extreme pollution inequality with one decile holding all pollution, the Lorenz curve sags all the way down to the axis, and the area between the line of perfect equality and the Lorenz curve approaches the full area under the line of perfect equality, making the Gini coefficient one. Thus, the Gini coefficient ranges from zero for no pollution inequality to one for the most extreme inequality in which all income is concentrated in single deciles. As an example, Figure 1.1 shows the relationship between GDP and pollution emissions, which in this case is consistent with the curvilinear relationship between percentage changes in GDP and percentage changes in emissions.

To construct the Suits Index, we can let $K$ denote the area below the line of proportionality, and let $L$ denote the area below or above the Lorenz curve. The Suits Index is defined as: $S = 1 - L/K$. For a proportional tax, $L$ approaches $K$, so the Suits Index $S$ approaches zero. If the Lorenz curve corresponding to progressive tax sags below the line of proportionality, the area $L$ is smaller than $K$. As a result, the index $S$ is positive for a progressive pollution. In the limiting case where the highest income countries generate the entire pollution emissions, the Lorenz curve lies along sides $OA$ and $AB$, so $L$ equals zero and hence $S = 1$. With a regressive pollution, the Lorenz curve arches above the line of proportionality, making the area $L$ larger than $K$, so $S$ is negative. An index of minus one indicates that pollution is completely regressive, with the lowest GDP countries generating all
the pollution. An index value of zero identifies a proportional pollution. It is important to notice that the Suits Index is used here as a measure of the average progressivity of pollution over GDP. Values of the index can vary from -1, where all pollution is attributed to low income countries, to +1, where all pollution derives from high income countries. Some pollution may be progressive over one range of GDP and regressive over another range. This is a familiar problem that arises with any average measurement. As a summary measure of the progressivity of pollution, the Suits Index is incapable of capturing subtleties that require information about higher moments of pollution. The concentration of pollution is presented in a manner that facilitates the calculation of the Suits Index.

Figure 1.1: Lorenz curves for Pollution
In Table 1, column 1 divides countries into deciles, with the accumulated percentage of industrial GDP in column 2. Columns 3 through 5 contain the corresponding accumulated percent of industrial value added, industrial exports and industrial trade respectively. The accumulated industrial pollution of CH\textsubscript{4}, N\textsubscript{2}O, and CO\textsubscript{2} are reported in column 6, 7, and 8. The accumulated percent income is measured on the horizontal axis as a variable $y$ that ranges from 0 to 100. The vertical axis represents the corresponding accumulated percent of total emissions $E_x(y)$, where $x$ is the pollutant. Therefore, the area under the curve can be approximated to the value of the integral as

$$L_x = \int_0^{100} E_x(y)\, dy \quad (1)$$

which is similar to

$$L_x = \sum_{i=1}^{10} \left[ E_x(y_i) + E_x(y_{i-1}) \right](y_i - y_{i-1})/2 \quad (2)$$

The values of $E_x(y)$ are only determined for 10 observations corresponding to the countries grouped into 10 deciles. Therefore, a close approximation of the progressivity of the emissions is given by

$$S_x = 1 - \left( L_x / K \right) \quad (3)$$

or in other words by

$$S_x = 1 - \left( 1 / K \right) \int_0^{100} E_x(y)\, dy \quad (4)$$
\[ S_x = 1 - \left( \frac{1}{K} \right) \sum_{i=1}^{10} \left[ E_i(y_i) + E_i(y_{i-1}) \right] \left( y_i - y_{i-1} \right) / 2 \]  

(5)

where the area \( K \) is the same for all pollutants and is defined as the triangle \( OAB \). \( K \) equals 5,000 since it is measured as half of the area of the figure, which has a base and altitude of 100.

**Data**

This study uses \( \text{CH}_4, \ \text{N}_2\text{O}, \ \text{CO}_2 \) emissions from 1970 to 2005 to describe and explain the relationship between economic growth and environmental deterioration for 157 countries. Estimated industrial and agricultural emissions for these countries are obtained from the Emissions Database for Global Atmospheric Research (EDGAR 4.0) from the Netherlands Environmental Assessment Agency (NEAA). Per capita income, measured in constant 2000 US dollars adjusted for purchasing power parity, is used as an approximation for income and is taken from the World Development Indicators (WDI), published by the World Bank (WB).\(^3\)

Per capita income is the sum of the gross value added by all resident producers in the economy, plus any product taxed and minus any subsidy not included in the value of products, divided by the mid-year population. Because of the limitations of per capita income, the United Nations Development Program launched in 1990 the Human Development Index (HDI), which measures social progress. The Human Development Index encompasses more than income and production and would be a better indicator, but its reliability and validity has not been fully proved. Today per capita income is still the most reliable measure of economic production.

\(^3\) Most of the World Bank data came from numerous international organizations, government agencies, and private and non-governmental organizations, like the Food and Agricultural Organization (United Nations), the International Monetary Fund (IMF), and 23 other worldwide organizations (The World Bank, 2009).
The ratios of total industrial value added to gross domestic product (IVA) and total agricultural value added to gross domestic product (AVA) are measures of a broad structural transformation. Industrial value added is the most important indicator to weigh industrial activities and a country’s manufacturing-based economy. Agricultural value added is the net output after adding up all outputs and subtracting intermediate inputs. It is calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. Trade data is taken from the World Bank and is measured as the sum of exports and imports of goods and services. Industrial and agricultural exports include goods and services that are produced in a country but sold to be used or consumed abroad. Imports are goods and services that are produced in a foreign country but used or consumed domestically. Therefore, international trade can be smaller, equal, or larger than gross domestic product.

Countries are divided into ten deciles according to their per capita GDP in order to compare the relationship between their economic activity and environmental deterioration using the Suits Index. To match the World Bank development definition, countries included in the first four deciles are referred to collectively as poor countries; the 5th, 6th, 7th, and 8th deciles are referred to as middle income countries, and finally the 9th and 10th deciles as high income countries. The EKC analysis countries are divided by the World Development Indicators (WDI) definition of Low, Middle, and High income, which correspond to <$935, $935 to $11,455, and >$11,250 in 2005 dollars, respectively.

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4 Industry corresponds to ISIC divisions 10-45 and includes manufacturing (ISIC divisions 15-37).
5 Agriculture corresponds to ISIC divisions 1-5 and includes forestry, hunting, and fishing, as well as cultivation of crops and livestock production. The origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3.
World Greenhouse gas emissions

This study focuses on the three largest greenhouse gases, CO₂, CH₄ and N₂O. According to the Kyoto protocol, there are six greenhouse gases that significantly affect the atmosphere and must be reduced: CO₂, N₂O, CH₄, SO₂, hydrofluorocarbons, and perfluorcarbons but CO₂, CH₄, and N₂O are the major sources of the change in the thermal equilibrium temperature of the planet, called the greenhouse effect. According to the EDGAR database, pollution emissions increased on average by 2.5, 0.9 and 1 percent per year for CO₂, CH₄, and N₂O respectively, during 1970-2005. The carbon dioxide concentration in the atmosphere was approximately 280 parts per million in pre-industrial times. As of March 2009, carbon dioxide in the earth’s atmosphere was at a concentration of 387 parts per million.⁶

Carbon dioxide pollution emissions include road transportation, rail transportation, other transportation, public electricity and heat production, other energy industries, manufacturing industries and construction, domestic aviation, residential and other sectors, fugitive emissions from solid fuels, oil and gas, production of minerals, and production of chemicals and metals. Other important sources are industrial processes and forest fires (forest fires are not included in this study). A predominant source of anthropogenic CO₂ emissions is from fossil fuel combustion and some non-energy production processes such as cement production.⁷

Methane is also a relatively potent greenhouse gas with a high global warming potential of 75 (averaged over 20 years) or 25 (averaged over 100 years) (IPCC Fourth Assessment

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⁶ The data is collected monthly at Mauna Loa Observatory, Hawaii. NOAA/ESRL. www.esrl.noaa.gov/gmd/ccgg/trends
⁷ The Intergovernmental Panel on Climate Change (IPCC) stated that “the increased amount of CO₂ is leading to climate change and will produce, on average, a global warming of the Earth’s surface because of its enhanced greenhouse effect-although the magnitude and significance of the effects are not yet fully resolved” (IPCC 1996)
Methane’s lifetime is usually counted the same as the lifetime of CO2, but it lasts only a decade. Methane emissions result from agriculture and industrial production. Agricultural CH4 emissions are emissions from livestock, animal waste, rice production, and agricultural waste burning. Industrial CH4 emissions come from the handling, transmission, and combustion of fossil fuels and biofuels. Methane’s relative abundance and its clean burning process as fuel have made it popular and have lead to an increase in man-made CH4. Methane is the principal component of natural gas and, when burned in the presence of oxygen, produces carbon dioxide and water. Agriculture emissions represented 43 percent of total CH4 emissions in 2005, followed by industrial emissions with 35 percent, and the “others” sector with the remaining percentage.

Nitrous oxide is a powerful greenhouse gas with an estimated lifetime of 114 years. Nitrous oxide emissions can originate from both industrial and agricultural activities. Industrial emissions include public electricity and heat production, other energy industries, manufacturing industries and construction, domestic aviation, road transportation, rail transportation, other transportation, residential and other sectors, fugitive emissions from solid fuels, fugitive emissions from oil and gas, international aviation and navigation, production of chemicals, solvent and other product use. Other sources of N2O pollution include solid waste disposal on land, wastewater handling, waste incineration, other waste handling, indirect NOx from non-agricultural N2O, indirect NOx from non-agricultural NH3, and other sources.

In 2005, approximately 82 percent of the world total N2O emissions came from the agricultural sector, followed by the other sources.
sector and industrial emissions with 12.6 and 5.5 percent, respectively (EDGAR 2009). Almost 80 percent of the world N₂O increases during the last decade came from the agricultural sector, in which soil emissions, manure, and fertilizer were the major sources. Per kilogram global warming potential of N₂O is nearly 310 times that of carbon dioxide within 100 years. N₂O and N₂O per capita, measured in thousand metric tons of CO₂ equivalents, are the operational definitions of N₂O in this study (Edgar v4.0).

Carbon dioxide, CH₄, and N₂O are measured in thousand metric tons or 1000 kilotons (kt) of CO₂ equivalent which is the unit used by the World Development Indicators (World Bank, 2008). In order to compare different greenhouse gas emissions, the emissions of individual gases have to be converted into CO₂ equivalents. Several international cooperative actions have been developed during the last decades to establish short, medium and long term reduction goals. The United Nations Framework Convention on Climate Change (UNFCCC) is an international treaty produced at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro in 1992. The treaty provides for protocols that set mandatory emission limits. The Kyoto protocol was signed in 1997 in Kyoto, Japan and entered into force on 2005 but will expire in 2012. Under the Protocol, 37 industrialized countries commit to a collective reduction of CO₂,
CH₄, N₂O, and sulfur hexafluoride SF₆, emissions by 5.2 percent from the 1990 level. Prior to the UNFCCC conference, in 1987 the Montreal Protocol was signed and designed to protect the ozone layer by phasing out the production of several groups of halogenated hydrocarbons that have been shown to be ozone depleting substances. There is evidence of a successful decrease of ozone-depleting substances in the atmosphere.¹⁶

Figure 1.2 shows that emissions of major greenhouse gas emissions increased by an average of 2 percent per year during the period 1970 to 2000. Since then, global greenhouse emissions have shown an even stronger annual increase. Figure 1.3 shows the distribution of CO₂ emissions by country during the period 1970-2005. Fossil fuel combustion is a predominant source of CO₂ emissions and is trending up due to an increase in electrical and heat production as well as an increase in road transportation (EDGAR). Non-road transportation and residential emissions remain almost constant over time. Industrial emissions show a modest increase from 1970-1995, but production of building materials like cement and metal shows a significant increase (EDGAR).

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In 1970, approximately 50 percent of CO$_2$ emissions came from the United States and other OECD countries. In 2005, OECD countries represented 36 percent of the world CO$_2$ emissions. Around 11 percent of the total increase in emission flow during the period 1970-2005 can be attributed to the OECD countries, 45 percent to China, 10 percent to India, and the remaining 35 percent to other developing and less developed countries. China and India increased their emissions by 590 and 460 percent during the last 35 years, respectively. In 2004, China became the largest emitter of CO$_2$ surpassing the United States. The total stock of CO$_2$ increased from 310 ppm in 1970 to 387 ppm in March 2009.\footnote{17 Monthly mean of CO$_2$ flow measured at Mauna Loa Observatory, Hawaii.}

Figure 1.4 shows an increasing flow of N$_2$O emissions during the last 35 years of around 1.1 percent per year. Approximately 35 percent of those increases come from China, 17 percent from India, 14 percent from Brazil, and the remaining 34 percent from the rest of the World. The OECD countries, including the United States, decreased their flow of emissions by 20 percent during the last 35 years. On the other hand, China and India expanded their flow of emissions of N$_2$O by 230 and 140 percent during the last 35 years, respectively. Almost 90 percent of the total increase on emissions during the period 1970-2005 comes from the agricultural sector, and the remaining 10 percent from the other emissions sector. Emission flows from the industrial sector decreased by 55 percent during the same period. Almost all of that decrease comes from OECD countries. The total stock of N$_2$O accumulated pollution in the atmosphere increased from 0.30 ppm in 1970 to 0.32 ppm in 2005 (Mauna Loa Observatory, Hawaii).

Figure 1.5 shows the flow of emissions of CH$_4$ increased by 34 percent worldwide during the period 1970-2005, or about 1 percent per year. 28 percent of this increase in
emissions comes from China, 15 percent from India, 15 percent from Brazil, and the remaining 45 percent from the rest of the world. The United States flow of emissions of CH$_4$ remained stable and the rest of the OECD countries decreased their emissions by 13 percent during the last 35 years. Forty-eight percent of the total world increase in methane emissions during the last 35 years was from an enormous increase in urban waste generation linked to the increase of per capita consumption. The main destination of waste is dumps, without any exploitation of CH$_4$ for energy use. This sector has grown more than 85 percent over the last 35 years. Another 42 percent comes from industrial emissions, and the remaining 10 percent from the agricultural sector.$^{18}$ The total stock of CH$_4$ increased from 1.5 ppm in 1970 to 1.7 ppm 2005.$^{19}$

![Figure 1.3: Carbon dioxide emissions per country during 1970-2005](chart)

Source: EDGAR 4.0

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$^{18}$ A reduction of such emissions could be significant if projects to change the waste management are put in place.

$^{19}$ Monthly mean of CO$_2$ flow measured at Mauna Loa Observatory, Hawaii.
Figure 1.4:
Nitrous oxide emissions per country during 1970-2005 (CO2 equivalents)
Source: EDGAR 4.0

Figure 1.5:
Methane emissions per country during 1970-2005 (CO2 equivalents)
Source: EDGAR 4.0

Results

Countries in Tables 1.1 and 1.2 are divided into ten deciles according to their per capita GDP to facilitate the calculations of the Suits Index. Columns 1 and 2 show the accumulated percentage of countries and GDP. The accumulated percentages of industrial value added, industrial exports, and trade are used to compare the relationship between their economic activity and the environment, as shown in columns 3, 4, and 5. Columns 6 through 8 report the
accumulated percentages of annual flow of emissions of industrial CH$_4$, N$_2$O, and CO$_2$, respectively. The first three deciles are grouped in poor countries, the 4$^{th}$, 5$^{th}$, 6$^{th}$, 7$^{th}$, and 8$^{th}$ deciles in middle income countries, and finally the 9$^{th}$ and 10$^{th}$ in high income in order to match the World Bank definitions of development.

Greenhouse gas emissions are found to be concentrated among the lower income countries in Tables 1.1 and 1.2. For example, the poorest 50 percent of the countries account for almost 5 percent of the world industrial GDP, 10 percent of the industrial value added, 3 percent of the industrial exports, 6 percent of the total industrial trade. They are responsible for 50 percent of the world industrial CH$_4$ emissions, 19 percent of the N$_2$O emissions, and 30 percent of CO$_2$ emissions for the year 1970. In 2005, the same 50 percent of poorest countries accounted for 10 percent of the industrial GDP, 16 percent of the industrial value added, 15 percent on industrial imports, and 14 percent of the world trade of industrial goods. They account for 58, 31, and 39 percent of the world industrial CH$_4$, N$_2$O, and CO$_2$ emissions. This implies that during the last 35 years, the 50 percent of the poorest countries increased their GDP by 117 percent, their industrial value added by 60 percent, and their industrial exports by 431 percent, with China accounting for most of those increases. During 1970-2005 China’s share of the total world GDP increased by 5.2 percent and its share of the world industrial exports by 10.9 percent, but surprisingly China’s share of industrial value added remained the same during that period.

Pollution emissions are more concentrated among the lower income countries, as the accumulated percentages of CH$_4$, N$_2$O, and CO$_2$ emissions are found to exceed the accumulated percentages of GDP (Table 1.1 and 1.2). This suggests that at the first stages of development environmental degradation increases in a more than proportional way. Poor countries account
for more pollution than expected for their level of economic activity, wellbeing, and
development. Moving up the per capita income scale, industrial CH₄, N₂O, and CO₂ show a
significant increase in accumulated percentage terms after the second decile. This jump is
largely due to the presence of China’s emissions in the fourth decile.

Table 1.2 and Figures 1.6-1.7 show the relationship between per capita GDP and
accumulated percent of industrial CH₄, N₂O, and CO₂, respectively. Results are consistent with
the inverted U-shape pollution-GDP relationships reported in many other studies. Industry N₂O
reaches a peak in the eighth decile, where the difference between accumulated percentage of
GDP and accumulated N₂O emissions is greater. Other studies reported similar levels of per
capita income. Magnani (2001) reports peaks for N₂O industrial emissions around $9,000 and
$12,000. Hill (2002) found turning points around $7,500 and $12,000. Industrial CH₄ and CO₂
reach peaks at deciles 5 and 8. The per capita income for decile five is $1,335 to $2,006 and for
decile eight is $5,857 to $14,002 where the greatest difference is observed between the
accumulated percentage of CO₂ and the accumulated percentage of both exports and total trade.

Figures 1.8 and 1.9 show that the IVA-pollution relationship is consistent with an
inverted U-shape. The relative size of the industrial sector (IVA) is a key economic activity and
a significant indicator of the state of the economy, and has been used as a growth determinant.
### Table 1.1:
Concentration of Industrial Pollution (Accumulated Percentages, 1970)

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Suits Index - GDP: **-0.57**  **-0.25**  **-0.17**  **-0.28**
Suits Index - IVA: **-0.52**  **-0.22**  **-0.13**  **-0.24**
Suits Index - Exports: **-0.59**  **-0.26**  **-0.51**  **-0.13**
Suits Index - Trade: **-0.53**  **-0.14**  **-0.21**

Source: European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.0.

### Table 1.2:
Concentration of Industrial Pollution (Accumulated Percentages, 2005)

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Suits Index - GDP: **-0.58**  **-0.25**  **-0.30**
Suits Index - IVA: **-0.53**  **-0.22**  **-0.26**
Suits Index - Exports: **-0.51**  **-0.13**  **-0.19**
Suits Index - Trade: **-0.52**  **-0.14**  **-0.21**

Source: European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.0.
The Industrial sector is a major structural component of total economic activity which hints at basic driving forces associated with sustainable development. Industrial value added rather than per capita GDP is the core element to the development process (Chenery Hollis, 1979). Comparing figures in column 3, with column 6, 7, and 8 shows that the accumulated percentages of CH₄, N₂O and CO₂ exceed the accumulated percentages of industrial value added across the income scale.

The higher the measure of trade (exports plus imports) of a country, the larger its degree of openness. An open economy is a market economy mostly free from trade barriers.²⁰ The relationship between pollution and both industrial exports and trade is identified in columns 4 through 5 and Figures 1.10 through 1.13. The relationship between openness and pollution shows a concentration of pollution in the least “open” economies as the accumulated percentages of pollution for each of the three sources exceed the accumulated percentages of both exports and trade. Industrial N₂O and CH₄ emissions reach a peak in the 5th and 6th deciles, where the difference between accumulated percentage of industrial exports and industrial trade, and accumulated nitrous oxide pollution is greater. The per capita income for these deciles varies from $1,589 to $3,959, which indicates that industrial trade and exports may help decrease the turning points of emissions of these two sources. Levinson and Taylor (2006) found that increasing the degree of openness through trade may be harmful to the environment. Others studies like Shafik and Bandyopadhyay (1992) and Ederington et al. (2004) did not find a significant relationship between pollution emissions and trade intensity. Dasgupta (1997) and Liddle (2001) found that trade might enhance environmental quality by stimulating growth of less polluting firms and the adoption of more efficient and cleaner technologies.

²⁰ No economy is totally open or closed in terms of trade restrictions. All governments have varying degrees of control over movements of capital and labor.
Figure 1.6  
GDP and industrial emissions, 1970

Figure 1.7  
GDP and industrial emissions, 2005

Figure 1.8  
IVA and industrial emissions, 1970

Figure 1.9  
IVA and industrial emissions, 2005

Figure 1.10  
Industrial Exports and emissions, 1970

Figure 1.11  
Industrial Exports and emissions, 2005
Suits Index values, shown in Table 1.2, summarize the overall degree of pollution concentration among countries displaying widely different levels of economic activity and wellbeing. An examination of Suits Index values shows that CH$_4$, N$_2$O, and CO$_2$ are concentrated among countries with low levels of economic activity. This finding holds regardless of the measure of economic activity used. All Suits Index values are negative, ranging from -0.13 for the industrial N$_2$O-Exports relationship to -0.58 for the industrial N$_2$O-GDP relationship.

In Tables 1.3 and 1.4, columns 6 and 7 show the accumulated agricultural emissions of CH$_4$ and N$_2$O. Accumulated GDP, agricultural value added, agricultural exports, and agricultural trade are reported in columns 2, 3, 4, and 5. Results from Table 1.4 and Figures 1.14 through 1.21 show that agricultural N$_2$O emissions and CH$_4$ emissions are highly concentrated among the least developed countries. The fifth line of Table 1.4 shows that the poorest 50 percent of the countries account for almost 11 percent of the world GDP, 47 percent of the industrial value added, 12 percent of the merchandize exported, 19 percent of the total
agricultural trade, and 56 percent of the world agricultural CH\textsubscript{4} and 56 percent of the agricultural N\textsubscript{2}O pollution for the year 2005.

For the third and fourth deciles, agricultural CH\textsubscript{4} indicates an abrupt increase in accumulated percentage terms mostly due to India and China’s emissions in the third and fourth decile, respectively. The percent of accumulated agricultural exports for the poorest nations decreased from 17 to 12 percent, but trade (exports plus imports) increased by almost 77 percent during the last 35 years. The small reduction in exports and increase in trade indicates that those countries increased significantly their imports of agricultural products. Almost all of that change is captured in the fourth decile by China. Most of the accumulated percentages of agricultural N\textsubscript{2}O and CH\textsubscript{4} emissions are generated by India and China in the third and fourth deciles and are trending up. Comparing pollution from the industrial sector and agricultural sector in Figures 1.7 and 1.15 shows that when the source of pollution is from the agricultural sector, emissions are heavily concentrated in the least developed countries and seem to reach their peaks at a higher level of accumulated percent of GDP. Therefore, turning points for the agricultural sector are expected to occur later than the industrial sector and at higher per capita pollution.

\textsuperscript{21} China and India represent 22 percent of both world arable land and world livestock (FAO, 2005). Brazil represents 14 percent of the world livestock and 6 percent of the arable land.

\textsuperscript{22} Agricultural value added is closely related to other economic and environmental indicators reflecting the level of development and use of natural resources, depletion of resources, as well as the share of agriculture exports.
Table 1.3: Concentration of Agricultural Pollution (Accumulated Percentages, 1970)

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Suits Index - GDP
Suits Index - AVA
Suits Index - Exports
Suits Index - Trade

Source: European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.0.

Table 1.4: Concentration of Agricultural Pollution (Accumulated Percentages, 2005)

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Suits Index - GDP
Suits Index - AVA
Suits Index - Exports
Suits Index - Trade

Source: European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.0.
Table 1.4 and Figures 1.14 through 1.21 show an inverted U-shape between environmental quality and all measures of economic activity selected. Agricultural CH$_4$ and N$_2$O emissions reach a peak in the eighth decile, where the greatest difference is observed between the accumulated percentage of CH$_4$ and N$_2$O and the accumulated percentage of GDP. Per capita income varies between $5,857 and $14,002 across the eighth decile. The turning points for CH$_4$ and N$_2$O from industrial and agricultural sources occur at the same decile, but turning points for agricultural emissions for both pollutants are expected to occur at a higher bound than for industrial emissions.

Pollution is found to be concentrated in the least “open” economies as the accumulated percentage of both N$_2$O and CH$_4$ are found to exceed accumulated percentages of both exports and trade throughout the entire income scale. Perkins (2005), Iwami (2005) and Liang (2006) also found more open economies to actually have less toxic emissions.

Collectively, these findings suggest that openness brings an initial phase of environmental degradation followed by an eventual improvement. Trade impacts firm scales, and scale is expected to have a negative impact on environmental quality. Early in the process of economic development, growth is stimulated by capital accumulation that tends to degrade the environment by shifting the composition of outputs in favor of dirty products. As development proceeds, the technology (technique effect) starts to offset the scale effect. Composition effect for high income might actually reinforce the technique effect as these countries specialize in the production of cleaner goods and service activities. Overall trade is expected to improve environmental quality.
Figure 1.14
GDP and agricultural emissions, 1970

Figure 1.15
GDP and agricultural emissions, 2005

Figure 1.16
AVA and agricultural emissions, 1970

Figure 1.17
AVA and agricultural emissions, 2005

Figure 1.18
Agricultural Exports and emissions, 1970

Figure 1.19
Agricultural Exports and emissions, 2005
Suits Index values from the industrial and agricultural sector are negative, implying that emissions from both sources are more concentrated among poorer countries for all measures of economic activity. Index values for agricultural emissions range from -0.20 for the CH$_4$-AVA relationship and -0.66 for the CH$_4$-GDP relationship. Except for the industrial N$_2$O-IVA relationship, all Suits Index values are significantly larger for agricultural sources than corresponding figures for industrial sources. This indicates that pollution from agricultural sources is more concentrated than emissions from industrial sources in countries with low levels of economic activity. It also indicates that turning points for agricultural sources will take a longer time and will occur at higher levels than for industrial sources. Agricultural pollution from N$_2$O and CH$_4$ are concentrated in developing countries and represented approximately 82 and 42 percent of the N$_2$O and CH$_4$ emissions in 2005 and is trending up.$^{23}$ Implementing policies to reduce pollution from the agricultural sector will be more efficient in wealthier nations. Enforcing stricter environmental standards for agricultural practices in

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$^{23}$ Emission Database for Global Atmospheric Research (EDGAR).
developed countries will encourage investment in the development of cleaner technology and newer, environmentally friendly practices that will eventually transfer to developing countries.

**Conclusions**

The Suits Index shows the overall degree of pollution concentration among countries with different degrees of development. CO₂, CH₄, and N₂O from industrial and agricultural sources are concentrated among lower income countries regardless of the measure of economic activity used. Agricultural emissions are found to be more concentrated among poor countries and to reach turning points later and at a higher peak than industrial emissions despite the economic indicator used. To that extent, pollution accounts for more than would be expected for their levels of economic activity and well being.

Collective efforts have been made through the United Nations Climate Change Conference to reduce developed countries’ flow of emissions and ultimately the stock of GHGs in the atmosphere. This will improve and flatten the economic activity-pollution tradeoff curves shown in Figures 1.6 through 1.21. It does not make sense to wait for economic growth to eventually improve environmental quality by changing the composition and techniques of production and by stimulating the use of more efficient and cleaner technology through the demand for cleaner goods. Environmental degradation must be addressed before middle income levels are reached.

Economic activity-pollution relationships identified in the present paper are consistent with the inverted U-shaped relationship between per capita income and pollution emissions.

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24 The purpose of the 15th Conference of the Parties (COP 15), the Copenhagen Summit, was to create global awareness, demonstrate the potential to create huge opportunities for innovation and economic growth through tackling climate and to lays the foundation for a post-Kyoto agreement.
reported in many earlier studies. Although the EKC exists for both sources of pollution, environmental degradation from agricultural practices is a problem that will not go away automatically. Due to the significant contribution of this sector to total emissions, policy intervention is necessary to change the shape and the slope of the agricultural EKC. As Grossman and Krueger (1995) argued, “the strongest link between income and pollution in fact is via an induced policy response”. Imposing and enforcing stricter environmental standards in developed countries will encourage the development of more environmentally friendly technology and practices that overtime will also be available for poorer countries.
A Cross-country Examination of Trade, Gross Domestic Product, and the Environmental Kuznets Curve for Methane and Nitrous Oxide Emissions, 1970-2005
Introduction

According to the environmental Kuznets curve (EKC), at the first stage of economic development, pollution pressure increases as per capita income increases, but after a certain point these pressures diminish as income levels continue to rise. In other words, once individuals reach a given level of income or consumption, they begin to generate a greater demand for a cleaner environment. This is the primary message implicit in the inverse U-shaped EKC: Gross Domestic Product (GDP) is both the origin of and the solution for environmental problems. Another common explanation of the EKC is that it represents the stages of economic growth as countries move from agriculture to industrially based economies and then from industry to services, which are friendlier to the environment, resulting in a decrease in pollution. Several studies suggest that there is an inverse relationship among environmental pressure, pollution reduction, and per capita income levels (Grossman and Krueger, 1991; World Bank, 1995; Stern, Common and Barbier, 1998). Most of these studies considered environmental quality as a luxury good for which, at a certain point, demand increases as income increases. This model is constructed to reflect two other realities: countries differ greatly in their industrial and agricultural pollution intensity, and industrial and agricultural emissions are different in their pollution characteristics and should be analyzed separately. The global nature of methane and nitrous oxide and their crucial role in the greenhouse effect draw special interest in the analysis of the relationship of these emissions and per capita income.

25 Simon Kuznets suggested at the 67th meeting of the American Economic Association, that as per capita income increases, income inequality also increases at first but then, after some turning point, starts to decline (Kuznets 1955, 23-24).
During the last 15 years the degree of openness to trade increased by 50 percent worldwide (World Bank, 2008). This unprecedented increase in international trade is expected to affect the EKC. Trade affects the environment through the interaction of three elements: the composition effect, the technique effect, and the scale effect. The composition effect refers to economies changing their emphasis from agricultural to industrial activities and from industrial activities to services. The composition effect for developing countries is likely to increase pollution, but for developed countries the expected result is the opposite. Therefore, the process of development creates a structural shift from polluting industries to less polluting processes and service activities. The technique effect is a result of higher income populations’ looking for a better environment and cleaner production leading both to the enforcement of higher environmental standards and regulations and to the adoption of cleaner technologies. The scale effect has a positive correlation with pollution since more production implies a greater emission of pollutants.\footnote{The scale effect is expected to be positively related to pollution as in Copeland and Taylor (2004) and Gale and Mendez (1996).} It is also true that the scale effect is associated with growth. With growth comes a greater willingness to pay for a cleaner environment, which in the end results in less environmental deterioration. For the EKC inverted U-shape to occur, the technique effect should more than neutralize the composition and scale effects.

Copenhagen talks to reverse global temperature increases focused on carbon dioxide (CO$_2$), the leading greenhouse gas. Nevertheless, even if the largest cuts proposed in Copenhagen are implemented, a reduction of CO$_2$ will take decades if not centuries.\footnote{The Intergovernmental Panel on Climate Change (IPCC) estimates developed countries need to reduce emissions to 25-40 percent below 1990 levels by 2020 and 80-95 percent below 1990 levels by 2050 to stabilize atmospheric GHG concentrations at 450 ppm CO$_2$ equivalents.} Methane has been overlooked as a GHG pollutant. If methane GHG capacity is measured according to
its atmospheric lifetime then the effect of methane on the overall GHG effect is significantly magnified. Methane is a relatively potent greenhouse gas with an atmospheric lifetime of 12 ± 3 years and a Global Warming Potential of 72 over 20 years, 25 over 100 years and 7.6 over 500 years (IPCC Fourth Assessment Report). Methane is traditionally measured as 25 times the Global Warming Potential of CO$_2$ and its value in this analysis is calculated with the same lifetime as CO$_2$ using the 100-year listing of IPCC.\textsuperscript{28} According to Robert Watson and Mohamed El-Ashry, “methane is responsible for 75 percent as much warming as carbon dioxide measured over any given 20 years”.\textsuperscript{29} Cutting methane is a cheap way to cool the planet since it only requires modest investment and can have an immediate effect. Suppressing methane will decrease the temperature quickly and will allow cooling to follow within a decade and not centuries.

Nitrous oxide is a powerful GHG; it has 310 times the warming potential of CO$_2$, and is the single most important ozone-depleting man-made substance. The breakdown of ozone enables its molecules to absorb dangerous ultraviolet radiation.\textsuperscript{30} Cutting both CH$_4$ and N$_2$O requires only modest investment compared to CO$_2$ and has the potential to be more economically meaningful. Results suggest that agricultural turning points will occur at a higher income than the industrial sector and will take a longer time to reach their peaks in the absence of regulations. Agriculture is also the largest contributor of total emissions from both pollutants, which implies that imposing tighter regulations on the industrial sector may not decrease the flow of emissions from N$_2$O and CH$_4$.

\textsuperscript{28} Global Warming Potential (GWP) is a measure of how much a given mass of greenhouse gas contributes to global warming relatively scaled with carbon dioxide, which by definition has a GWP of 1.
\textsuperscript{29} Robert Watson is the former chair of the Intergovernmental Panel on Climate Change and Mohamed El-Ashry is a senior fellow at the United Nations (UN) foundation.
http://online.wsj.com/article/SB10001424052748704039704574616130812043404.html
\textsuperscript{30} A reduction of the ozone layer allows more radiation to reach the Earth's surface. In terms of human health an overexposure to UV rays can lead to a weakened immune system, skin cancer, and cataracts.
This analysis differs from previous studies that evaluate cross country pollution patterns in several different ways. First, this research focuses on methane (CH$_4$) and nitrous oxide (N$_2$O) two of the three major sources of greenhouse emissions that have received much less attention than carbon dioxide (CO$_2$). Second, the dataset used to measure CH$_4$ and N$_2$O allows the creation of a much larger sample of countries over a longer period of time than the ones used in previous EKC studies.$^{31}$ Third, this analysis disaggregates industrial pollution data from agricultural pollution, which has been disregarded in previous EKC literature. Different results from the industrial and agriculture sector are expected due to three main factors: 1) The contribution of the agricultural sector from these pollutants is significant and is trending up for both sources of GHG gases, 2) the agricultural sector is heavily subsidized in most developed countries and some developing countries, and 3) industrial technology can be easily transferred across countries and regions compared to agricultural technology.

**Literature review**

The inverted U relationship derives its name from Simon Kuznets (1955), who postulated the relationship between income distribution and economic growth. This curve was later adapted for environmental research by Grossman and Krueger (1991), who suggested that the Kuznets Curve could be applied to the environment, postulating the relationship between per-capita pollution and per-capita income. When applied to environmental issues, pollution grows rapidly in the first stages of development as society is poor and more interested in jobs and income than in the consequences of environmental pollution. Dasgupta (1997) found that

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$^{31}$ European Commission, Joint Research Centre (JRC) / Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.0.
as income rises, individuals give greater value to a cleaner environment and implement institutional reforms and regulations designed to decrease pollution. According to Komen (1997), wealthier nations can afford to spend more on research and development, generating cleaner technology that improves environmental quality, than poorer nations. As a result, environmental degradation will increase as the structure of the economy changes from rural to urban or agricultural to industrial, but will start to fall when the economy changes from energy intensive industry to services and cleaner technologies. This generates the inverted U-shaped curve when pollution indicators are plotted against per capita income. Grossman and Krueger (1995) estimated an EKC for 42 countries. They suggested that the downward sloping and inverted U-shaped patterns might arise due to citizens’ demand for more attention paid to non-economic aspects of their living conditions via induced policy responses and the development of technology that is cleaner than before. Grossman and Krueger found that the turning point for ambient concentration of sulfur dioxide, dark particles, and fine smoke, lies around a per capita income of $8,000 in 1985 US dollars. Magnani (2001) using emissions pollution data collected by the United Nations Environmental Program (UNEP) from 1994, analyzed carbon dioxide, nitrous oxide, and sulfur dioxide turning points. In her cross-sectional analysis of nitrous oxide emissions, Magnani found that emissions start declining around $9,000 and $12,000 in 2000 US dollars. Nevertheless, the results do not follow a specific time trend: $11,620 in 1975, $12,100 in 1980, $9,000 in 1985, and $10,020 in 1990. Using the same model, Magnani found that CO\textsubscript{2} emissions increased with per capita income.

Hill and Magnani (2002) analyzed nitrous oxide, carbon dioxide, and sulfur dioxide emissions for 156 countries for four separate years (1975, 1980, 1985 and 1990). They found that the EKC relationship for carbon dioxide was highly sensitive to the sample of countries
and the time period. They also found that two important variables were omitted, education and inequality. For carbon dioxide, the turning point was high and near the upper end of the per capita income distribution. For nitrous oxide, maximums occurred at $8,000 in 1975, $12,000 in 1980, $9,000 in 1985, and $9,000 in 1990 in 1985 US dollars, although the explanatory power of both specifications decreased between 1975 and 1990. Roca et al. (2001) analyzed six atmospheric pollutants in Spain during the period of his analysis (1980-1996) and suggested that there was no correlation between higher incomes levels and pollution reduction, except for sulfur dioxide. The author rejected the EKC for CH₄, arguing that CH₄ is one of the gases that is unlikely to follow the EKC hypothesis. List (1999) found per capita income at $15,623 and $12,547 in 2000 US dollars for quadratic and cubic EKC models, respectively, analyzing nitrogen oxide pollution data for 48 states in the United States. Millimet (2003) estimated nitrogen oxide peaks in the United States for two periods, 1929-1984 and 1985-1994. Results suggested a turning point at $12,548 and $15,322 in 2000 US dollars for each period, respectively. Selden and Song (1994) found nitrogen oxide turning points of $18,013 and $32,573 in 2000 US dollars, with fixed and random effect specifications for 67 countries over the period 1973-1984. When population density was included in their model, the turning point decreased to $16,780 and $26,693 in 2000 US dollars, respectively. Selden and Song suggested that lower population densities increase emissions due to lack of transportation efficiencies and reduce the pressure to adopt more stringent environmental regulations.

Trade liberalization and economic development are among the top policy priorities in most developing countries. Trade has potentially mixed effects on the environment, since it may increase pollution but also motivate its reduction. According to Jones and Rodolfo (1995) and Lee and Roland-Holst (1997) trade leads to an increase in economic growth and may
exacerbate environmental degradation, but many economists have long argued that trade is not
the root cause of environmental damage. Liddle (2001) suggested that trade liberalization can
be good for the environment because it increases real incomes, which may in turn create
demand for tighter environmental regulations.

Using data from China’s State Environmental Protection Agency (SEPA), Dean (2002)
analyzed China’s trade and its relationship with water and air pollution. Results suggested that
trade was not to blame for China’s pollution, and that Chinese imports and exports are
becoming cleaner over time. Dean also suggested that freer trade aggravates environmental
damage via the terms of trade, but mitigates it by income growth. Antweiler (2001) found that
economic growth spurred by trade overwhelmed the negative effects of trade. He found that as
trade expands, there was a tendency to adopt cleaner production techniques. Beckerman (1992)
analyzed the conflicting interest in the development-growth relationship for air and water
pollutants. He argued that demand for environmental improvement is an almost unavoidable
consequence of economic growth. Shafik (1992) tested the hypothesis that the higher the
degree of openness of a country, the cleaner the production processes employed in that country.
The hypothesis that “openness and competition will tend to increase investment in new
technology, which embodies cleaner processes to meet the higher environmental standards of
analyzed whether greater openness to trade lead to lower environmental standards for
atmospheric urban concentrations of sulfur dioxides. They found that sulfur dioxide levels were
significantly lower in cities located in countries that conducted relatively more trade but
concluded that the magnitude of this impact is small.
Trade entails the movement of goods produced in one country for consumption (or further processing) in another. This implies that the pollution generated in the production of traded goods is related to consumption in the other country. Therefore, it is crucial to examine the effect of the cross-country movement of goods associated with pollution. Suri (1998) argued that EKC models should account for how pollution levels in one area are related to the volume of goods imported or exported from that location. If trade is correlated with income, then ignoring trade may affect the reliability of the estimates of the income-GDP coefficients on emissions. Suri also found that pollution control may not be a critical cost factor for most private firms. Analyzing the effects of regulations on competitiveness, Jaffe (1995) found that the cost of pollution abatement and control expenditures to comply with environmental regulations for the Organization for Economic Co-operation and Development (OECD) industries was surprisingly small. Cernat (2003) found evidence that increased integration with the European Union (EU), a reduction of protectionism and duties, and a higher degree of openness were associated with better output performances in central and eastern European countries. Liang (2006) suggested that environmental quality can be improved by trade agreements because it increases the scale of production and enhances efficiency by improving production technologies with less impact on the environment.

Panayotou (1993) and Vukina, Beghin, and Ebru (1999) point out that at initial stages of economic growth the negative impact on the environment prevails due to scale effects, the EKC hypothesis suggests that eventually the scale effect will be outweighed by the positive reduced emission levels impact of the composition and technique effects. Perkins and Neumayer (2005) suggested that developing countries can absorb and diffuse new technology through their economies faster than early technology adopters (i.e., developed countries). Perkins also found
that new technologies diffused more rapidly when countries were more open to international trade and investment. Iwami (2005) found that latecomer economies in East Asia diffused new abatement technologies more quickly than early adopting countries. This occurred because both government and industry in Southeast Asia learned from the experiences of Japan and took early initiatives to prevent environmental degradation. Iwami concluded that if abatement technologies for carbon dioxide were created by developed countries, they would surely affect the development policies of developing countries.

**Econometric model**

The traditional EKC model specification is used to analyze the relationship between CH$_4$ and N$_2$O emissions from industrial and agricultural sources for 157 countries during the period 1970-2005. Equation (1.1) uses the traditional EKC model to explore the shape of the relationship between income ($Y$) and each environmental indicator ($E$). The traditional model used to analyze the relationship between pollution emissions and income is:

$$E_{it} = \beta_0 + \lambda_t + \beta_1(Y_{it}) + \beta_2(Y_{it})^2 + \nu_i + \mu_{it}$$

(1.1)

Where $E_{it}$ represents per capita emissions of CH$_4$ or N$_2$O in country $i$ at time $t$ ($t = 1970, 1971, \ldots, 2005$) and $\beta_i$ is the unknown vector of potentially heterogeneous slope coefficients and intercepts. $Y$ is the per capita income, $\lambda_t$ represents year-specific effects, $\nu_i$ is a country-specific effect, and $\mu_{it}$ an independent and identically distributed error term. A basic issue to
address concerns the exclusion from equation (1.1) of any other variable except per capita GDP.\textsuperscript{32}

Since the objective is to measure the direct and indirect consequences of the growth on emissions, other factors are omitted from the single-equation model. Equation (1.1) suggests the following hypothesis between environmental-economic relationships:

(i) $\beta_1 > 0, \beta_2 = 0$ (a monotonic increasing or linear relationship).

(ii) $\beta_1 > 0, \beta_2 < 0$ (an inverted U-shaped relationship),

(iii) $\beta_1 < 0, \beta_2 > 0$ (a U-shaped relationship).

The inverted U-shape of the EKC (ii) suggests that at the beginning of the development of the country pollution increases as per capita income increases, which implies that environmental damage is unavoidable in the initial stages of development/growth (Figure 2.1). Emissions can be said to be exhibit a meaningful relationship with GDP if $\beta_1 > 0, \beta_2 < 0$ and if the turning point is relatively low. According to the environmental Kuznets curve hypothesis, pollution pressure increases with per capita income growth as an economy develops up to a certain point at which pollution pressure starts diminishing as per capita income increases.

\textsuperscript{32} Apart from growth, trade, and economic structural changes, there are a number of country-specific factors that influence the country pollution levels, such as resource endowment, culture, climate, and geographical location. These aspects of a country are not expected to change or may change very slowly over time. These factors are controlled by including a country-specific dummy variable. Dummy variables for each year are also used to control for factors that evolve over time and impact all countries.
Figure 2.1:
“Inverse-U” relationship between emissions and per capita income

The major criticism of the EKC model in its traditional form is that it does not account for trade patterns that may partially explain emissions. To account for trade patterns, equation (1.1) is modified to capture the effect of trade as well as the technique, scale, and compositions effects on the environment (eq. 1.2) for the period 1970-2005.

\[ E_{it} = \beta_0 + \lambda_i + \beta_1 (Y_{it}) + \beta_2 (Y_{it})^2 + \phi_1 XIG_{it} + \phi_2 MIG_{it} + \phi_3 XAG_{it} + \phi_4 MAG_{it} + \phi_5 IVAG_{it} + \phi_6 AVAG_{it} + \phi_7 OPEN_{it} + \phi_8 SCALE_{it} + \nu_i + \mu_{it} \]  

(1.2)

Where \( i = 1 \) indexes countries and \( t = 1..T \) indexes time, \( E_{it} \) is the per capita CH\(_4\) or per capita N\(_2\)O emissions, and \( Y \) represents the per capita income.\(^{33}\) The terms \( \lambda_i \) and \( \nu_i \) are the country effect and the time-specific effect that permits us to capture how factors that evolve in time affect the position of the EKC, and \( \mu_{it} \) is the error term. XIG, MIG, XAG and MAG represent

\(^{33}\) Emissions data are measured in gigagrams (10\(^9\) grams), which represents one thousand metric tons of carbon dioxide equivalents and are measured in per capita terms.
the share of industrial trade and agricultural trade in the GDP. The following definitions are used:

OPEN represents the degree of openness of a country, calculated as \((X+M)/GDP\),

SCALE represents the GDP of country \(i\), scaled by the ratio of the largest city’s share of the country to country \(i\)’s population,

XIG represents the share of industrial exports in the GDP,\(^{34}\)

MIG represents the share of industrial imports in the GDP,

XAG represents the share of agricultural exports in the GDP,

MAG represents the share of agricultural trade in the GDP, and

IVA and AVA represent the ratio of total industry value added and agricultural value added to gross domestic industrial and agricultural product (more generally, changes in output structure).\(^{35}\)

XIG, MIG, IVA, SCALE, and OPEN variables are expected to increase/decrease the magnitudes \(CH_{4}\) and \(N_{2}O\) emissions. This is important because these variables were introduced for the purpose of capturing some of the effects explained only by income in the traditional model. Following theoretical predictions, time should shift the EKC downward and to the left, and both the level of income per capita corresponding to the turning point and the pollution per capita peak should decrease.

The functional form is expected to reflect the relative cost and benefits that individuals attach to addressing certain environmental problems at different stages of economic development. Results for the panel data regression are presented in Tables 2.3 through 2.6. \(\beta_1\)

\(^{34}\) The XIG and XAG variables control for country size and help determine if the country is becoming more/less trade oriented.

\(^{35}\) The ratio of industry to gross domestic product (XIG) provides a crude but effective measure of the relative size and importance of industry and conversely of the relative size of services and agriculture.
is the coefficient for the income variable, and $\beta_2$ is the coefficient for the income squared term. The covariates of equation (1.2) help understand the role of trade and the technique, scale, and composition effect on pollution. Serial correlation and heteroskedasticity diagnostic tests are used to detect the presence of both conditions. They are corrected using heteroskedasticity and autocorrelation consistent (HAC) standard errors. The Hausman test (1978) is used to formally test whether fixed effects and random effects estimations are significantly different. If they are not, then random effects estimation is consistent and efficient, but, if they are, there may be omitted variable bias, necessitating the fixed effects estimation.

Data

A panel data set on methane emissions, nitrous oxide emissions, and income was used in the study, along with degree of openness, scale, industrial value added, agricultural value added, industrial trade and agricultural trade for 157 countries over the period 1970-2005. To ensure compatibility with per capita GDP, per capita CH$_4$ and N$_2$O emissions for individual countries were calculated using country populations. The estimated industrial and agricultural emissions were obtained from the Emissions Database for Global Atmospheric Research (EDGAR). Per capita GDP, measured in constant 2000 US Purchasing Power Parity (PPP)-adjusted dollars, was used to approximate income, and is extracted from the World Bank and complemented with the Penn World tables (PWT 6.2). The ratios of exports and imports of all industrial and agricultural goods to domestic industrial and agricultural production are XIG, MIG and XAG, MAG, respectively. The ratio of total industrial value added to gross domestic product (IVA) and total agricultural value added to gross domestic product (AVA) are similar

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in that they reflect levels of industrial/agricultural development. However, there are important differences in what these variables proxy.\textsuperscript{37} The economic scale measure (SCALE) was obtained by normalizing a country’s GDP by the ratio of the largest city’s population to country’s population.\textsuperscript{38} Scale effect and degree of openness (OPEN) were obtained from the World Development Indicator of the World Bank. Countries were divided by the World Bank definition of Low, Middle, and High income, which correspond to less than $935, $935 to $11,250, and more than $11,250 in PPP dollars, respectively. The panel was divided into industrial CH\textsubscript{4} and N\textsubscript{2}O emissions, and agricultural CH\textsubscript{4} and N\textsubscript{2}O emissions. This approach enables separate analysis of each emission source, assuming that the sources of each gas are fundamentally different. The data was separated by source categories according to Intergovernmental Panel of Climate Change (IPCC) guidelines.\textsuperscript{39}

As observed in Tables 2.1 and 2.2, anthropogenic CH\textsubscript{4} and N\textsubscript{2}O emissions increased constantly during the study period. The primary sources of CH\textsubscript{4} and N\textsubscript{2}O emissions are industrial, agricultural, and the “other” emissions sector.\textsuperscript{40} Figure 2.1 indicates that the world N\textsubscript{2}O emissions increased from 1970 to 2005 by 34 percent, or similarly by almost 1 percent per year. Approximately 80 percent of the total N\textsubscript{2}O increase during that period came from the agricultural sector, in which soil emissions, manure and fertilizers were the major sources. The remaining 20 percent came from the “other” sectors (EDGAR 2009). The “other” emissions

\textsuperscript{37} IVA and AVA include production of goods for the domestic market in addition of production for export. It is a measure of a broad structural transformation that an economy goes through as it develops.
\textsuperscript{38} Same as Gale and Mendez (1996).
\textsuperscript{39} The IPCC is considered the world’s leading scientific authority in climate change.
\textsuperscript{40} Other emissions of methane pollution includes: Solid waste disposal on land, wastewater handling, waste incineration, other waste handling, fossil fuel fires, and other sources.
sector includes wastewater handling (97 percent of that increase) with waste incineration composing the remaining 3 percent.\textsuperscript{41}

According to the Environmental Protection Agency (EPA), industrial N\textsubscript{2}O emissions are produced during the manufacturing of adipic acid and nitric acid. Adipic acid is used in the manufacture of synthetic fibers, plastics, coatings, synthetic lubricants, urethane foams, and elastomers. Nitric acid is an inorganic compound used primarily as a feedstock for synthetic commercial fertilizer and is also a major component in the production of adipic acid. The flow of emissions from the industrial N\textsubscript{2}O is trending down over time. Nitrous oxide industrial emissions decreased by almost 50 percent during the period 1970-2005 (Table 2.1).

![Nitrous oxide and methane GHG emissions in CO\textsubscript{2} equivalents 1970-2005](source: EDGAR 4.0)

\textsuperscript{41} Other emissions of nitrous oxide pollution include solid waste disposal on land, wastewater handling, waste incineration, other waste handling, indirect nitrogen oxides from non-agricultural nitrous oxide, indirect nitrogen oxides from non-agricultural NH\textsubscript{3}, and other sources.
Tables 2.1 show that 82 percent of the world N\textsubscript{2}O emissions come from agricultural sources, 13 percent from other sources, and almost 6 percent from the industrial sector in 2005. The flow of emissions from the agricultural sector and the other sector are trending up over time. Agricultural N\textsubscript{2}O emissions are by-products of fertilizer use, the production of animal manure, and the burning of grassland. Nitrous oxide per kilogram global warming potential is nearly 310 times that of CO\textsubscript{2} within 100 years.\textsuperscript{42} Nitrous oxide and per capita N\textsubscript{2}O are measured in thousand metric tons (kt) of CO\textsubscript{2} equivalent. Nitrous oxide has been the focus of considerable public attention due to its contribution to the ground-level ozone problem. Nitrous oxide is the single most important ozone-depleting man-made substance and has an estimated lifetime of 114 years. Nitrous oxide reduces ozone in the atmosphere through chlorine or nitrogen oxide-catalyzed reactions. Ozone depletion is also caused by nitric oxide, hydroxyl, atomic chlorine, and bromine, but the production of these elements has sharply decreased due to the Montreal Protocol limits on production of chlorofluorocarbons and bromofluorocarbons.\textsuperscript{43}

\textsuperscript{42} The degree of warming varies with the gas’ concentration in the atmosphere and its ability to absorb infrared radiation.

\textsuperscript{43} The Montreal protocol was designed to protect the ozone layer by phasing out the production of ozone-depleting substances. The Kyoto protocol’s goal is to stabilize the greenhouse gas concentrations in the atmosphere to a level that would prevent climate change. It establishes legally binding commitment for the reduction of six gases (carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, hydrofluorocarbons and perfluorocarbons).
Table 2.1: Total volumes of world N\textsubscript{2}O pollution by sources of emissions

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial emissions</td>
<td>388,120 (17%)</td>
<td>334,800 (13%)</td>
<td>243,040 (9%)</td>
<td>162,130 (5%)</td>
</tr>
<tr>
<td>Agricultural emissions</td>
<td>1,675,240 (73%)</td>
<td>2,009,110 (77%)</td>
<td>2,272,920 (80%)</td>
<td>2,425,130 (82%)</td>
</tr>
<tr>
<td>Other emissions</td>
<td>227,850 (10%)</td>
<td>274,660 (10%)</td>
<td>332,320 (11%)</td>
<td>373,860 (13%)</td>
</tr>
</tbody>
</table>

Source: Data from the Emissions Database for Global Atmospheric Research (EDGAR 4.0). Emissions are measured in gigagrams (10\textsuperscript{9} grams) which are equivalent to 1,000 tonnes of CO\textsubscript{2} equivalent.

Table 2.2 shows that CH\textsubscript{4} emissions increased by 58 percent from 1970 to 2005, or similarly by 1.66 percent per year (EDGAR 2009). Approximately 31 percent of the world methane increase during the last 35 years was from the “other” emissions sector, 42 percent from industrial emissions, and the remaining 27 percent from the agricultural sector. The “other” emissions sector has grown more than 109 percent over the last 35 years due to the enormous increase in urban waste generation linked to the increase of per capita consumption. The main destination of waste is dumps, without any exploitation of CH\textsubscript{4} for energy use.\textsuperscript{44} The largest CH\textsubscript{4} pollution source is agriculture (Table 2.2), with ruminants contributing 65 percent of that amount.\textsuperscript{45}

Industry is the second largest CH\textsubscript{4} pollution source, and increased from 1970-2005 by 82 percent. According to the Emission database for global atmospheric research, 67 percent of the industrial CH\textsubscript{4} emissions result from the handling, transmission, and combustion of fossil fuels and biofuels. Methane’s relative abundance and its clean burning process as a fuel have resulted in an increase in its use. It is the principal component of natural gas and when burned

\textsuperscript{44} If projects to change the waste management are put in place and are successful, the reduction of such emissions could be significant.

\textsuperscript{45} A ruminant is a mammal that digests plant-based food. Ruminating mammals include cattle, water buffalo, sheep, and goats, among other species.
in the presence of oxygen produces CO$_2$ and water. Agricultural CH$_4$ is the largest CH$_4$
polluting sector and its emissions come from livestock, animal waste, rice production, and
agricultural waste burning. CH$_4$ and N$_2$O and per capita CH$_4$ and N$_2$O, measured in thousand
metric tons (kt) of CO$_2$ equivalent, are the operational definitions of CH$_4$ and N$_2$O in this study.
Methane, together with N$_2$O and CO$_2$, is a major contributor of GHG greenhouse gases.

Figure 2.3 illustrates an inverted U-shape for N$_2$O emissions from OECD countries. Non-OECD countries and total emissions (OECD and non-OECD) increased for the period 1970-2005. Total industrial N$_2$O emissions decreased by 50 percent during that period (Table 2.1). Approximately 94 percent of these reductions come from OECD countries from which 46 percent can be attributed to the United States.$^{46}$ Total agricultural N$_2$O increased by 44 percent with approximately 89 percent of that increase coming from non-OECD countries.

<table>
<thead>
<tr>
<th>Table 2.2: Total volumes of world CH$_4$ pollution by sources of emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Industrial Emissions</td>
</tr>
<tr>
<td>Agricultural emissions</td>
</tr>
<tr>
<td>Other emissions</td>
</tr>
</tbody>
</table>

Source: Data from the Emissions Database for Global Atmospheric Research (EDGAR 4.0). Emissions are measured in gigagrams (10$^9$ grams) which are equivalent to 1,000 tonnes of CO$_2$ equivalent.

$^{46}$ The Acid Rain Program (ARP), established under Title IV of the 1990 Clean Air Act Amendment (CAAA) was responsible for a large portion of this reduction, even though other programs like the Ozone Transport Commission (OTC) and other regional N$_2$O programs also contributed significantly to N$_2$O reductions achieved by industrial sources in 2005.
Figure 2.3:
Nitrous oxide OECD and non-OECD emissions in CO₂ equivalents
Emissions are measured in gigagrams (10⁹ grams) which are equivalent to 1,000 tonnes of CO₂ equivalent.

From the total increase in agricultural N₂O emissions of the last 35 years, 67 percent can be attributed to China, India, and Brazil. Total emissions from non-OECD countries are rising mostly due to China, India, and Brazil’s significant emission expansion. Total aggregated emissions from those countries increased by 185 percent during 1970-2005. In 2005, they represented 29 percent of the world N₂O emissions, and their emissions are trending up.

Figure 2.4 is consistent with the EKC hypothesis for OECD countries for the period 1970-2005. Total industrial CH₄ emissions increased by 33 percent (Table 2.2) with 100 percent of those increases coming from non-OECD countries. China represented half of the total industrial CH₄ increases of the last 35 years. Total agricultural CH₄ increased by 10 percent (Table 2.1) with 100 percent of that increase coming from non-OECD countries. Brazil represents more than two thirds of those increases.
Table 2.3 contains summary estimates from the traditional EKC model. In this model the main source of environmental improvement is per capita GDP, which may be due to resource efficiencies arising from increased competitiveness or from greater access to “green” technologies. Turning points for industrial emissions varies significantly depending on the source of emissions and the degree of development of the countries. Methane and nitrous oxide emissions in OECD countries reach their peak when income attains $9,401 and 21,875 in constant 2000 US dollars, respectively. Most OECD countries are expected to already surpass their turning points, which are consistent with the inverted U-shape in Figure 2.3. Non-OECD turning points for nitrous oxide of $11,720 are large considering that the average per capita income for non-OECD countries in 2008 was only $1,717 in constant 2000 US dollars. Therefore, non-OECD countries will take a long time to start decreasing their per capita emissions.

Figure 2.4:
Methane OECD and non-OECD emissions in CO₂ equivalents
Emissions are measured in gigagrams (10⁹ grams) which are equivalent to 1,000 tonnes of CO₂ equivalent.

Results
Table 2.3:
Summary estimates of Industrial emissions for OECD and Non-OECD countries (1970-2005)

<table>
<thead>
<tr>
<th>Region</th>
<th>OECD</th>
<th>OECD</th>
<th>Non-OECD</th>
<th>Non-OECD</th>
<th>World</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Industrial N₂O</td>
<td>Industrial CH₄</td>
<td>Industrial N₂O</td>
<td>Industrial CH₄</td>
<td>Industrial N₂O</td>
<td>Industrial CH₄</td>
</tr>
<tr>
<td>Income</td>
<td>-1.79e-11</td>
<td>-1.1E-01***</td>
<td>-5.02e-10*</td>
<td>-1.1E-01***</td>
<td>-3.52e-11***</td>
<td>-3.82e-09</td>
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<tr>
<td>(1.31e-11)</td>
<td>(1.2E-03)</td>
<td>(2.98e-10)</td>
<td>(2.7e-02)</td>
<td>(1.1e-11)</td>
<td>(9.8e-09)</td>
<td></td>
</tr>
<tr>
<td>Income²</td>
<td>-1.26e-15***</td>
<td>8.6E-08</td>
<td>2.14e-14***</td>
<td>8.2E-06***</td>
<td>-1.08e-15***</td>
<td>8.1e-13***</td>
</tr>
<tr>
<td>(3.29e-16)</td>
<td>(5.3E-08)</td>
<td>(7.58e-15)</td>
<td>(1.5E-06)</td>
<td>(3.1e-16)</td>
<td>(2.8e-13)</td>
<td></td>
</tr>
<tr>
<td>Adj. R²</td>
<td>0.452</td>
<td>0.116</td>
<td>0.069</td>
<td>0.022</td>
<td>0.35</td>
<td>0.16</td>
</tr>
<tr>
<td>Obs.</td>
<td>957</td>
<td>902</td>
<td>1,076</td>
<td>4,746</td>
<td>1,774</td>
<td>5,660</td>
</tr>
<tr>
<td>T.Point</td>
<td>21,875*</td>
<td>9,401**</td>
<td>11,720***</td>
<td>----</td>
<td>16,231*</td>
<td>----</td>
</tr>
</tbody>
</table>

Notes: * significant at 1%; ** significant at 5%; *** significant at 10%. Per capita incomes and turning points are measured in constant US$ 2005 purchase power parity dollars. Standard errors are in parentheses.

Table 2.4 parameter estimates are consistent with the inverted U-shaped curve between per capita income and pollution emissions. Therefore, pollution emissions increase in a decreasing fashion up to the turning point where emissions start to decrease in an increasing way. Estimated turning points for industrial emissions from OECD and non-OECD countries peak at incomes between $8,541 and $12,926 in 2000 constant US dollars, respectively. Methane in OECD countries reaches a turning point at $7,285 per capita income. Given that per capita income levels ranged from $89 to $52,307 during 1970-2005, the data will be able to capture both the upward and downward sloping portions of the EKC. It is expected for CH₄ and N₂O industrial pollution sources that, when income increases, more stringent pollution standards are desired and older technology is replaced by new and less polluting technology. It is also expected that higher incomes in the recipient country also force companies in the producing country to switch to new technologies. The peaks estimated for industrial CH₄ and N₂O for OECD and non-OECD countries are all statistically significant. Turning points for industrial emissions decreased for OECD countries and increased for non-OECD countries when covariates were included.
The beneficial effect of trade is expected to be mixed: it generates changes in industry composition by expanding the industrial sector of a country, which is positively related with pollution, but it can also bring more efficient technology into the host country and improve energy efficiency and productivity (technique effect). Results suggest that CH$_4$ and N$_2$O emissions are negatively related to MIG and XIG for non-OECD countries. Therefore pollution decreases with more XIG and MIG in non-OECD countries. This may be due to exports from developing markets to developed markets, and the quality requirements in the latter encourage the use of the latest technologies, which is usually cleaner than older technology. It may also be interpreted as resource efficiencies arising from increased competitiveness or from greater access to cleaner production technologies. To that extent it may be said that when countries becomes more trade oriented they can accelerate the EKC downturn for industrial nitrous oxide and methane emissions. With increasing world trade it is likely that this trend will intensify. Results from column (4) estimates that an increase in the ratio XIG for industrial N$_2$O in non-OECD countries by one unit decreases pollution by 1.15e-06 gigagrams over 35 years or roughly 3.2e-08 gigagrams per capita per annum. Industrial emissions are positively related with XIG and negatively related with MIG in OECD countries; the opposite is true for CH$_4$. Therefore, the more export-oriented the OECD countries are, the greater the increase in emissions from N$_2$O and decrease from CH$_4$. A one percent increase in the MIG ratio decreases emissions of N$_2$O by 2.3e-06 gigagrams 35 years or 6.5e-08 per capita per year. Although XIG and MIG are statistically significant, their environmental degradation impact is relatively small. When pollution comes from industrial CH$_4$, the larger the share of the industrial sector in GDP, the larger the aggregate pollution from this sector in that country. Theoretically, an increase in the industrial sector is expected not only to increase pollution but also to help reduce pollution.
through the incorporation of technology and return to scale. Except for industrial N\textsubscript{2}O, the negative relationship between SCALE and industrial emissions in OECD and non-OECD countries may result from incorporation of newer and cleaner technology that increases output and decreases the use of inputs. For industrial CH\textsubscript{4} emissions, this decrease may be also triggered by an increase in transportation efficiencies due to population agglomerations, since almost 60 percent of the industrial CH\textsubscript{4} emissions come from fugitive emissions from oil and gas (EDGAR 4.0).

<table>
<thead>
<tr>
<th>Region</th>
<th>OECD</th>
<th>OECD</th>
<th>Non-OECD</th>
<th>Non-OECD</th>
<th>World</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Industrial N\textsubscript{2}O</td>
<td>Industrial CH\textsubscript{4}</td>
<td>Industrial N\textsubscript{2}O</td>
<td>Industrial CH\textsubscript{4}</td>
<td>Industrial N\textsubscript{2}O</td>
<td>Industrial CH\textsubscript{4}</td>
</tr>
<tr>
<td>Income</td>
<td>5.89e-11***</td>
<td>-1.0e-09***</td>
<td>1.17e-10***</td>
<td>190e-02***</td>
<td>4.10e-11***</td>
<td>-8.5e-09</td>
</tr>
<tr>
<td>Income\textsuperscript{2}</td>
<td>-3.45e-15***</td>
<td>7.09e-14***</td>
<td>-4.51e-15</td>
<td>-0.355</td>
<td>-3.2e-15***</td>
<td>1.3e-12***</td>
</tr>
<tr>
<td>XIG</td>
<td>4.16e-07</td>
<td>-6.2e-05***</td>
<td>-1.15e-06***</td>
<td>-981e-03</td>
<td>-2.7e-07</td>
<td>-4.9e-05</td>
</tr>
<tr>
<td>MIG</td>
<td>-2.30e-06***</td>
<td>7.13e-05***</td>
<td>-4.90e-07*</td>
<td>-446e-04</td>
<td>-1.2e-06***</td>
<td>-2.5e-04***</td>
</tr>
<tr>
<td>IVA</td>
<td>-2.78e-10</td>
<td>1.16e-06***</td>
<td>6.59e-10</td>
<td>233e-03</td>
<td>5.8e-09***</td>
<td>1.2e-05***</td>
</tr>
<tr>
<td>SCALE</td>
<td>3.21e-18***</td>
<td>-6.7e-17***</td>
<td>-1.31e-18*</td>
<td>-940e-06***</td>
<td>3.1e-18***</td>
<td>-1.5e-15***</td>
</tr>
<tr>
<td>OPEN</td>
<td>8.95e-09***</td>
<td>-5.9e-08***</td>
<td>3.45e-09**</td>
<td>-806</td>
<td>5.6e-09***</td>
<td>-2.7e-07</td>
</tr>
<tr>
<td>Adj. R\textsuperscript{2}</td>
<td>0.435</td>
<td>0.512</td>
<td>0.114</td>
<td>0.102</td>
<td>0.0515</td>
<td>0.339</td>
</tr>
<tr>
<td>Obs.</td>
<td>912</td>
<td>974</td>
<td>603</td>
<td>2,330</td>
<td>1515</td>
<td>3398</td>
</tr>
<tr>
<td>T. Point</td>
<td>8.541***</td>
<td>7.285***</td>
<td>12.926*</td>
<td>----</td>
<td>8.413***</td>
<td>----</td>
</tr>
</tbody>
</table>

Notes: * significant at 1%; ** significant at 5%; *** significant at 10%. Per capita incomes and turning points are measured in constant USS 2005 purchase power parity dollars. Standard errors are in parentheses.
The more export oriented the country is, the larger the degree of openness will be. For this coefficient results vary depending on the type of pollutant. Results for N₂O show that the larger the degree of openness and exports, the larger the per capita pollution. For CH₄ the result may be driven by the fact that in many cases the major polluters are not the major exporters of industrial goods and vice versa. The scale and technique effect also help decrease emissions and seem to overpower the structural changes on those countries which decreased by 10 percentage points during the last 35 years.

Results from Table 2.4 show that estimating the EKC for non-OECD with covariates yields higher estimated turning points than when the EKC was estimated using the traditional model. These higher turning points are caused by an explosive expansion of CH₄ and N₂O emissions from industrial sources in countries like China, India and Brazil. In those countries the scale effect overwhelms the other two effects. The findings may suggest that if environmental policies are not put in place to change the structure of the technology, then economic growth will result in a significant growth of emissions. One of the most important issues in the policy arena is related to developing countries and their role in global pollution. This will continue to be an important issue mainly when dealing with the agricultural sector due to its relevant share of the overall pollution. Industrialized countries agreed to reduce 5 percent of their greenhouse gas emissions relative to 1990 emissions levels, but developing countries made no such commitment.

Agriculture is the major source of emissions of methane and nitrous oxide. Within agriculture, CH₄ and N₂O come from a wide variety of sources. Agriculture is trending up and increasing by an average of 1.5 percent per year since 1970 and in 2005 represented 82 percent of the total N₂O emissions. Turning points in Table 2.5 are significant and extremely high for
agricultural emission sources. These very high turning points are caused by a heavily subsidized agricultural sector in those countries; $36,661 for CH$_4$ in high income OECD countries. Most OECD agricultural farmers in developed countries receive subsidies to supplement their income. Subsidies on major crops influence the cost and supply of such commodities. These lower prices on feed grains are transferred to feedlots, increasing their production and therefore shifting up the turning points. Removing subsidies and ensuring a clear definition and enforcement of property rights over natural resources can also help flatten the curve (Panayotou 1993). Non-OECD countries’ turning points are also very high. Peaks for CH$_4$ and N$_2$O are $28,773 and $24,707 respectively.

SCALE has a negative relationship with CH$_4$ and N$_2$O emissions from agricultural sources in non-OECD countries. Population agglomeration may generate a larger demand for protein due to higher incomes and may increase the demand for feedlots that on a per-cow basis produce less methane than cattle raised on pasture. It also may result from a reduction in demand for beef as consumers substitute their protein sources by turning to a lower-priced product like chicken. Structural changes on the economy do have some positive economic impact on non-OECD country emissions and a negative but economically insignificant effect on OECD countries when they come from the agricultural sector. For non-OECD countries, an increase of 1 percent in AVA will decrease CH$_4$ and N$_2$O emissions by 1.31e-07 and 5.89e-08 gigagrams, respectively. This may reflect that, unlike industrial emissions, agricultural emissions are generated during the production process and not the processing process. CH$_4$ and

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48 Grossman and Krueger (1993) found scale to be positively related with pollution concentration.
49 The consumption shift from beef to poultry could be interpreted as a response to changing relative prices. These large price movements can result from structural changes on the supply side (Chavas, 1983). These price changes induced consumers' change in diet from red to white meat. This change is also seen as a healthier option.
N$_2$O are mostly generated during the digestive process of the livestock and when applying fertilizer, respectively.

Pollution decreases with agricultural exports in OECD countries and with agricultural imports in non-OECD countries. An increase on exports in OECD countries generates more production of value added goods, which results in less pollution per output. On the other hand, more imports of agricultural commodities in non-OECD countries results in less local production of polluting commodities and reduces their pollution. OPEN was found to be significant and positively related to CH$_4$ and N$_2$O emissions, implying that an increase in openness will have a negative impact on pollution coming from the agricultural sector. Agricultural value added is negatively related with pollution for agricultural sources. An increase in the value added from the agricultural sector is expected to have a negative but almost insignificant effect on emissions.

Table 2.5: Summary estimates of agricultural emissions for OECD and Non-OECD countries (1970-2005)

<table>
<thead>
<tr>
<th>Region</th>
<th>OECD</th>
<th>OECD</th>
<th>Non-OECD</th>
<th>Non-OECD</th>
<th>World</th>
<th>World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>agricultural N$_2$O</td>
<td>agricultural CH$_4$</td>
<td>agricultural N$_2$O</td>
<td>agricultural CH$_4$</td>
<td>agricultural N$_2$O</td>
<td>agricultural CH$_4$</td>
</tr>
<tr>
<td></td>
<td>(9.09e-12)</td>
<td>(2.45e-10)</td>
<td>(1.44e-11)</td>
<td>(1.76e-10)</td>
<td>(8.78e-12)</td>
<td>(1.42e-10)</td>
</tr>
<tr>
<td>Income$^2$</td>
<td>1.17e-16</td>
<td>2.57e-14***</td>
<td>7.42e-16***</td>
<td>1.67e-14***</td>
<td>5.80e-16***</td>
<td>1.89e-14***</td>
</tr>
<tr>
<td></td>
<td>(1.5e-16)</td>
<td>(4.35e-15)</td>
<td>(2.15e-16)</td>
<td>(3.34e-15)</td>
<td>(1.41e-16)</td>
<td>(2.59e-15)</td>
</tr>
<tr>
<td>Adj. R$^2$</td>
<td>0.032</td>
<td>0.097</td>
<td>0.0004</td>
<td>0.002</td>
<td>0.0005</td>
<td>0.007</td>
</tr>
<tr>
<td>Obs.</td>
<td>1,076</td>
<td>1,076</td>
<td>4,596</td>
<td>4,620</td>
<td>5672</td>
<td>5,696</td>
</tr>
<tr>
<td>T.Point</td>
<td>---</td>
<td>36,661***</td>
<td>24,707**</td>
<td>28,773**</td>
<td>32,152***</td>
<td>34,471***</td>
</tr>
</tbody>
</table>

Notes: * significant at 1%; ** significant at 5%; *** significant at 10%. Per capita incomes and turning points are measured in constant US$ 2005 purchase power parity dollars. Standard errors are in parentheses.
Some clear patterns of environmental degradation emerge from this previous analysis.

First, the environmental indicators behave differently depending on whether the pollution comes from the industrial or agricultural sector. The environment appears to benefit from rising incomes for industrial sources of pollution. Second, the turning point results obtained for industrial N$_2$O emissions are close to environmental indicators from other studies. Previous studies used emissions data collected by the United Nations Environmental Program for the period 1970-1990 (Magnani 2001, Hill 2002). This study uses the EDGAR v4.0 data source for the period 1970-2005. The turning points are higher than those found in existing literature. Using cross sectional data for 5 time periods (1970, 1975, 1980, 1985, and 1990), Magnani (2001) found that N$_2$O emissions start declining at around $9,000 and $12,000 in constant 2000

Agricultural N₂O emissions increased by 44 percent during the period 1970-2005 and are trending up (Table 2.1). Almost all of that increase comes from non-OECD countries. Concluding that pollution is a temporary problem would be inaccurate due to the estimated global warming potential of both pollutants and that the contribution of the agricultural sector is extremely large and is trending up. Therefore, when the source of pollution is agriculture, if stricter regulations are not put into place, like the implementation of better environmental management practices as well as research and development on more environmentally friendly technologies, then changes in the flow and stock of those two pollutants will not take place. In other words, regulating only industrial emissions of CH₄ and N₂O will not result in significant decreases of total emissions due to the significant share and increasing contribution of agricultural emissions.

**Conclusion**

This study has investigated the EKC hypothesis for methane and nitrous oxide emissions for 157 countries during the period 1970-2005. The existence of the environmental Kuznets curve for the two pollutants was tested using a panel model estimation, in which per capita pollution was regressed upon per capita income and other macroeconomic variables that capture the technology effect, the effect of trade, the scale effect, and the composition effect.
Industrial nitrous oxide appears to reach pollution turning points at income around $21,875 in constant 2000 US dollars which is higher than turning points reported in previous studies by Magnani (2001) and Hill (2002) that also used a traditional EKC model. Nevertheless, results are consistent with the data on Figure 2.3. Concerns about the negative effects of trade on the environment from industrial sources seem unjustified. The negative relationship of exports and imports on emissions from both pollutants help decrease the turning points on non-OECD countries. Environmental quality appears to benefit from growth and trade, which suggests that the aggregate effect of trade on pollution is beneficial but small. Although trade speeds the absorption of frontier technologies the XIG and MIG coefficient are statistically significant, their environmental impact is not substantial.

The higher turning points of industrial nitrous oxide for non-OECD countries stress the need for low and middle income countries to turn their attention to addressing environmental problems during earlier stages of development. Aggregated non-OECD emissions are trending up and represented 82 and 86 percent of the total share of pollution for CH₄ and N₂O, respectively, during 2005. Non-OECD countries’ turning points from both industrial and agricultural sources are significantly high. Agricultural N₂O turning point for non-OECD countries peak at $11,720 in constant 2000 US dollars. When China and India are excluded, results do not hold and the turning points decrease to $9,104 in constant 2000 US dollars, a value that is still far above the 2008 average per capita GDP of $1,717 in non-OECD countries. Agricultural emissions are the main source of pollution for both CH₄ (43 percent) and N₂O (82 percent), and their shares of total pollution are growing. In the absence of regulations, agricultural turning points will take a long time to achieve and will occur at a high per capita pollution. Removing policy distortions such as agricultural subsidies or policy failures, in the
sense of unmitigated market failures, can also help decrease the height and increase the convexity of the EKC.

Even with the largest cuts proposed in Copenhagen, a reduction of CO₂ will take decades if not centuries. Methane’s short life will allow suppressing temperature quickly and allow cooling to follow within a decade, not centuries as with CO₂. Methane is responsible for 75 percent as much warming as CO₂ measured over any given 20 years when its lifetime is not counted as the lifetime of CO₂. Cutting CH₄ and N₂O emissions requires only modest investment compared to CO₂ and has the potential to be more economically meaningful. Reducing agricultural CH₄ and N₂O emissions will require introducing policies for better, more environmentally friendly agricultural practices, as well as an increase of popular awareness to help diffuse information on environmentally friendly agricultural management practices. To that extent, trade can help diffuse best-practice management and environmentally friendly technology.
A Dynamic Cross-country Examination of Trade and Gross Domestic Product for
Carbon dioxide, Methane and Nitrous oxide Emissions, 1970-2005
Introduction

From 1970 to 1995, trade represented on average thirty percent of world gross domestic product (GDP), with manufacturing as the major contributor. After 1995, trade started increasing systematically by approximately 1.1 percent per year and reached 47 percent of gross world GDP in 2005 (World Bank, 2008). This was the result of a combination of several factors, like decreases in trade restrictions, lower transportation costs, and an increasingly integrated global economy. When trade barriers are reduced, the environment is expected to be affected by expansions of scale economies, changes in the composition of economic activity, and changes in production technology (Grossman and Krueger, 1991). If trade is correlated with income and ignored, this will affect the reliability of estimates of the coefficients relating income and emissions. It is necessary to account for the fact that pollution levels in one area are related to the volume of goods that are imported or exported from thence.

The relationship between trade liberalization and growth has been extensively analyzed and the consequences of trade liberalization have been vigorously debated during the last decade, but only a few analyses have considered its relationship with greenhouse gas emissions (GHG). Since the North American Free Trade Agreement (NAFTA), trade economists and proponents of trade liberalization have argued that trade would lead to seemingly automatic improvements in environmental conditions in developed and developing countries. Since environmental quality is a normal good, trade-related income growth causes people to demand a cleaner environment. Growth suggests a greater willingness to pay for a cleaner environment and the adoption of cleaner technologies (technique effect) that result in slowing the rate of

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50 See, for example, Grossman and Krueger (1993), Antweiler, Copeland, and Taylor (2001), Shafik and Bandyopadhyay (1992), and Stern (2007).
environmental deterioration (Copeland and Taylor, 2004). Free trade supporters have generalized the environmental benefits of trade liberalization from the so-called Environmental Kuznets Curve (EKC) hypothesis. Opponents of trade liberalization fear that if production techniques do not change, then the environment will deteriorate through an increase in the scale of economic activities. They also argue that the environment would worsen in countries with a comparative advantage in the production of dirty goods. Lowering standards in less developed countries would attract highly polluting firms from developed countries. Concerns have arisen over the impact of trade liberalization on the environment over the last two decades, particularly regarding NAFTA. In Mexico’s case, some environmental degradation has occurred since NAFTA’s implementation, not because it became a haven for pollution, but because the proper mechanisms were not in place to help Mexico manage its economic growth in an environmentally sustainable manner (Gallagher, 2004).

This paper investigates the relationship among carbon dioxide, methane, and nitrous oxide emissions from industrial and agricultural sources, trade liberalization, and the level of economic activity as countries develop and increase per capita income. Existing literature on the effect of trade liberalization on the environment usually consists of single equation models which focus primarily on this static relationship. Stern, Common, and Barbier (1996) states that in the presence of bidirectional causality from growth to environmental quality, estimating a single equation relationship introduces biases and may result in inconsistent estimates. This paper develops an alternative simultaneous equation model that allows for both a direct effect of free trade on growth of environmental damage via changes in relative prices and an indirect effect via the effects of trade on income growth. This will give a better understanding of trade’s effect on the environment.
Although results show trade accelerates the growth process, which leads to larger effects on the environment via income, little evidence is found on trade openness causing significant environmental degradation. Openness affects pollution through direct and indirect effects. Openness indirectly affects GHG pollution by increasing income growth via trade liberalization, but its effect on pollution is found to be small. Its direct effects on pollution are ambiguous for both sources of pollution and all three GHG gases and enter insignificantly across all country groups. Results also confirm the importance of capital accumulation in economic growth and show positive results for exogenous technological progress (catch-up variable) across all country groups. This study does not find evidence that trade liberalization causes significant environmental damages from GHG gases which suggest that concerns about the effect of openness on pollution from GHG gases may be unjustified.

This paper makes three primary contributions. First, it develops a simultaneous equation model that allows for both a direct and indirect effect of trade on environmental damage. Second, this study analyses the trade pollution relationship from both industrial and agricultural sources of pollution for three GHG pollutants, carbon dioxide, methane, and nitrous oxide. Third, this analysis focuses on nitrous oxide and methane, which have received no attention with respect to their relationship with trade and environmental degradation.

**Literature review**

Trade liberalization and development are among the top policy priorities in most developing countries. Trade liberalization can be good for the environment, since it increases

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51 Despite its large contribution the agricultural sector has previously been disregarded.
trade and raises real income, which creates demand for stricter environmental protection standards and forces firms to invest in cleaner and more environmentally friendly technologies. Trade also leads to an expansion of the economy, which increases environmental degradation since the production of goods in the economy creates pollution as a joint product. Therefore, trade has contradictory impacts on the environment, since it increases pollution but also motivates its reduction. Trade entails the movement of goods produced in one country for consumption (or further processing) to another. This implies that pollution generated in the production of these goods is related to consumption in another country. Therefore, it is important to examine the effect of the international movement of goods that generate pollution as part of their production processes.

There is an extensive literature on the impact of trade on the environment. A number of studies have found no clear evidence of rising environmental degradation due to trade expansion. Grossman and Krueger (1991) analyzed whether or not greater openness to trade will lead to lower environmental standards for atmospheric urban concentrations of SO$_2$. They found that SO$_2$ levels are significantly lower in cities located in countries open to trade. Gale and Mendez (1998) re-estimated Grossman and Krueger’s sulfur emissions while including the effect of trade; they found that an increase in income has a detrimental effect on environmental quality and that the effect of trade liberalization on pollution is not significant. Grossman and Krueger (1995) noted that the downward sloping portion of the EKC could be caused by the assumption that cities with more trade have less pollution but concluded in their study that the magnitude of this impact is small. Shafik and Bandyopadhyay (1992) analyzed eight air, water, and deforestation environmental indicators and found that technology seems to work in favor of improved environmental quality but that trade has little generalized effect on the
Frankel and Rose (2005) estimated the effect of trade on the environment for a given level of GDP. They supported the proposition that trade accelerates the growth process, which leads to larger effects on the environment via income, but they found little evidence that trade openness causes significant environmental degradation. Antweiler, Copeland, and Taylor (2001) found that international trade affects the composition of the structure of the economy, but creates relatively small changes in SO$_2$ concentrations.

Many researchers, including Cernat and Vranceanou (2003) and Liang (2006), suggested that environmental quality will be improved by free trade agreements and foreign direct investment because they increase the scale of production and enhance production efficiencies by improving production technologies. Dean (2002) analyzed water pollution in China and found that trade liberalization increased environmental pollution but mitigated this effect through income growth. At the same time, Dean found income and terms of trade to be negatively correlated with pollution emissions. Lucas, Wheeler, and Hettige (1992) showed that among rapidly growing economies trade reduces the growth rate of the toxic intensity of output. This may be a reflection of more rapid introduction of cleaner technology.

Trade openness also affects indirectly the environment through increases in income growth. Higher income populations look for better environments leading to tighter regulations, cleaner production through the adoption of new technology, and more abatement. Perkins and Neumayer (2005) suggested that new technologies diffuse more rapidly when countries are open to international trade. They also found that latecomer economies, such as

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52 Shafik and Bandyopadhyay (1992) also suggested that it is possible to overcome some environmental problems, but investments and policies are necessary, since the process is not automatic.

53 Liddle (2001) found that trade is not welfare-enhancing for all countries since the benefits of trade depends on the country’s factor endowment.

54 Beckerman (1992) argued an increase in per capita income in developing countries will not necessarily make them replicate the environmental experiences of developed countries.
those of developing countries, can absorb new technology more quickly and easily than earlier environmental improving technology adopters. Holtz-Eakin, Selden, and Iwami (2005) suggested that latecomer economies can diffuse new technology quicker than early adopting countries (e.g. Japan). Jaffe, Peterson, Portney, and Stavins (1997) found that the cost of compliance for Organization for Economic Cooperation and Development (OECD) industries is surprisingly small, only a tiny fraction of operating costs. Wheeler (2001) found that pollution control is not a critical cost factor for most private firms. Several cost benefit analyses like Dasgupta, Wang and Wheeler (1997) have shown that, even in low income economies, the economic return to pollution abatement would justify tightening the regulations.

Other studies, such as Andonova, Mansfield, and Milner (2007) and Mabey and McNally (1998) criticized the effects of trade liberalization and foreign direct investment on the environment. Three theories are addressed with respect to the effect of trade liberalization and foreign direct investment and their impact on the environment: the pollution haven hypothesis, the pollution halos hypothesis, and the race to the bottom hypothesis. The pollution haven hypothesis states that companies will move operations to countries with lax environmental standards to take advantage of lower regulatory standards. Yandle, Bhattarai, and Vijayaraghavan (2004) pointed out that increases in foreign direct investment decreases the environmental quality of the recipient country as long as there exists a difference in environmental standards between countries. According to Zarsky (1999), the race to the bottom hypothesis states that host countries must reduce environmental standards to capture foreign direct investment capital in the global economy, or environmental standards will collapse in domestic countries because polluters threaten to relocate to “pollution havens” in the developing world.
The abovementioned studies are some of the numerous studies that contribute on the understanding of the effect of trade liberalization on the environment. However, few studies explored the effect of trade on GHG emissions, especially from nitrous oxide and methane. Furthermore, little have been done exploring the effect of trade from agricultural sources and its effect on the flow of GHG gases. This paper contributes to the literature by exploring direct and indirect effects of trade on emissions from industrial and agricultural sources for the three major GHG gases.

**Econometric model**

A dynamic simultaneous equation model is used to estimate the relationship between trade liberalization and the environment, directly incorporating the effects of openness on growth and income and of income growth on environmental damage. Assuming Cobb-Douglas technology $Y_i = A_i (H_i) K_i^\alpha L_i^\beta$ and taking log differences, the changes in income per capita from period $t$ to time $t - 1$ can be written as

$$\ln (Y_i_t - Y_{i,t-1}) = [\ln A_i (H_i_t) - \ln A_i (H_i_{t-1})] + \alpha (\ln K_i_t - \ln K_i_{t-1})$$

$$+ \beta (\ln L_i_t - \ln L_i_{t-1}) + (\ln \varepsilon_i_t - \ln \varepsilon_i_{t-1})$$

Where $Y_{i,t}$ represents per capita income Purchase Power Parity (PPP) of country $i$ at time $t$ ($t=1970, 1975, \ldots, 2005$). $L_i$ represents the level of employment (labor force) at time $t$. $K_i$ represents the investment of a country at time $t$ (the level of capital) and $H$ the level of school enrollment at the secondary education level. A standard approach is to treat human capital as an
input in the production function (Mankiw, Romer, and Weil, 1992). $H$ is used as an approximation for human capital. The assumption is that an educated labor force can adopt, develop, and implement new technology better. Then the growth of the productivity factor is given by

$$\ln A_n(H_u) - \ln A_{n-1}(H_{u-1}) = c + gH_u + nH_{u-1}[Y^\text{max}_{u-1} - Y_{u-1}]$$  \hspace{1cm} (2)

$$[(Y^\text{max}_{u-1} - Y_{u-1})/Y_{u-1}]H_u$$  \hspace{1cm} (3)

The first term of equation (1), the productivity growth, depends on two factors, the level of literacy and an interactive term that involves the level of literacy and the technological lag of countries behind their leader (equation 2), where $c$ represents the exogenous technological process, $g$ the endogenous technological process, and $[(Y^\text{max}_{u-1} - Y_{u-1})/Y_{u-1}]H_u$ the diffusion of technology from foreign countries. This last term is called the catch-up effect (Nelson and Phelps, 1966). This model allows human capital levels to affect the speed of technological catch-up and presumes that a nation’s ability to employ new technology is a function of its human capital accumulation. Countries with the highest stock of human capital are assumed to “create” growth by expanding the set of knowledge and to come out as technological leaders for a finite time.

Sub Equation (3) can be simplified to

$$\ln A_n(H_u) - \ln A_{n-1}(H_{u-1}) = c + (g - n)H_u + nH_{u-1}[Y^\text{max}_{u-1} / Y_{u-1}]$$  \hspace{1cm} (4)

Substituting (4) into (1) and rearranging gives
\[
(\ln Y_{it} - \ln Y_{it-1}) = c + (g - n)H_{it-1} + nH_{it-1}(Y_{it-1}^{\text{max}} / Y_{it-1}) + \alpha(\ln K_{it} - \ln K_{it-1}) \\
+ \beta(\ln L_{it-1} - \ln L_{it-1}) + (\ln \varepsilon_{t} - \ln \varepsilon_{t-1})
\]  \tag{5}

The level of labor force, capital, and the income per capita are measured as ratios instead of first differences.

\[
\Delta Y_{it} = \ln Y_{it} - \ln Y_{it-1}, \\
\Delta K_{it} = \ln K_{it} - \ln K_{it-1}, \\
\Delta L_{it} = \ln L_{it} - \ln L_{it-1},
\]

Let

\[
c = \beta_{0},
\]

\[
g - n = \beta_{1},
\]

\[
n = \beta_{2},
\]

\[
\alpha = \beta_{3},
\]

\[
\beta = \beta_{4},
\]

\[
Y_{it}^{*} = Y_{it}^{\text{max}} / Y_{it}
\]

Then we have equation (7)
\[
\Delta Y_{it} = \beta_0 + \beta_1 H_{it-1} + \beta_2 H_{it-1}[Y_{it-1}^{max} - Y_{it-1}] + \beta_3 \Delta K_{it} + \beta_4 \Delta L_{it} + \varepsilon_{it}^* \tag{7}
\]

Adding fixed effects for time and for countries gives

\[
\Delta Y_{it} = \beta_0 + \beta_1 H_{it-1} + \beta_2 H_{it-1}Y_{it-2}^* + \beta_3 \Delta K_{it} + \beta_4 \Delta L_{it} + c_i^* + \tau_i^* + \varepsilon_{it}^* \tag{8}
\]

where \(c_i^*\) and \(\tau_i^*\) are country and time fixed effects

Let

\[
\Delta E_{it} = \ln E_{it} - \ln E_{it-1}
\]

\[
\Delta \text{open}_{it} = \ln \text{open}_{it} - \ln \text{open}_{it-1}
\]

The emission equations is

\[
\ln E_{it} - \ln E_{it-1} = \delta_0^* + \delta_1 [\ln Y_{it} - \ln Y_{it-1}] + \delta_2 [\ln \text{open}_{it} - \ln \text{open}_{it-1}] + \mu_{it}^* \tag{10}
\]

Therefore,

\[
\Delta E_{it} = \delta_0^* + \delta_1 \Delta Y_{it} + \delta_2 \Delta \text{open}_{it} + \mu_{it}^* \tag{11}
\]

with fixed effects

\[
\Delta E_{it} = \delta_0^* + \delta_1 \Delta Y_{it} + \delta_2 \Delta \text{open}_{it} + c_i^E + \tau_i^E + \mu_{it}^* \tag{12}
\]
Then, a dynamic panel equation model (13) will be used to estimate the relationship between trade and the environment, directly incorporating the effects of openness on growth and income, and of income on environmental damage.

\[
\Delta Y_{it} = \rho Y_{it-1} + \beta_0 + \beta_1 H_{it-1} + \beta_2 H_{it-1}[Y_{it}^{\text{max}}] + \beta_3 \Delta K_{it} + \beta_4 \Delta L_{it} + c_i^y + \tau_i^y + \varepsilon_{it}^y
\]  

(13)

\[
\Delta E_{it} = \rho E_{it-1} + \delta_0 + \delta_1 \Delta Y_{it-1} + \delta_2 \Delta open_{it} + c_i^E + \tau_i^E + \mu_{it}^E
\]  

(14)

Where \( E_t \) represents pollution emissions from either nitrous oxide or methane sources measured in metric tonnes (kt) of CO\(_2\) equivalent. The degree of openness represents the relative prices of a country's export to import (\( X + M \)).

Endogenous Partial Adjustment Model:

\[
\Delta Y_{it} = \rho Y_{it-1} + \beta_0 + n_1 \Delta E_{it} + \beta_1 H_{it-1} + \beta_2 H_{it-1} Y_{it-1}^* + \beta_3 \Delta K_{it} + \beta_4 \Delta L_{it} + \beta_5 \Delta open_{it} + c_i^y + \tau_i^y + \varepsilon_{it}^y
\]  

(15)

\[
\Delta E_{it} = \rho E_{it-1} + \delta_0 + n_1 \Delta Y_{it} + \delta_2 \Delta open_{it} + c_i^E + \tau_i^E + \mu_{it}^E
\]  

(16)

Collecting terms and summarizing

\[
Z_{it}^y \theta^y = \beta_0 + \beta_1 H_{it-1} + \beta_2 H_{it-1} Y_{it-1}^* + \beta_3 \Delta K_{it} + \beta_4 \Delta L_{it} + c_i^y + \tau_i^y + \varepsilon_{it}^y
\]  

(17)

\[
Z_{it}^E \theta^E = \delta_0 + \delta_2 \Delta open_{it} + c_i^E + \tau_i^E + \mu_{it}^E
\]  

(18)

Rewriting equation (15) and (16):
\[ \Delta Y_t - n_Y \Delta E_t = \rho_Y \Delta Y_{t-1} + Z^{\gamma}_{it} \theta^Y + \varepsilon^*_t \]  
(19)

\[ \Delta E_t - n_E \Delta Y_t = \rho_E \Delta E_{t-1} + Z^{E}_{it} \theta^E + \mu^*_t \]  
(20)

In matrix form

\[
\begin{pmatrix}
1 & -n_Y \\
-n_E & 1
\end{pmatrix}
\begin{pmatrix}
\Delta Y_t \\
\Delta E_t
\end{pmatrix} = 
\begin{pmatrix}
\rho_Y \Delta Y_{t-1} + Z^{\gamma}_{it} \theta^Y \\
\rho_E \Delta E_{t-1} + Z^{E}_{it} \theta^E
\end{pmatrix} + 
\begin{pmatrix}
\varepsilon^*_t \\
\mu^*_t
\end{pmatrix}
\]  
(21)

Data

Annual cross sectional time series data is used on industrial and agricultural nitrous oxide and methane emissions, income, and share of industrial and agricultural trade as a percentage of GDP and as a percentage of industrial and agricultural production for 157 countries over the period 1970-2005. To ensure compatibility with the per capita GDP in the model, per capita nitrous oxide and methane emissions for individual countries are calculated using population sizes. The estimated industrial and agricultural emissions for these countries are obtained from the Emissions Database for Global Atmospheric Research (EDGAR 4.0) from the Netherlands Environmental Assessment Agency (NEAA).\(^5\) Pollution data is disaggregated into industrial nitrous oxide and methane emissions and agricultural nitrous oxide and methane emissions. The purpose of this approach is to provide for the individual analysis of each emission source due to the characteristic differences in each pollution source.

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\(^5\) European Commission, Joint Research Centre (JRC)/Netherlands Environmental Assessment Agency (PBL). Emission Database for Global Atmospheric Research (EDGAR), release version 4.0.
The data breaks down by source categories according to the Intergovernmental Panel of Climate Change (IPCC) guidelines. The per capita GDP, measured in terms of 2000 constant US Purchase Power Parity (PPP)-adjusted dollars, is used as an approximation for income and is taken from the World Bank and complemented with the Penn World table (PWT 6.2).56

The degree of openness (Open), expressed as exports plus imports, is also taken from the World Development Indicators (WDI) of the World Bank for the period 1970-2005. Countries are divided into thirds, poorer countries, the middle third and wealthier countries, which correspond to less than $960, $960 to $4,794 and more than $4,794 in 2000 PPP dollars, respectively. Dummy variables are assigned depending on the income level specification, $d = 2$ if in the wealthier third, $d = 1$ if in the middle third countries, and $d = 0$ if in the poorer third. Data for physical capital (K), human capital (H), and labor (L) are available through the World Bank. Secondary school enrollment, which represents investment levels in human capital, will be used as an approximation for human capital, H. Human capital has been approximated in the literature by school enrollment ratios or literacy rates, but literacy rate may include measurement problems across countries.57 The World Bank defines gross enrollment secondary ratio as the ratio of total enrollment, regardless of age, to the population of the age group that officially corresponds to the level of education shown. Previous literature has usually used gross investment rates as an approximation for K (Barro, 1991).58 Physical capital accumulation (gross domestic investment) consists of outlays on additions to the fixed assets of

57 Adult literacy rate is defined by the United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics as the percentage of people ages 15 and above who can, with understanding, read and write a short, simple statement on their everyday life.
58 The United Nations Educational, Scientific, and Cultural Organization (UNESCO) Institute for Statistics defines secondary education as “the completion of the provision of basic education that began at the primary level, and aims at laying the foundations for lifelong learning and human development, by offering more subject- or skill-oriented instruction using more specialized teachers”.
the economy plus net changes in the level of inventories.\textsuperscript{59} Total labor force (L) is taken from the International Labor Organization (ILO) using World Bank population estimates and comprises people ages 15 and older who meet the International Labor Organization definition of the economically active population. The level of factor productivity is captured by the effect of the domestic endogenous innovation ($h$) variable and the catch-up variable (catch-up). This last interactive term captures the level of technological lag of countries with respect to the leader, or in other words the “catch-up” effect. The domestic endogenous innovation suggests that the $h$ variable independently enhances technological progress. The catch-up term implies that holding $h$ constant, countries with lower initial productivity levels should experience faster rates of growth of total factor productivity.

Anthropogenic CO\textsubscript{2}, N\textsubscript{2}O and CH\textsubscript{4} emissions increased constantly and markedly during the period 1970-2005 and are trending up faster during the last lustrum. The total annual volume of CO\textsubscript{2} equivalent emitted during the study period from CO\textsubscript{2}, N\textsubscript{2}O and CH\textsubscript{4} increased by approximately 86, 34, and 34 percent, or by an average of 2.4, 1, and 1 percent per year (EDGAR 4.0). The accumulation of the emissions increased the stock of GHG gases in the atmosphere to 387 ppm of CO\textsubscript{2}, 1.74 ppm of CH\textsubscript{4} methane and 0.31 ppm of N\textsubscript{2}O in 2009 from 280 ppm of CO\textsubscript{2}, 0.70 ppm of CH\textsubscript{4} methane and 0.27 ppm of N\textsubscript{2}O in 1750.

The overall picture for the past 35 years that emerges from Figure 3.1 is that trade expanded significantly with a steeper increase during the early nineties for all three income groups. In 2005, the degree of openness (exports plus imports) for the poorer, middle, and wealthier countries was 55, 65 and 45 percent, respectively. As indicated by the high ratio of trade to GDP, middle income and poorer economies have a higher degree of openness than

\textsuperscript{59} Inventories are defined by the World Bank national accounts data and the OECD national accounts files as stocks of goods held by firms to meet temporary or unexpected fluctuations in production or sales, and work in progress.
higher income economies, due primarily to their small market scale, narrow range of resources, and inability to support certain types of production. Nevertheless, poorer third economies only represented 1 percent of the international trade in 2005. Wealthier countries and middle income countries represented 73 and 26 percent of the total international trade, respectively, and experienced a larger expansion of their degree of openness compared to poorer countries since the beginning of 90’s (Figure 3.2).

Figure 3.3 shows that per capita capital accumulation, measured in constant 2000 dollars, is trending up in the three country categories but increased more significantly in the middle third countries. During the last 25 years, per capita accumulation increased in poorer, middle, and high income countries by 165, 195, and 60 percent, respectively. From the total increase of physical capital accumulation during the last 25 years, the share of poorer, middle and higher income countries was 16, 61, and 22 percent, respectively. Most capital accumulation was generated in a few middle third countries. China represents 63 percent of the share of the middle third countries, or 38 percent of the total increase of the three income groups together (WDI database). Brazil and Russia follow with 9 and 7 percent, respectively.

Figure 3.1: Degree of openness for poor, middle, and wealthier countries 1970-2005
Source: Data from the World Development Indicators (WDI) of the World Bank
Schultz (1971) suggested human capital is necessary to improve the production capacity of a nation and can encourage the accumulation of other factors of production. The absence of qualified workers may reduce the number of entrepreneurs and also lower the rate of growth of physical capital. Lucas (1990) suggested that one of the possible reasons why capital accumulation failed to flow to poorer countries was difference in endowment of labor quality or
human capital per worker. In 2005, school enrollment was 100 percent in high income countries and 65 and 39 percent in middle and low income countries.

Results

Table 3.2 starts by examining the effects of human capital, physical capital, labor, openness, and emissions as inputs in economic growth. In this study, the growth framework is chosen instead of the levels framework. To capture growth performance of countries, the log difference of per capita GDP is regressed on log differences of human capital, physical capital, labor, and differences of openness and emissions. An advantage to that approach is that it helps overcome endogeneity through reverse causality and omitted variable bias (Dollar and Kraaf, 2004). Each model represents one third of the entire population on the basis of their 2005 per capita income. Columns 2, 3 and 4 represent the poorer countries of the sample, columns 5, 6 and 7 the middle income countries, and columns 8, 9 and 10 the wealthier nations. This approach models the growth of total productivity as a function of the level of emissions of carbon dioxide, methane and nitrous oxide.

The theory suggests that an educated labor force is better at developing and adopting new technologies and as a result is better at increasing output and generating growth.\(^{60}\) Results indicate a positive role of human capital in per capita income, but its coefficient estimates are significant at 5 percent level only for poorer countries. Insignificant coefficients result for middle and wealthier countries, which may be explained by higher school enrollment rates for middle income countries and values close to unity in wealthier nations. One explanation for the significant coefficient of poorer income countries is that they began the period with low stocks

\(^{60}\) According to Lucas (1988), human capital generates increases in productivity through technological externalities.
of human capital. In 1991, school enrollment in the poor countries group was only 24 percent, but it increased by more than 1 percent per year during the next 15 years to 41 percent in 2005 (WDI, 2008). Nevertheless, Benhabib (1994) found that although various poor countries improve their stock of human capital, many of them did not experience a similar result with their outputs.\(^{61}\) Lucas (1990) noted that human capital may also attract other factors of production such as physical capital. An increase in physical capital per worker precedes a higher growth rate of output per worker. Log difference of capital accumulation enters with the expected sign and is positively correlated with log differences in per capita income at the 10 percent confidence level in all specifications. The larger coefficients for middle and wealthier nations imply higher productivity from physical capital for these two groups.\(^{62}\)

Log differences in labor coefficient estimates, measured as total labor force, d.In.L, enter with the expected positive sign and are significant at a 5 percent confidence level for poorer and wealthier countries. Therefore, the inclusion of additional labor will have a larger impact on GDP in poorer and wealthier countries. Although, the level of education of the incoming labor force does have an impact on labor productivity and output in poorer countries, the same cannot be said about wealthier countries.

There is a strong consensus amongst economists that openness to trade tends to promote economic welfare, although the general public, particularly in less developed countries, has increasing concerns. The relationship of per capita GDP and degree of openness for the poorer and wealthier countries shows positive results, although the coefficient estimates appear to be

\(^{61}\) Benhabib (1994) found a negative relationship between human capital and growth. He included country dummies for Africa and Latin America, and the results held for these two groups, but he concluded that these countries alone do not drive the negative results.

\(^{62}\) Hall and Jones (1999) studied the differences in productivity between the United States and Niger and found that differences in K in those countries were also driven by differences in institutions and government policies.
low and the variable is rarely significant. Interestingly, the trade variable does not always show positive impact on growth.\(^{63}\)

Table 3.1: Structural specification for cross-country growth regression. Dependent variable d.lnY.

<table>
<thead>
<tr>
<th>Country</th>
<th>Const.</th>
<th>d.lnH</th>
<th>d.lnL</th>
<th>d.lnK</th>
<th>d.open</th>
<th>d.indn2O</th>
<th>d.indch4</th>
<th>d.indnco2</th>
<th>Obs.</th>
<th>R^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poorer countries N(_2)O</td>
<td>-0.026</td>
<td>-0.016</td>
<td>0.051</td>
<td>-0.061</td>
<td>0.039</td>
<td>0.008</td>
<td>0.008</td>
<td>0.066</td>
<td>26</td>
<td>0.84</td>
</tr>
<tr>
<td>Poorer countries CH(_4)</td>
<td>-0.222(^a)</td>
<td>-0.106</td>
<td>0.101(^a)</td>
<td>0.011</td>
<td>1.04</td>
<td>0.067</td>
<td>0.016</td>
<td>0.027</td>
<td>0.001</td>
<td>0.40</td>
</tr>
<tr>
<td>Poorer countries CO(_2)</td>
<td>(0.063)</td>
<td>(0.027)</td>
<td>(0.132)</td>
<td>(0.082)</td>
<td>(0.048)</td>
<td>(0.024)</td>
<td>(0.034)</td>
<td>(0.028)</td>
<td>(6.8e-07)</td>
<td>(1.4e-08)</td>
</tr>
<tr>
<td>Middle(_3)rd countries N(_2)O</td>
<td>-0.016</td>
<td>0.011</td>
<td>0.104</td>
<td>0.067</td>
<td>0.016</td>
<td>0.027</td>
<td>-0.009</td>
<td>0.043</td>
<td>150</td>
<td>0.31</td>
</tr>
<tr>
<td>Middle(_3)rd countries CH(_4)</td>
<td>0.051</td>
<td>1.04</td>
<td>0.067</td>
<td>0.016</td>
<td>0.027</td>
<td>-0.009</td>
<td>0.043</td>
<td>0.067</td>
<td>187</td>
<td>0.57</td>
</tr>
<tr>
<td>Middle(_3)rd countries CO(_2)</td>
<td>-0.061</td>
<td>0.067</td>
<td>0.016</td>
<td>0.027</td>
<td>-0.009</td>
<td>0.043</td>
<td>0.067</td>
<td>0.067</td>
<td>168</td>
<td>0.77</td>
</tr>
<tr>
<td>Wealthier countries N(_2)O</td>
<td>0.039</td>
<td>0.016</td>
<td>0.027</td>
<td>0.043</td>
<td>0.067</td>
<td>0.067</td>
<td>0.067</td>
<td>0.067</td>
<td>126</td>
<td>0.82</td>
</tr>
<tr>
<td>Wealthier countries CH(_4)</td>
<td>0.008</td>
<td>0.027</td>
<td>-0.009</td>
<td>0.043</td>
<td>0.067</td>
<td>0.067</td>
<td>0.067</td>
<td>0.067</td>
<td>156</td>
<td>0.82</td>
</tr>
<tr>
<td>Wealthier countries CO(_2)</td>
<td>0.008</td>
<td>-0.009</td>
<td>0.043</td>
<td>0.067</td>
<td>0.067</td>
<td>0.067</td>
<td>0.067</td>
<td>0.067</td>
<td>156</td>
<td>0.82</td>
</tr>
</tbody>
</table>

Notes: \(^a\) significant at 1%; \(^b\) significant at 5%; \(^c\) significant at 10%. Standard errors are in parentheses.

Wealthier third of the sample; per capita income in 2000 greater $4,794.
Middle third of the sample; per capita income in 2000 less than $4,794 and greater than $960.
Poorest third of the sample; per capita income in 2000 less than $960.

\(^{63}\) Frankel and Romer (1999) suggested that trade raises income by spurring the accumulation of physical and human capital and by increasing output for a given level of output.
Pollution from GHG is negatively related to growth in developed countries and positively related to growth in poorer and middle income countries. Negative results of pollution coefficients with GDP can be interpreted as increases in efficiencies from the industrial sector involved in emissions from that source.

Table 3.3 includes the “catch-up” term, or diffusion of technology from foreign countries, $nH_{t-1}[(Y_{t}^{\text{max}})/Y_{t-1}]$ as well as the endogenous technological process $(g - m)H_{t-1}$. Results from the coefficient estimates on the log difference of $h ((g - m)H_{t-1})$ are negative and significant for low and middle income countries, which is consistent with Benhabib (1994). Catch-up enters positively and becomes larger as we move up the income scale. This implies that wealthier countries lying below their “leader nations” will catch up at a faster pace than poorer nations. While the correlation is positive with log differences in income, the coefficients are not large. Therefore, the outcome appears to favor catch-up over endogenous technological progress as a channel for human capital to affect economic growth. Although technological adoption from abroad may be the convenient choice for low income countries, the opposite may hold for technologically advanced countries.64

The coefficient of the log difference of capital accumulation enters positively at the 5 percent confidence level in all specifications and increases as countries develop and augment their GDP. This rate of return on capital increases as countries become wealthier for both industrial emissions. Lucas (1990) suggested that the marginal product of physical capital in less developed countries may not actually be that high despite its apparent scarcity relative to developed countries.

64 Benhabib (1994) found that for the richest nations the coefficient estimate for the catch-up term enters insignificantly and relatively small
International economics literature stresses the openness of countries as an important instrument for growth. An increase in the degree of openness positively affects the per capita income of wealthier nations, although its impact is small and coefficient estimates enter insignificantly for middle income and poorer countries.

Table 3.2: Structural specification for cross-country growth regression. Dependent variable d.lnY

<table>
<thead>
<tr>
<th></th>
<th>Poorer countries</th>
<th>Poorer countries</th>
<th>Poorer countries</th>
<th>Middle third countries</th>
<th>Middle third countries</th>
<th>Middle third countries</th>
<th>Wealthier countries</th>
<th>Wealthier countries</th>
<th>Wealthier countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>l.d.lnY</td>
<td>0.170&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.179&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.266&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.208&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.246&lt;sup&gt;a&lt;/sup&gt;</td>
<td>6.49e-08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.152&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.200&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.242&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>l.h</td>
<td>-0.008&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.008&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.0015&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.003&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.004&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.0027&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.0004&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.0006&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-0.0009&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>l.catchup</td>
<td>0.0001&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0001&lt;sup&gt;c&lt;/sup&gt;</td>
<td>9.17e-06&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0002&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0002&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0001&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0002&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.001&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0003&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>d.lnL</td>
<td>0.120</td>
<td>0.155</td>
<td>-0.103</td>
<td>-0.402&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.024&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.0729&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.069&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.011&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.0157&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>d.lnK</td>
<td>0.109&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.106&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.131&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.201&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.183&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.2072&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.286&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.291&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.249&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>d.indn2o</td>
<td>0.0004</td>
<td>-0.066</td>
<td>0.008</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d.indch4</td>
<td>0.0001</td>
<td>-0.0010&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-0.0012&lt;sup&gt;c&lt;/sup&gt;</td>
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<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>d.indco2</td>
<td>1.2e-06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>6.5e-08&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.8e-09&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>d.open</td>
<td>-0.0004</td>
<td>-0.0004</td>
<td>-0.0009</td>
<td>-0.001</td>
<td>-0.0012</td>
<td>0.001&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.001&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.0008&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Hansen J</td>
<td>1.90</td>
<td>1.886</td>
<td>0.228</td>
<td>0.201</td>
<td>1.588</td>
<td>1.467</td>
<td>0.211</td>
<td>3.558</td>
<td>1.990</td>
</tr>
<tr>
<td>P-value</td>
<td>0.386</td>
<td>0.389</td>
<td>0.892</td>
<td>0.904</td>
<td>0.452</td>
<td>0.473</td>
<td>0.899</td>
<td>0.168</td>
<td>0.369</td>
</tr>
<tr>
<td>Endog.test</td>
<td>0.082</td>
<td>0.132</td>
<td>1.064</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P-value</td>
<td>0.774</td>
<td>0.716</td>
<td>0.302</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obs.</td>
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<td>141</td>
<td>122</td>
<td>62</td>
<td>152</td>
<td>138</td>
<td>102</td>
<td>134</td>
<td>124</td>
</tr>
<tr>
<td>R²</td>
<td>0.54</td>
<td>0.54</td>
<td>0.22</td>
<td>0.92</td>
<td>0.75</td>
<td>0.57</td>
<td>0.83</td>
<td>0.89</td>
<td>0.59</td>
</tr>
</tbody>
</table>

Notes: <sup>a</sup> significant at 1%; <sup>b</sup> significant at 5%; <sup>c</sup> significant at 10%. Standard errors are in parentheses.

Wealthier third of the sample; per capita income in 2000 greater $4,794.
Middle third of the sample; per capita income in 2000 less than $4,794 and greater than $960.
Poorest third of the sample; per capita income in 2000 less than $960.

---

65 Krueger (1998) indicated that relaxing trade restrictions can result in gains if there are no other policies in effect that thwart their impact. Dollar and Kraay (2004) found that globalization leads to faster growth and also helps poverty reduction in poor countries.
Methane emissions are negatively correlated with GDP and with larger coefficients as per capita GDP increases, suggesting that as nations develop they increase their efficiency and reduce pollution per output. Carbon dioxide enters positive and significant for poor and middle income countries, but its economic impact is very close to zero.

Table 3.4 estimates dynamic regression of 5-year changes in log difference of per capita GDP, log difference of emissions, and differences in measures of openness to evaluate how much pollution can be explained by greater openness and improved GDP using the first differenced GMM technique for all three country categories. All regressions include an unreported time dummy.

Log difference of per capita income is significant and positively related with emissions from N₂O and CH₄ for middle income countries. The point estimates suggest that increasing a middle income country’s per capita income by one unit raises emissions from N₂O by 1/10th of a unit or more and CH₄ by 25 units. In other words, increase in per capita income in middle income countries increases industrial N₂O and CH₄ emissions by 0.63 and 0.45 percent, respectively.

The effect of openness on pollution is ambiguous and enters insignificantly in these dynamic panel data regressions across all country groups. The level of the degree of openness (exports plus imports) will typically depend on the country’s excess production and the composition of their exports. Log difference of emissions in this dynamic regression indicates that pollution at time \( t \) can be explained by pollution at time \( t-1 \). The coefficient estimates of emissions also indicate that pollution is growing in poor and middle income countries but decreasing in wealthier countries.
Table 3.3: Structural specification for cross-country growth regression. Dependent variable d.lnE

<table>
<thead>
<tr>
<th></th>
<th>Poorer countries</th>
<th>Poorer countries</th>
<th>Middle 3rd countries</th>
<th>Middle 3rd countries</th>
<th>Wealthier countries</th>
<th>Wealthier countries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N₂O</td>
<td>CH₄</td>
<td>N₂O</td>
<td>CH₄</td>
<td>N₂O</td>
<td>CH₄</td>
</tr>
<tr>
<td>l.d.indn₁₀</td>
<td>-0.376</td>
<td>-0.411⁺</td>
<td>0.391⁺</td>
<td>(0.343)</td>
<td>(0.183)</td>
<td>(0.074)</td>
</tr>
<tr>
<td></td>
<td>(0.061)</td>
<td></td>
<td>(0.060)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l.d.indch₄</td>
<td>-0.533⁺</td>
<td>-0.765⁺</td>
<td>-3.082⁺</td>
<td>0.261⁺</td>
<td>(0.061)</td>
<td>(0.045)</td>
</tr>
<tr>
<td></td>
<td>(0.125)</td>
<td>(0.001)</td>
<td>(85.24)</td>
<td>(0.002)</td>
<td>(0.373)</td>
<td>(0.315)</td>
</tr>
<tr>
<td>l.d.indco₂</td>
<td>-0.003</td>
<td>-17.29</td>
<td>0.0007</td>
<td>0.0588</td>
<td>-0.002</td>
<td>0.174⁺</td>
</tr>
<tr>
<td></td>
<td>(0.004)</td>
<td>(30.66)</td>
<td>(0.028)</td>
<td>(85.24)</td>
<td>(0.002)</td>
<td>(220.9)</td>
</tr>
<tr>
<td>d.open</td>
<td>0.157</td>
<td>-1.177</td>
<td>0.113⁺</td>
<td>25.44⁺</td>
<td>6686.7</td>
<td>0.254</td>
</tr>
<tr>
<td></td>
<td>(0.149)</td>
<td>(1.699)</td>
<td>(0.027)</td>
<td>(11.38)</td>
<td>(30195)</td>
<td>(0.344)</td>
</tr>
<tr>
<td>d.lnY</td>
<td>4.253</td>
<td>4.145</td>
<td>2.428</td>
<td>1.720</td>
<td>4.874</td>
<td>2.926</td>
</tr>
<tr>
<td></td>
<td>(0.149)</td>
<td>(1.699)</td>
<td>(11.38)</td>
<td>(30195)</td>
<td>(0.344)</td>
<td>(25.35)</td>
</tr>
<tr>
<td></td>
<td>(0.149)</td>
<td>(1.699)</td>
<td>(11.38)</td>
<td>(30195)</td>
<td>(0.344)</td>
<td>(25.35)</td>
</tr>
<tr>
<td>P-value</td>
<td>0.119</td>
<td>0.0125</td>
<td>0.0657</td>
<td>0.176</td>
<td>0.423</td>
<td>0.3005</td>
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<tr>
<td></td>
<td>(0.149)</td>
<td>(0.0125)</td>
<td>(0.0017)</td>
<td>(0.027)</td>
<td>(0.063)</td>
<td>(0.319)</td>
</tr>
<tr>
<td>Obs.</td>
<td>22</td>
<td>168</td>
<td>74</td>
<td>62</td>
<td>181</td>
<td>76</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>110</td>
<td>184</td>
</tr>
<tr>
<td>R²</td>
<td>0.40</td>
<td>0.53</td>
<td>0.69</td>
<td>0.08</td>
<td>0.31</td>
<td>0.98</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>0.25</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Notes:  
- a significant at 1%;  
- b significant at 5%;  
- c significant at 10%. Standard errors are in parentheses.

Throughout Table 3.5, the coefficients of capital accumulation enter with the expected sign and are positively correlated with per capita GDP in all three income groups. Consistent with the Lucas paradox, returns on capital accumulation are lower for poorer countries than middle income and wealthier countries. Human capital, labor, and physical capital, and openness foster growth in the long run for poorer countries. Education and training increases the skills of the potential labor force which can increase earnings from work and attract physical capital. Similarly, the impact of capital accumulation and human capital on growth is positive and significant for wealthier countries. In middle income countries, capital accumulation seems to be the driving force of output change.

---

66 Mankiw, Romer, and Weil (1992) suggested that higher investment raises total factor productivity.  
67 Lucas (1990) observed that capital does not flow from developed to developing countries despite the lower levels of capital per worker.  
68 Cohen and Soto (2003) noted that increases in life expectancy can also trigger economic development by pulling H and thus increasing the productivity of K.
Table 3.4: Structural specification for cross-country growth regression. Dependent variable d.lnY.

<table>
<thead>
<tr>
<th></th>
<th>Poorer countries</th>
<th>Poorer countries</th>
<th>Middle3rd countries</th>
<th>Middle3rd countries</th>
<th>Wealthier countries</th>
<th>Wealthier countries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N&lt;sub&gt;O&lt;/sub&gt;</td>
<td>CH&lt;sub&gt;_A&lt;/sub&gt;</td>
<td>N&lt;sub&gt;O&lt;/sub&gt;</td>
<td>CH&lt;sub&gt;_A&lt;/sub&gt;</td>
<td>N&lt;sub&gt;O&lt;/sub&gt;</td>
<td>CH&lt;sub&gt;_A&lt;/sub&gt;</td>
</tr>
<tr>
<td>Const.</td>
<td>-0.226&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.226&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-0.078</td>
<td>-0.068</td>
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<tr>
<td></td>
<td>(0.073)</td>
<td>(0.073)</td>
<td>(0.083)</td>
<td>(0.077)</td>
<td>(0.036)</td>
<td>(0.032)</td>
</tr>
<tr>
<td>d.lnH</td>
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<td>0.108&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.114</td>
<td>0.132</td>
<td>0.047</td>
<td>0.050</td>
</tr>
<tr>
<td></td>
<td>(0.041)</td>
<td>(0.041)</td>
<td>(0.087)</td>
<td>(0.088)</td>
<td>(0.031)</td>
<td>(0.031)</td>
</tr>
<tr>
<td>d.lnL</td>
<td>0.869&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.871&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.389</td>
<td>0.392</td>
<td>0.471&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.398&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(0.487)</td>
<td>(0.483)</td>
<td>(0.323)</td>
<td>(0.315)</td>
<td>(0.191)</td>
<td>(0.174)</td>
</tr>
<tr>
<td>d.lnK</td>
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<td>0.183&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.306&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.303&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>0.249&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(0.049)</td>
<td>(0.049)</td>
<td>(0.054)</td>
<td>(0.052)</td>
<td>(0.038)</td>
<td>(0.039)</td>
</tr>
<tr>
<td>d.open</td>
<td>0.0014&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.0014&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.0007</td>
<td>0.0006</td>
<td>0.0006&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0008&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>d.agn&lt;sub&gt;-o&lt;/sub&gt;</td>
<td>0.005&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.020</td>
<td>0.033&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.017)</td>
<td>(0.017)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>d.agch&lt;sub&gt;4&lt;/sub&gt;</td>
<td>0.0006&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0023</td>
<td></td>
<td>0.0017</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.001)</td>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obs.</td>
<td>177</td>
<td>177</td>
<td>187</td>
<td>187</td>
<td>168</td>
<td>168</td>
</tr>
<tr>
<td>R&lt;sup&gt;2&lt;/sup&gt;</td>
<td>0.39</td>
<td>0.40</td>
<td>0.57</td>
<td>0.58</td>
<td>0.77</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Notes: <sup>a</sup> significant at 1%; <sup>b</sup> significant at 5%; <sup>c</sup> significant at 10%. Standard errors are in parentheses.

Wealthier third of the sample: per capita income in 2000 greater $4,794.
Middle third of the sample: per capita income in 2000 less than $4,794 and greater than $960.
Poorest third of the sample: per capita income in 2000 less than $960.

Table 3.6 shows that while log differences in capital accumulation and lag of log difference in income are shown to be significant explaining income, the correlation with log differences in catch-up variables is less economically significant. All regressions include an unreported time dummy. The accumulation of factors is accounted for in this specification, and the role of the initial income in this regression is, as expected, positive and significant in all cases. Turning to the variable of interest, it is found that the signs of trade openness are positively correlated with growth for wealthier countries. Although the theory suggests that with larger degrees of openness countries are likely to grow faster, results indicate that the variable is not statistically significant for poor and middle income countries.\(^{69}\)

\(^{69}\) Krueger (1983) suggested that protection thought tariffs and non-tariff barriers is unacceptable as a mean of achieving domestic goals for manufacturing so it must be for agriculture.
Table 3.5: Structural specification for cross-country growth regression. Dependent variable d.lnY.

<table>
<thead>
<tr>
<th></th>
<th>Poorer countries N₂O</th>
<th>Poorer countries CH₄</th>
<th>Middle 3rd countries N₂O</th>
<th>Middle 3rd countries CH₄</th>
<th>Wealthier countries N₂O</th>
<th>Wealthier countries CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>l.d.lnY</td>
<td>0.170</td>
<td>0.170</td>
<td>0.2398</td>
<td>0.2258</td>
<td>0.2022</td>
<td>0.2002</td>
</tr>
<tr>
<td></td>
<td>(0.095)</td>
<td>(0.095)</td>
<td>(0.086)</td>
<td>(0.086)</td>
<td>(0.048)</td>
<td>(0.050)</td>
</tr>
<tr>
<td>l.h</td>
<td>-0.008*</td>
<td>-0.008*</td>
<td>-0.004*</td>
<td>-0.004*</td>
<td>-0.0018*</td>
<td>-0.0015*</td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.002)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>l.catchup</td>
<td>0.0001*</td>
<td>0.0001*</td>
<td>0.0002*</td>
<td>0.0002*</td>
<td>0.0004*</td>
<td>0.0004*</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.000)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>l.d.Ln</td>
<td>0.1206</td>
<td>0.1225</td>
<td>0.026</td>
<td>0.024</td>
<td>0.207</td>
<td>0.119</td>
</tr>
<tr>
<td></td>
<td>(0.172)</td>
<td>(0.172)</td>
<td>(0.143)</td>
<td>(0.123)</td>
<td>(0.221)</td>
<td>(0.207)</td>
</tr>
<tr>
<td>l.d.K</td>
<td>0.109*</td>
<td>0.109*</td>
<td>0.180*</td>
<td>0.175*</td>
<td>0.219*</td>
<td>0.225*</td>
</tr>
<tr>
<td></td>
<td>(0.040)</td>
<td>(0.040)</td>
<td>(0.026)</td>
<td>(0.024)</td>
<td>(0.051)</td>
<td>(0.050)</td>
</tr>
<tr>
<td>l.d.agn₂o</td>
<td>0.0004</td>
<td>0.0001</td>
<td>0.0227*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.002)</td>
<td>(0.007)</td>
<td>(0.012)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l.d.agch₄</td>
<td>0.0001</td>
<td>-0.0011*</td>
<td></td>
<td>0.0013</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.005)</td>
<td></td>
<td>(0.001)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>l.d.open</td>
<td>-0.0004</td>
<td>-0.0004</td>
<td>-0.0006</td>
<td>-0.0007</td>
<td>0.0008*</td>
<td>0.0010*</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>Hansen J</td>
<td>1.900</td>
<td>1.886</td>
<td>1.313</td>
<td>1.502</td>
<td>0.211</td>
<td>1.637</td>
</tr>
<tr>
<td>P-value</td>
<td>0.386</td>
<td>0.389</td>
<td>0.518</td>
<td>0.589</td>
<td>0.899</td>
<td>0.441</td>
</tr>
<tr>
<td>Obs.</td>
<td>141</td>
<td>141</td>
<td>152</td>
<td>152</td>
<td>134</td>
<td>134</td>
</tr>
<tr>
<td>R²</td>
<td>0.54</td>
<td>0.54</td>
<td>0.75</td>
<td>0.75</td>
<td>0.81</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Notes: * significant at 1%; ** significant at 5%; *** significant at 10%. Standard errors are in parentheses.

Wealthier third of the sample; per capita income in 2000 greater $4,794.
Middle third of the sample; per capita income in 2000 less than $4,794 and greater than $960.
Poorest third of the sample; per capita income in 2000 less than $960.

We next specify an alternative model in which emissions from both pollutants depends on income, degree of openness, and emissions at t − 1 (Table 3.7). The test of this specification does indicate that income in middle income countries and wealthier countries has a large positive effect on emissions. An increase in per capita income due to increases in agricultural production generates more pollution in those country groups. Therefore, more production will be associated with more pollution. A 1 percent increase in per capita income in middle income countries increases N₂O and CH₄ agriculture emissions by 0.39 and 0.04 percent, respectively. The effect of openness is insignificant across all country groups, and its effect depends on the pollution source. Similar to industrial emissions, agricultural emissions from N₂O and CH₄ are
expanding in poor and middle income countries but are being reduced in wealthier countries, as seen in Table 3.7.

Table 3.6: Structural specification for cross-country growth regression. Dependent variable d.lnE

<table>
<thead>
<tr>
<th></th>
<th>Poorer countries N₂O</th>
<th>Poorer countries CH₄</th>
<th>Middle 3rd countries N₂O</th>
<th>Middle 3rd countries CH₄</th>
<th>Wealthier countries N₂O</th>
<th>Wealthier countries CH₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>l.d.agn₂o</td>
<td>-0.514⁺</td>
<td>-0.338⁺</td>
<td>0.311⁺</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.003)</td>
<td>(0.029)</td>
<td>(0.073)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>l.d.agch₄</td>
<td>-0.465⁺</td>
<td>-0.046</td>
<td>0.359⁺</td>
<td>0.311⁺</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.006)</td>
<td>(0.041)</td>
<td>(0.170)</td>
<td>(0.073)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d.open</td>
<td>-0.0004</td>
<td>-0.0102</td>
<td>0.0017</td>
<td>0.0282</td>
<td>0.0002</td>
<td>-0.0333</td>
</tr>
<tr>
<td></td>
<td>(0.001)</td>
<td>(0.019)</td>
<td>(0.001)</td>
<td>(0.036)</td>
<td>(0.001)</td>
<td>(0.060)</td>
</tr>
<tr>
<td>d.lnY</td>
<td>0.0634</td>
<td>0.3848</td>
<td>0.6558⁺</td>
<td>1.169⁺</td>
<td>0.710⁺</td>
<td>12.598</td>
</tr>
<tr>
<td></td>
<td>(0.171)</td>
<td>(2.067)</td>
<td>(0.171)</td>
<td>(2.927)</td>
<td>(0.414)</td>
<td>(8.109)</td>
</tr>
<tr>
<td>Hansen J</td>
<td>5.091</td>
<td>8.641</td>
<td>10.27</td>
<td>2.477</td>
<td>1.586</td>
<td>1.160</td>
</tr>
<tr>
<td>P-value</td>
<td>0.078</td>
<td>0.013</td>
<td>0.005</td>
<td>0.289</td>
<td>0.452</td>
<td>0.559</td>
</tr>
<tr>
<td>Endog.test</td>
<td>0.471</td>
<td>2.597</td>
<td>0.024</td>
<td>1.089</td>
<td>6.286</td>
<td>2.178</td>
</tr>
<tr>
<td>P-value</td>
<td>0.492</td>
<td>0.107</td>
<td>0.877</td>
<td>0.296</td>
<td>0.012</td>
<td>0.140</td>
</tr>
<tr>
<td>Obs.</td>
<td>184</td>
<td>186</td>
<td>181</td>
<td>181</td>
<td>188</td>
<td>188</td>
</tr>
<tr>
<td>R²2</td>
<td>0.45</td>
<td>0.44</td>
<td>0.30</td>
<td>0.16</td>
<td>0.27</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Notes:  
⁺ significant at 1%;  
⁻ significant at 5%;  
⁻⁻⁻ significant at 10%. Standard errors are in parentheses.
Conclusions

There have been numerous studies that have attempted to uncover the effects of trade liberalization on the environment. Their findings have led to mixed results. In view of increasing concerns over GHG emissions this paper provides an updated analysis of the effect of trade liberalization on GHGs emissions using an alternative simultaneous equations model that enables both a direct and indirect effect of trade liberalization on emissions. Results suggest that openness affects per capita income, which affects emissions. Therefore, openness indirectly affects GHG pollution by increasing income growth via liberalization, although its effect is small. Direct effects of openness on pollution are ambiguous for both sources of pollution and all three GHG gases and enter insignificantly in this dynamic panel data regressions across all country groups. Consequently, this study is not able to show strong evidence of trade liberalization affecting pollution from GHG gases.

The first model, which includes capital accumulation, labor, human capital, openness and pollution, confirms the importance of capital accumulation in explaining the cross-country variations in economic growth. An increase in the share of GDP devoted to domestic investment predicts a higher level of output and faster growth rate of the economy. Coefficient estimates for labor and human capital shows a positive relationship with income, but their level of significance varies depending on the country groups. Although labor increases are positively related with growth in wealthier and poorer countries, the level of education of additional labor force plays a positive role only in poorer countries. Surprisingly, the degree of openness, as well as most pollutants, has a small impact on economic growth despite the overall significant share of trade in GDP.
When we incorporate into the model endogenous technological process and exogenous technological process (catch-up variable) to influence total productivity, we obtain more positive results. Catch-up enters positively and becomes larger as we move up the income scale, implying that in wealthier economies lying below their “leader nations” will catch up faster than poorer nations catch up to theirs.

Then we introduce a dynamic model to analyze the relationship of log difference of per capita GDP, log difference of emissions, and differences in measures of openness on pollution. Log difference of emissions, d.Ln.E, is negatively related to emissions at time t for poor and middle income countries from industrial and agricultural sources. The opposite is true for wealthier countries which suggest that wealthier nations are reducing their pollution overtime but poor and middle income groups are not. Results show log difference in per capita income entering positive and significant for middle income countries for both agricultural and industrial sources. An increase in per capita income by 1 percent increases industrial and agricultural N_{2}O emissions by 0.63 and 0.39 percent and industrial and agricultural CH_{4} emissions by 0.39 and 0.04 percent, respectively. Therefore, income growth has a significant impact on GHG emissions but the effect of openness on income is small. There are indeed both a direct and indirect effect of trade liberalization on emissions growth but their impact is small or insignificant. Moreover, in this analysis, concerns about the effect of openness on pollution from the major GHG gases seem unjustified.
References


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Quiroga, Miguel, Thomas Sterner, and Martin Persson. 2007. “Have Countries with Lax Environmental Regulations a Comparative Advantage in Polluting Industries”. Resources or the future. 412, Göteborg University, Department of Economics.


Appendix Chapter 1

List of countries – Full sample

**Low income**
Benin, Cameroon, Congo, Côte d'Ivoire, Gambia, Guyana, India, Indonesia, Kenya, Kiribati,
Madagascar, Malawi, Mali, Mauritania, Mozambique, Nicaragua, Niger, Pakistan, Rwanda,
Senegal, Sudan, Tanzania, Togo, Vietnam, Yemen, Zambia, Zimbabwe.

**Middle income**
Algeria, Argentina, Belize, Bolivia, Brazil, Bulgaria, Chile, China, Colombia, Costa Rica,
Ecuador, Egypt, El Salvador, Gabon, Greece, Guatemala, Honduras, Hungary, Iran, Jamaica,
Jordan, Malaysia, Mauritius, Mexico, Morocco, Oman, Panama, Paraguay, Peru, Philippines,
Poland, Portugal, Saudi Arabia, South Africa, Sri Lanka, Suriname, Swaziland, Syrian Arab
Republic, Thailand, Tonga, Trinidad and Tobago, Tunisia, Turkey, Uruguay, Venezuela.

**High income**
Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan,
Netherlands, New Zealand, Norway, Singapore, Spain, United Arab Emirates, United
Kingdom, United States.
Appendix Chapter 2

List of countries – Full sample

**OECD**
Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, Turkey, United Kingdom, United States.

**Non-OECD**
Afghanistan, Albania, Algeria, Angola, Antigua and Barbuda, Argentina, Armenia, Azerbaijan, Bahrain, Bangladesh, Belarus, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei, Bulgaria, Burkina Faso, Burundi, Cambodia, Cameroon, Cape Verde, Central African Republic, Chad, Chile, China, Colombia, Comoros, Congo, Costa Rica, Côte d’Ivoire, Croatia, Cuba, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Eritrea, Estonia, Ethiopia, Gabon, Gambia, Georgia, Ghana, Guatemala, Guinea, Guinea-Bissau, Guyana, Honduras, India, Indonesia, Iran, Iraq, Israel, Jordan, Kazakhstan, Kenya, Kiribati, Kuwait, Kyrgyzstan, Lao, Latvia, Lebanon, Lesotho, Liberia, Libya, Lithuania, Macedonia, Madagascar, Malawi, Malaysia, Mali, Mauritania, Mauritius, Moldova, Mongolia, Morocco, Mozambique, Myanmar, Namibia, Nepal, New Caledonia, Nicaragua, Niger, Nigeria, Oman, Pakistan, Panama, Paraguay, Peru, Philippines, Puerto Rico, Qatar, Romania, Russia, Rwanda, Saudi Arabia, Senegal, Serbia and Montenegro, Sierra Leone, Singapore, Slovenia, Somalia, South Africa, Sri Lanka, Sudan, Suriname, Swaziland, Syria, Taiwan, Tajikistan, Tanzania, Thailand, Togo, Tonga, Tunisia, Turkmenistan, Uganda, Ukraine, United Arab Emirates, Uruguay, Uzbekistan, Venezuela, Vietnam, Yemen, Zambia, Zimbabwe.
Appendix Chapter 3

List of countries – Full sample

**Poorer third**

**Middle third**
Albania, Algeria, Azerbaijan, Belarus, Belize, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Bulgaria, Cape Verde, China, Colombia, Congo Republic, Costa Rica, Dominican Republic, Ecuador, Egypt, El Salvador, Fiji, Gabon, Georgia, Guatemala, Guyana, Honduras, Jordan, Kazakhstan, Malaysia, Maldives, Mauritius, Morocco, Namibia, Panama, Paraguay, Peru, Philippines, Romania, Russia, Serbia, Slovak Republic, South Africa, Sri Lanka, Suriname, Swaziland, Syria, Thailand, Tunisia, Turkey, Vanuatu.

**Wealthier third**
Argentina, Australia, Austria, Bahrain, Barbados, Belgium, Canada, Chile, Croatia, Cyprus, Czech Republic, Denmark, Equatorial Guinea, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea Republic, Kuwait, Latvia, Lebanon, Lithuania, Luxemburg, Mexico, Myanmar, Netherland, Norway, Poland, Portugal, Puerto Rico, Saudi Arabia, Seychelles, Singapore, Slovenia, Somalia, Spain, Sweden, Switzerland, Trinidad and Tobago, United Arab Emirates, United Kingdom, United States, Uruguay, Venezuela.
Vita

Alejandro Dellachiesa was born in Buenos Aires, Argentina. He received his Bachelor degree in Agricultural Economics from the University of Belgrano in 1997. Shortly after graduating when working as a grains farm manager he studied for a Master Degree in Business Administration in the School of Economy and International Business of the University of Belgrano. In July of 2005 he received a M.S. degree in Agricultural Economics from the University of Tennessee. In August 2005 he reentered the University of Tennessee, to pursue a PhD in Economics and finalized it in June 2010. He is currently working at Bates College in Lewiston, Maine.