INTERNATIONAL ECONOMIC GROWTH AND ENVIRONMENTAL POLLUTION

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ABSTRACT

This paper estimates the relationship between the level of economic growth and the extent of environmental pollution for a wide range of both industrialized and emerging countries. Using data from 28 countries over the period 1975-1998, the paper finds support for an inverted U- shaped economic growth-pollution relationship. Using the aggregate level of CO2 as the measure of pollution and real GDP per capita as the measure of economic growth, the following countries appear to be operating on the rising portion of the inverted U relationship: India, China, Nigeria, and Thailand. On the other hand, the following eight countries appear to lie on the declining portion of the inverted U- relationship: Brazil, South Korea, Spain, United Kingdom, Canada, France, United States, and Japan. Furthermore, ten of the remaining fourteen countries, with per capita GDP below $4,000 exhibited a positive regression coefficient, although none were statistically significant. The turning point appears to occur at a level of GDP per capita, perhaps as low as $3,000-4,000. The paper explores the energy prospects and environmental polices of three of the worlds largest and fastest growing economies, China, India, and Brazil. These three countries are found to play a key role in the empirical findings of this study. The study demonstrates that growth in knowledge and improvements in environmental technology can compensate for an inevitable increase in the use of natural resources in production.

INTRODUCTION

Protective environmental policies are often seen as a constraint on economic growth. For less developed countries a clean environment is often viewed as a “luxury” that only advanced countries can afford. Alternatively, developing countries are encouraging not to repeat the costly environmental mistakes of the industrialized world. Widespread adoption of modern environmental technologies can lead to enhanced competitiveness in world markets and serve as a means of avoiding many of the social and cleanup costs incurred throughout the developed world. This paper makes a unique contribution to the literature by estimating the relationship between the level of economic growth, social commitment, and the extent of environmental pollution at the individual country level for both developed and emerging economies.

LITERATURE REVIEW

In a recent paper, Reichert (2004) empirically estimates the relationship between the level of economic growth, degree of social commitment, and the extent of environmental pollution across a wide range of both industrialized and newly developing countries. Employing aggregate data from 28 countries over the period 1975-1998, he finds empirical support for an inverted-U shaped economic growth-pollution relationship. Using real GDP per capita as the measure of economic growth and the aggregate level of CO2 as one measure of pollution, the model generates a negative turning point of approximately $14,100 measured in 1995 dollars. Certain public policy variables are also examined in the study. The empirical result suggests that the signing of the treaty on climate change passed in 1992 was perhaps a turning point in the effort to lower CO2 levels. The current paper extends this previous research and makes a unique contribution to the literature by estimating the relationship for each of the 28 individual countries. The disaggregate analysis identifies important country-specific differences in the economic growth/pollution relationship and leads to an informative discussion of the current environmental practices among three large developing countries: China, India, and Brazil. The analysis leads to important policy recommendations for environmental planners. A summary of the earlier literature in this area is provided below.

Gradus and Smulers (1993) develop several models to investigate whether a policy shift towards a cleaner environment necessarily affects an economy's long-run rate of growth. Their findings are sensitive to the assumptions regarding production technology and the relation between pollution, production, and abatement. Using a neoclassical production function that allows for substitution between polluting factors of production (e.g., physical capital) and non-polluting factors (e.g., skilled labor) a shift in favor of a clean environment results in a production process that uses polluting factors less intensively and yet maintains its initial rate of growth. In their endogenous growth model, long-run growth remains unchanged if the productivity of the growth generating factor, assumed to be skilled labor, is unaffected by any change in pollution.

Grossman and Krueger (1995) examine the relationship between both air and water pollution and GDP over the 1979-1990 period. The dependent variables in the reduced form equations are various measures of pollution which are regressed against both linear and non-linear measures of per capita GDP. In addition, a proxy measure for "permanent income" was included along with a vector of covariates which indicate the location of the pollution monitoring stations, population density, and type of pollution measuring device. Their results find no consistent evidence that economic growth has an adverse impact on the environment. While there is some evidence that pollution and income increase together for the poorest countries, the results indicate that air and water quality tend to improve as income increases above some threshold (approximately $8,000 in constant 1985 dollars). These results suggest that as income increases, the public demands positive action for a cleaner environment through both public and private abatement programs. (See Figure 1 for a depiction of the inverted U-shaped relationship estimated in this paper).

Selden and Song (1994), using the same data on air pollution employed by Grossman and Krueger, also find an inverted-U relationship with per capita GDP as the dependent variable. The authors hypothesize that as economic growth proceeds at some point there is reduction of pollution due to: 1) a positive income elasticity for environmental quality, 2) changes in the composition of consumption and production toward less-polluting activities, 3) increased levels of education and environmental concern, and 4) a more open and responsive political system. They estimate a cross-sectional model by regressing per capita emissions against real per capita GDP, along with population density. Population density is included to capture differences in regional environment concerns with rural areas hypothesized to be less concerned about pollution than more heavily populated regions. Selden and Song estimate a negative per capital GDP turning-point which consistently exceeds $8,000.

Cole (2000) also addresses the issue of an inverted U-shaped relationship between per capital income and pollution. Data on emissions of sulfur dioxide and nitrogen oxides were collected from 1971-1991 for twenty less developed and advanced economies. To determine if the composition of manufacturing has become "cleaner", the degree of pollution intensity of manufacturing and the share of manufacturing output in GDP modeled. To identify the impact of factor costs on the level of pollution, the ratio of "dirty" to "clean" manufacturing output is regressed against population density as a proxy for the price of land, the average manufacturing wage, the real rate of interest, and the price of industrial electricity. The hypothesis being that dirty manufacturing tends to be more land, capital, and energy intensive than clean manufacturing which is more labor intensive. Cole finds that the reduction in pollution is due to: 1) a shift towards a cleaner composition of manufacturing and a declining proportion of manufacturing in total GDP, 2) reduced income elasticity of demand for "dirty" products, and 3) factors prices for land, labor, and capital determine the extent of "dirty" industry within a country's manufacturing sector.

Hofkes (2001) explores the issue whether economic growth and environmental quality are two opposing or complementary goals. He analyzes both short term and the long term effects using a two-sector growth model in which both economic and environmental relationships and their interactions are considered. In his model, the environment is viewed as a consumption good which has a direct impact on social welfare. His model employs a production function producing final goods and a "knowledge sector" which produces knowledge regarding pollution-reducing technologies. Furthermore, according to his model, physical production can be consumed, used for abatement, or invested. While pollution is viewed as an inevitable by-product of the production process, cleaner technologies are developed within the model's knowledge-sector, reducing the amount of pollution for a given level of physical production. In addition, the public sector can decide to invest in pollution abatement at the expense of either consumption or capital accumulation. Hofkes finds that under certain conditions there exists a sustainable growth path along which the economy grows at a constant rate, keeping environmental quality at a stable level. Thus, growth in knowledge and improvements in environmental technology compensate for the growing use of natural resources in production, leaving environmental quality constant along the optimal growth path.

DATA SAMPLE

The World Bank's Development Indicators provides data on 225 countries. Thirty-nine countries with populations in excess of 25 million during 2002 were initially selected. Nine countries with a significant degree of missing data were excluded from the sample, leaving the following 28 countries in the sample. These 28 countries collectively represent 4.2 billion people, or 70% of the world's population in 2000.

Algeria	Congo, Dem. Rep.	Kenya	Philippines
Argentina	Egypt	South Korea	South Africa
Bangladesh	France	Mexico	Spain
Brazil	India	Morocco	Sudan
Canada	Indonesia	Nigeria	Thailand
China	Italy	Pakistan	United Kingdom
Columbia	Japan	Peru	Unites States

National environmental strategies and participation in international treaties on environmental issues provide evidence of a country's commitment to sound environmental management. Many countries prepare detailed national environmental and conservation strategies and environmental action plans along with environmental profiles and biological diversity strategies. Environmental profiles indicate how economic activity can stay within the constraints imposed by the need to conserve natural resources and often consider issues of equity, justice, and fairness. Biodiversity profiles provide information on species diversity, protected areas, major ecosystems, and habitat types.

Furthermore, as described in the 2002 World Bank's Development Indicators publication, many nations have also signed formal international treaties and agreements following the 1972 United Nations Conference on Human Environment in Stockholm and the 1992 United Nations Conference on Environment and Development in Rio de Janeiro. The Framework Convention on Climate Change is intended to prevent concentrations of greenhouse gases from damaging the biosphere. The Vienna Convention for the Protection of the Ozone Layer promotes research on the effects of changes in the ozone layer and promotes measures to counteract adverse environmental impacts. The Montreal Protocol for CFC Control required that countries reduce excessive ultraviolet radiation by cutting chlorofluorocarbon consumption by 50 percent by 1999. The 1994 United Nations Convention on the Law of the Sea established international rules and national legislation to prevent and control marine pollution. The Convention on Biological Diversity promotes conservation of biodiversity through scientific cooperation, access to genetic resources, and the sharing of ecologically friendly technologies. The following list of eight policy variables and national treaty commitments were included in the model developed in the next section.

1. ACTPLAN refers to environmental strategies and action plans that help integrate environmental concerns with the development process.

2. PROFILE refers to environmental profiles which identify how economic growth can proceed consistent with natural resource conservation needs.

3. BIOASS refers to assessments, strategies, and action plans included biodiversity profiles.

4. CLIMATE refers to the Framework Convention on Climate Change, New York, 1992.

5. OZONE refers to the Convention for the Protection of the Ozone Layer, Vienna, 1985.

6. CFC refers to the Protocol for CFC Control, Montreal, 1987.

7. SEALAW refers to the United Nations Convention on the Law of the Sea, Jamaica, 1982.

8. BIODIV refers to the Convention on Biological Diversity, Rio de Janeiro, 1992.

HYPOTHESES AND MODEL DESIGN

The model seeks to test the following two working hypotheses at the individual country level:
1) during the beginning phase of economic development, increased economic growth and increased pollution are likely to be positively related, 2) at some later stage the use of more environmental-friendly production technologies and greater environmental awareness on the part of policy makers may combine such that an inverse relationship may ultimately develop, and 3) at some point between these two phases a country may achieved pollution-neutral economic growth. Thus, the paper attempts to locate the position of individual countries on an inverted-U pollution-growth relationship. Thus, a country-specific model is estimated which relates the total production of CO2 to gross domestic product per capita (GDPCAP). Control variables in the model are included to account for structural and social differences between countries, such as the extent of urbanization, and differences in the energy intensive-nature of the productive sector, as measured by the level of both total commercial energy use and electrical energy production. Finally, the effect of changes in national priorities and the level of environmental commitment are measured by two variables which indicate the year following the date of signing of the treaties relating to climate change and the ozone layer. (These policy dummy variables are placed one-year into the future to allow for subsequent changes in production procedures and processes as a result of these treaty commitments).

Models were estimated with both balanced and unbalanced data panel designs. In a balanced panel (reported in this paper), observations are included only when data on all variables are available for all cross-sections (countries) for all years. While the World Bank data set contains data from 1960-1999, case-wise deletion required by the balanced research design, reduces the effective data period from 1972 to 1998, a total of 27 years. To adjust for auto-correlation in the error term an auto-regressive term is included as a dependent variable in the model. This provides a total of 728 data points to estimate the model.

Since the primary focus of the model is the relationships between the levels of pollution (CO2) and the level of GDP per capita, a flexible model is employed which simultaneously estimates this relationship for each of the 28 countries in the sample. The following fixed-effects country-specific model was estimated using data for the 28 countries mentioned above over the period 1975-1998. In addition to the linear model, a number of alternative functional forms were considered. The linear specification provided the greatest level of statistical significance as measure by the model's F-statistic. (The author will supply the other results upon request) The estimated fixed-effects country-specific equation is as follows:

$$CO2TOTAL_{t,j} = B_{1...28} + B_{29...56}(GDPCAP_{t,j}) + B_{57}(URBPOP_{t,j}) + B_{58}(TOTCOMENG_{t,j}) + $$

$$+ B_{59}(TOTELEC_{t,j}) + B_{60}(CLIMATE_{t-1,j}) + B_{61}(OZONE_{t-1,j}) + B_{62}(AR_{t-1}) + $$

$$B_{63}(AR_{t-2}) + B_{64}(AR_{t-3}) + e_{tj} \quad (1)$$

Where,

t = the year of the observation (t = 1975…1998)
j = the country of interest (j = 1…28)
$B_{1...28}$ = the fixed-effects constant-term regression coefficients for each of the 28 counties.
$B_{29...56}$ = the country-specific regression coefficients for each GDPCAP variable.
$B_{57...61}$ = the regression coefficients for each of the control variables in the model.
$B_{62...64}$ = the regression coefficients for each of the autoregressive error terms.
e_{tj} = a normally distributed error term.

The following economic and environmental variables were obtained from the 2002 World Bank Indicators Database.

CO2TOTAL measures total carbon dioxide emissions generated by the use of fossil fuels.

GDPCAP equals gross domestic product divided by total population in constant 1995 U.S. dollars. The country's total population includes all residents regardless of legal status or citizenship.

URBPOP is the percentage of the total population living in urban areas as defined by each country.

TOTCOMENG measures total commercial energy use and equals domestic production plus imports and stock changes, less exports.

TOTELEC measures the total electric power consumption from the production of various types of power plants less distribution losses, and own-use by heat and power plants.

The year in which the previously defined environmental commitments were either submitted or signed was initially included in the basic model: ACTPLAN, PROFILE, BIOASS, CLIMATE, OZONE, CFC, BIODIV, and LAWSEA. (Note: While the eight different treaties and environment policy measures were individually tested, Reichert (2004) found that the CLIMATE and OZONE treaties were the only two measures of environmental commitment that were statistically significant. Hence, only these two commitment variables are included in the current country-specific analysis. (Table 2, indicates the year in which each of these two treaties went into effect for each country in the sample).

EMPIRICAL RESULTS

Table 1 presents the main regression results of the paper. To conserve space the country-specific intercepts are omitted. In terms of the control variables, the level of total energy use in the country (TOTCOMENG) is directly related to the level of pollution and highly significant. On the other hand, the size of the urban population (URBPOP) carried a positive but insignificant regression coefficient. The coefficient on level of total electric power consumption (TOTELEC) was negative but also insignificant.

Turning to the primary explanatory variables, the date of signing the Climate Change treaty (advanced one year) is statistically significant and carries a negative coefficient, indicating a significant reduction in the level of pollution one year following the signing of the treaty.

Table 1- Fixed Effects Model: Country-Specific GDP Regression Results

Independent Variables	Regression Coefficient	Standard Error	T-Value	Prob.
URBPOP	0.001704	0.002426	0.702307	0.4828
TOTCOMENG	0.002824	0.0000785	35.99419	0.0000***
TOTELEC	0.0000289	0.0000541	-0.535352	0.5926
CLIMATE(-1)	-8139084	3068807	-2.652198	0.0082***
OZONE(-1)	-4729829	3074554	-1.538379	0.1245
GDPCAP Bangladesh (BGD)	4453.152	168347.8	0.026452	0.9789
GDPCAP Brazil (BRA)	-40179.84	21690.17	-1.852445	0.0644*
GDPCAP China (CHN)	509914.3	96235.81	5.298592	0.0000***
GDPCAP Congo D. Rep. (COG)	35966.68	100611.8	0.35748	0.7209
GDPCAP Egypt (EGY)	-8076.133	45172.25	-0.178785	0.8582
GDPCAP France (FRA)	-38596.91	2856.856	-13.51028	0.0000***
GDPCAP India (IND)	298817.7	161053.8	1.85539	0.0640*
GDPCAP Indonesia (IDN)	-51840.93	33383.92	-1.552871	0.121
GDPCAP Italy (ITA)	-1517.59	3130.586	-0.484762	0.628
GDPCAP Japan (JPN)	-12000.27	1628.692	-7.368039	0.0000***
GDPCAP Mexico (MEX)	268.7452	24459.93	0.010987	0.9912
GDPCAP Nigeria (NGA)	347868	184418.9	1.886293	0.0597*
GDPCAP Pakistan (PAK)	-96748	91671.1	-1.055382	0.2917
GDPCAP Philippines (PHI)	32925.91	83299.45	0.395272	0.6928
GDPCAP Thailand (THA)	24113.82	10273.03	2.347295	0.0192**
GDPCAP Great Britain (GBR)	-14986.02	3025.79	-4.952762	0.0000***
GDPCAP United States (USA)	-16381.41	7171.16	-2.284346	0.0227**
GDPCAP Algeria (DZA)	-44443.95	57753.91	-0.76954	0.4419
GDPCAP Argentina (ARG)	-1183.147	7471.688	-0.158351	0.8742
GDPCAP Canada (CAN)	-12998.64	4216.572	-3.08275	0.0021***
GDPCAP Colombia (COL)	2726.93	28422.39	0.095943	0.9236
GDPCAP Kenya (KEN)	-25087.02	387265.1	-0.06478	0.9484
GDPCAP Korea (KOR)	-9377.077	2777.731	-3.375804	0.0008***
GDPCAP Morocco (MAR)	9611.344	43532.3	0.220787	0.8253
GDPCAP Peru (PER)	-623.4892	21472.85	-0.029036	0.9768
GDPCAP South Africa (ZAF)	-14558.11	19626.18	-0.74177	0.4585
GDPCAP Spain (ESP)	-10546.08	3617.355	-2.915411	0.0037***
GDPCAP Sudan (SDN)	46635.18	182364.5	0.255725	0.7982
AR(1)	0.659743	0.046753	14.11137	0.0000***
AR(2)	-0.110747	0.053475	-2.071013	0.0388**
AR(3)	0.011672	0.046981	0.248439	0.8039

Adjusted R^2	0.999
S.E. of regression	15288624
F-statistic	41081
Prob(F-statistic)	0.000
Durban-Watson	1.855

Level of Statistical Significance: *** = 1%, ** = 5%, * = 10%

The date of signing the Ozone treaty (advanced one year) also carries a negative regression coefficient but was not statistically significant at the ten percent level. Furthermore, four of the regression coefficients on the country-specific GDP per capita variables are positive and statistically significant. These four countries are China, India, Nigeria, and Thailand, with the most significant positive relationship reported for China and Thailand. On the other hand, eight countries reported a negative and statistically relationship. These eight countries are Brazil, France, Japan, Great Brittan, United States, Canada, South Korea, and Spain. Among these countries, the inverse relationship was the weakest for Brazil. For the remaining sixteen countries whose regression coefficients were not statistically significant, seven coefficients were positive while nine were negative.

From another perspective, Table 2 indicates average GDP per capita ranked in descending order for the entire 1960-1998 period. The values in bold face indicate the countries where the current model generates statistically significant results at previously reported in Table 1. The top one-third of the table identifies the wealthier countries where the statistically significant relationship was estimated to be negative, while the lower two-thirds of the table indicates lower income levels where the relationship was statistically significant and positive. The dividing line appears approximately $3,000 which is generally consistent with the findings reported by Cole. As illustrated in Figure 1, the results suggest a rather extensive “plateau” or leveling-off of the growth-pollution relationship for countries with per capital GDP in the range of $1,000 to $3,000. It is perhaps in these transitional countries, such as Brazil, where the introduction of new technologies and more enlightened environmental policies such as greater use of ethanol and renewable energy sources such as hydroelectric power can make the greatest near term contribution. Perhaps Brazil’s experience can serve as a good model as discussed below.

The World Bank (May 2006) recently released a report which explores ways for three of the worlds largest and fastest growing economies, China, India, and Brazil, to increase their energy efficiency as an important means of reducing greenhouse gases which is often linked to global warming. China and India rank among the world’s 10 top energy users and they are quickly becoming the top green house gas admitters. For example, China’s emissions are expected to double by 2020, which will place China ahead of the US as the world’s largest greenhouse gas emitter. China is both the world’s largest coal producer and consumer. While reliance on coal in their energy mix is projected to decline from 66% to 41% between 2002 and 2030, the level of CO_2 emissions is projected to increase from 3.3 billion tons to 7.1 billion tons per year. The study finds that certain cost-effect production retrofits and the adoption of advanced technologies could reduce energy use by 25 percent and 10%, respectively. With the assistance World Bank funding China is encouraging its banks to finance large-scale energy efficient investments. The report indicates that many energy efficiency projects have a return on investment as high as 20-40 percent, with a payback period as short as 2 ½ years. China has officially adopted a goal of becoming a “conservation-oriented society” which gives equally high priority to both energy efficiency and energy development.

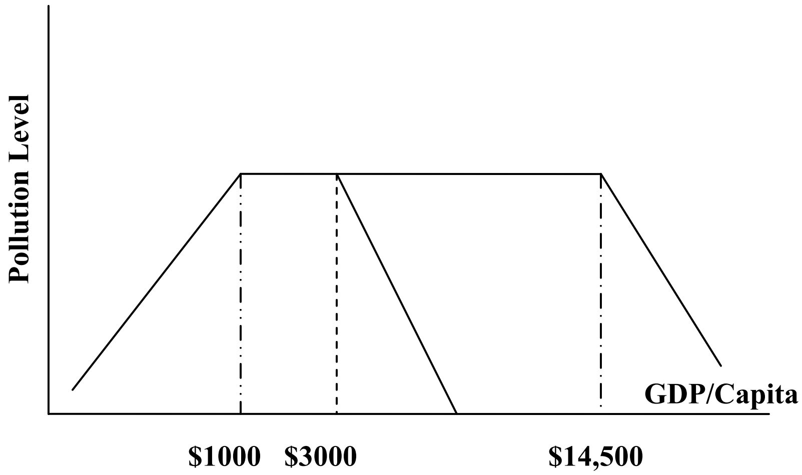
India’s economy is not as large or quite as fast growing as China’s, but India’s power generation capacity has tripled over the past two decades and is expect to more than triple again by 2025. This conservative growth estimate is based on an optimistic scenario which includes major efforts to modernize existing power plants, improve transmission/distribution efficiency, and add more efficient generation capacity. In spite of these efforts, C02 emissions are forecast to increase from 1.0 billion to 2.3 billion tons by 2030, much of the increase due to burning low quality coal. Given these forecasts, India’s potential energy efficiency market is estimated to exceed $3 billion which would generate savings of more than terawatts hours per year. To help capture these potential savings the Indian government has established a Bureau of Energy Efficiency to promote and coordinate energy efficiency project nationwide. As a consequence, five of India’s largest Banks have introduced innovative lending programs to promote energy efficiency among small and medium size enterprises (SME) where energy waste is often high and conservation awareness is frequently quite low. The banks have developed a “cluster” approach to lending where they have developed a standardized energy efficiency loan available to various groups of small industries. These loans have increased the energy efficiency, profitability and competitiveness of these SMEs.

Table 2: Sample Data

Country Name	Elect Power	CO2	Comm. energy	Urban pop (%)	GDP ('95$)	GDP (60-99)	Population	Climate	Ozone
Significant – coefficients in bold									
Japan (JPN)	7286.50	8.97	4042.5	78.5	43609	**27799**	126,410,000	1994	1988
United States(USA)	11936.7	19.82	8023.6	76.8	30166	**21231**	274,894,016	1994	1986
France (FRA)	6287.13	6.33	4356.5	75.2	28333	**20431**	58,398,000	1994	1988
Canada (CAN)	15074.7	15.45	7846.9	76.9	20966	**16430**	30,247,900	1994	1986
Great Britain (GBR)	5326.88	9.15	3887.3	89.4	20718	**14602**	59,255,000	1994	1987
Italy (ITA)	4430.78	7.20	2882.7	66.8	20007	13852	57,588,000	1994	1988
Spain (ESP)	4195.30	6.28	2864.6	77.2	16480	**10852**	39,371,000	1994	1988
Korea, South (KOR)	4712.56	7.83	3550.2	80.4	11022	**5085**	46,430,000	1994	1992
Argentina (ARG)	1891.40	3.79	1708.5	88.9	8463	6815	36,125,000	1994	1990
Brazil (BRA)	1791.09	1.80	1058.6	80.1	4506	**3410**	166,045,568	1994	1990
Significant + coefficients in bold									
South Africa (ZAF)	3831.93	8.30	2643.4	54.3	3923	3987	41,402,392	2000	1990
Mexico (MEX)	1507.82	3.93	1553.7	74.0	3544	2773	95,225,432	1994	1987
Thailand (THA)	1345.18	3.22	1111.8	21.0	2621	**1348**	59,793,500	1995	1989
Colombia (COL)	845.11	1.66	759.2	74.0	2406	1753	40,804,000	1995	1990
Peru (PER)	641.59	1.12	578.0	72.0	2354	2306	24,801,000	1994	1989
Algeria (DZA)	563.12	3.61	910.0	58.8	1566	1440	29,507,000	1994	1993
Morocco (MAR)	442.99	1.15	327.7	54.5	1403	1050	27,775,000	1996	1996
Egypt (EGY)	860.31	1.72	679.6	44.9	1143	715	61,580,000	1995	1988
Philippines (PHI)	426.39	1.04	536.0	56.8	1127	994	72,775,448	1994	1991
Indonesia (IDN)	320.41	1.15	646.2	38.8	972	548	203,678,368	1994	1992
Congo Dem Rep (COG)	42.32	0.05	293.9	29.7	113	279	48,178,168	1995	1995
China (CHN)	721.60	2.50	879.9	31.1	725	**259**	1,242,179,968	1994	1989
Pakistan (PAK)	338.74	0.74	444.1	35.9	500	340	131,582,000	1994	1993
India (IND)	363.48	1.08	481.1	27.8	428	**262**	979,672,896	1994	1991
Bangladesh (BGD)	80.41	0.18	138.5	23.4	348	254	126,564,704	1994	1990
Kenya (KEN)	127.10	0.32	513.3	31.3	340	296	28,726,000	1994	1989
Sudan (SDN)	44.63	0.12	497.4	34.2	290	222	29,978,890	1994	1993
Nigeria (NGA)	84.75	0.65	710.4	42.2	254	**256**	120,817,264	1994	1989

Brazil has one of the largest and most diverse ecosystems in the world and is considered by many to be an environmental leader among developing countries. While Brazil is the world's 10th largest energy user, its emissions of C02 relative to energy utilization is relative low due to heavy reliance on hydroelectricity, extensive use of ethanol and other gasoline blends and substitutes. According to Vatalaro (2006), Brazil has promoted the use of ethanol for over thirty years and ethanol currently meets approximately 40% of Brazil's fuel needs. Most of the gasoline used in Brazil is a blend of 25 percent ethanol, compared to only 10 percent in the United States, where ethanol meets only two percent of America's fuel needs. Brazil produces ethanol efficiently from sugar cane, which produces approximately eight times the amount of energy required to produce it. Furthermore, automotive technology has improved such that a significant number of cars in Brazil run on alcohol, although this percent has declined due to higher production costs for alcohol. In comparison, in the United States ethanol is primarily produced from corn, which yields approximately the same amount of energy as it takes to produce it. Looking into the future, a recent study by the PEW Center on Global Climate Change (2000) concludes that Brazil will be forced to shift from it current reliance on hydroelectric power to natural gas fueled electricity generating plants.

Figure 1 – GDP per Capita Growth-Pollution Plateau



While gas plants generate 60 percent less carbon dioxide than coal burning units, green house emissions are forecasted to rise rapidly in Brazil. Some estimates suggest that CO2 emissions will likely increase from 302 million to 665 million tons by 2030. Even so Brazil's C02 emissions will remain low in absolute terms. Research indicates that an aggressive policy of energy efficiency could reduce energy demand by as much as 40%, generate savings of $37 billion per year and stabilize C02 emissions by 2020 (Guardian Unlimited, 2006). At the same time Brazil is not without its own unique challenges. According to Gurgel (2006), Brazil needs to curtail extensive deforestation by burning in the Amazon region, which is pumping millions of tons of CO2 into the atmosphere. Experts estimate that approximately 20% of the 1.6 million square miles of rainforest in the Amazon region has been deforested by development, logging, or farming.

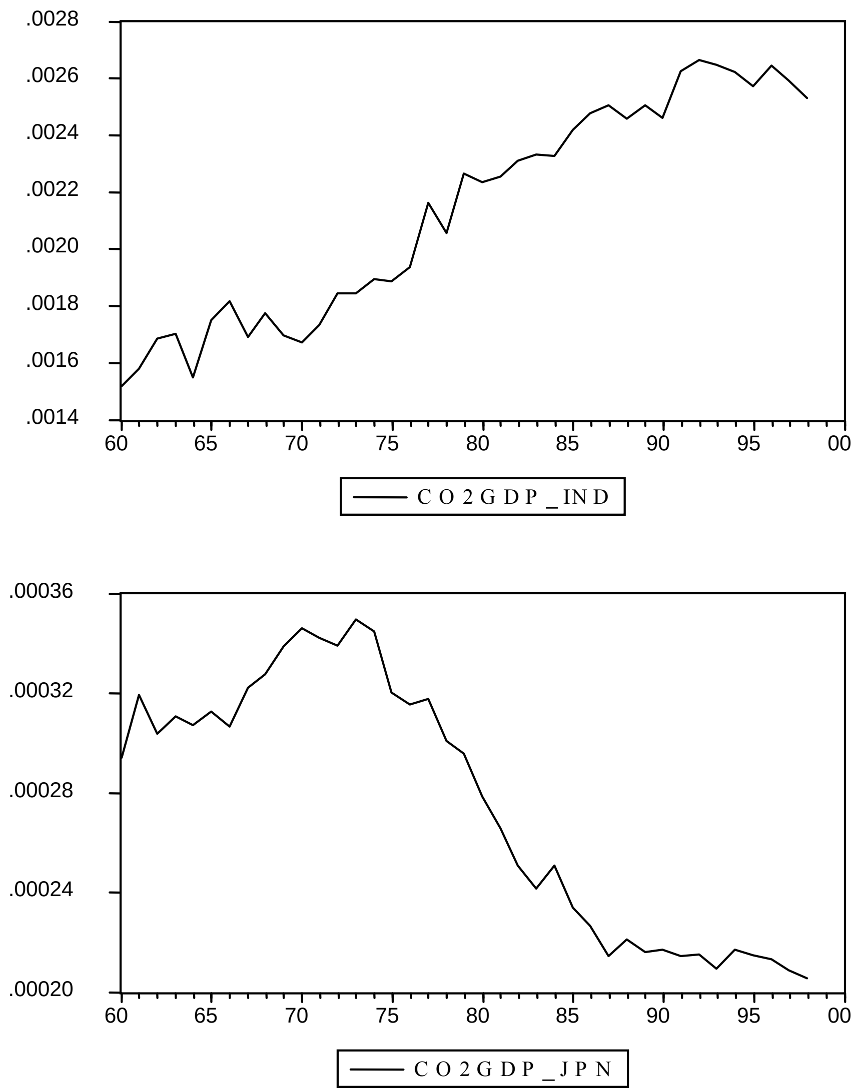
To help visualize and interpret the statistical results, Figures 2 shows the graph of the ratio of CO2/GDP for Japan and India. The CO2/GDP ratio is employed as an inverse measure of pollution-efficiency since it indicates the amount of CO2 pollution generated per dollar of real GDP. Thus, a lower ratio indicates greater environment efficiency in the production process, while a higher ratio indicates reduced environment efficiency. Japan's level of pollution efficiency actually declined until the mid 1970's as reflected by a rise in the ratio. On the other hand, the index improved dramatically from 1974 until 1987. Since then the efficiency measure has remained constant. For India the level of pollution efficiency dramatically declined from 1960 through 1992. Since then the measure has remained relatively constant.

CONCLUSIONS

A persistent and reoccurring debate regarding efforts to expand the level of worldwide economic growth revolves around the potential impact on the environment. Some argue that economic growth and environmental protection are contradictory and that resources directed towards a clean environment necessarily represents a drain on the productive capacity of the economy. If true, many countries would be better served if they devoted their scarce resources to expand production facilities and infrastructure investment regardless of the environmental impact. Such "growth-pessimists" argue that investing in a clean environment is a "luxury" which invariably leads to a reduced rate of economic growth. At the opposite end of the debate are the "growth-optimists" who feel that environmental quality is a necessary

prerequisite to sustain economic growth in the long run. One's view regarding the impact of technology and the role of public policy is a crucial part of the debate.
This paper extends an earlier paper by Reichert (2004) by empirically estimating the unique country-specific relationship between the level of economic growth, degree of social commitment, and the extent of environmental pollution for a wide range of both industrialized and newly developing countries. Using data from 28 countries over the period 1975-1998, the paper finds empirical support for an inverted-U shaped economic growth-pollution relationship and identifies the location of individual countries on the curve. Using real GDP per capita as the measure of economic growth and the aggregate level of CO2 as the measure of pollution, the following countries appear to be operating on the rising (positive) portion of the inverted-U relationship: India, China, Nigeria, and Thailand.

Figure 2 - CO2/GDP for Japan and India



On the other hand, the following eight countries appear to lie on the declining (negative) portion of the inverted-U relationship: Brazil, South Korea, Spain, United Kingdom, Canada, France, United States, and Japan. Furthermore, ten of the remaining fourteen countries, with per capita GDP below $4,000 exhibited a positive regression coefficient, although none were statistically significant. The turning point appears to occur at a level of GDP per capita, perhaps as low as $3,000-4,000 for countries like Brazil which has been a leader in the use of ethanol. It should be added that the shift to a negative relationship is much more definitive when per capita GDP reaches approximately $14,000. But many of these developing countries simply cannot wait decades to achieve this level of wealth. Unfortunately this may not be necessary as demonstrated by Brazil whose current environmental progress supports Hofkes' findings and the work of World Bank's production efficiency program which demonstrate that growth in knowledge and improvements in environmental technology can compensate for an inevitable global increase in the use of natural resources in production.

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