Distinguishing Development in Carbon Dioxide Modeling

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Introduction

Historically, the developed countries have generated most of the world's carbon dioxide emissions. However, the emerging nations will be responsible for ever-increasing amounts. In contrast, the developing countries have not had nor will soon have a major impact on overall global emissions. If developing countries do not have large emissions, assuming mitigation in these countries will produce major emissions reductions is unsound policy. If developing countries are predicted to have large future emissions, then a more careful analysis of the emissions sources and potential mitigation in developing countries is essential. According to the International Energy Agency, global energy demand is expected to grow by 52% from 2004 to 2030, and a large portion of that growth will occur in developing countries (IEA 2006). Clearly, there is a need for serious analysis of these emissions to help focus and maximize the impact of mitigation efforts.

Emissions are growing all around the world, but are growing at the fastest rate in emerging countries. While the emissions per capita for most developing and emerging nations remains much lower than that of developed nations, the GHG emissions per unit of GDP_{ppp} is 56% higher in non-Annex I countries than in Annex I countries (IPCC 2007a). This points to a potential for improvement in emissions efficiency. If many low-cost improvements have not yet been made in many developing countries, then it follows that the marginal cost of reduction could be lower in those regions. Furthermore, in emissions projections to 2030, the IPCC's business-as-usual scenario estimates that there will be a 40% to 110% increase in energy related carbon dioxide emissions, and two-thirds to three-quarters of that growth is expected to take place in non-Annex I countries (IPCC 2007b). Thus, it may be true that where there is the highest growth, there is the highest potential for low cost mitigation. However, the hypothesis of low hanging fruit in developing countries needs to be explored more carefully.

To accurately predict carbon dioxide emissions as economies grow and change and to develop a clear estimate of greenhouse gas abatement opportunities, it is vital to clearly understand basic factors that explain emissions. Previous studies have addressed this question, but have treated countries fairly homogenously, examined only a few individual countries at a time, or have focused solely on the relationship between GDP and emissions. This study seeks to look at the entire globe and tease out how major macroeconomic and energy use factors impact emissions on a national level. A balance should be struck between wide applicability and accuracy of a model, thus it is necessary to recognize the differences among different levels of economic development. To do this, a distinction is made between developed, emerging, developing and least developed countries. These groups have very different energy needs and economic characteristics and are expected to have significantly different contributing factors to overall carbon dioxide emissions.

Background

In 2004, 46% of emissions came from advanced economies while the developing world, as a whole, was the source of the majority of emissions (Figure 1). Emerging countries emitted nearly as much as advanced economies.

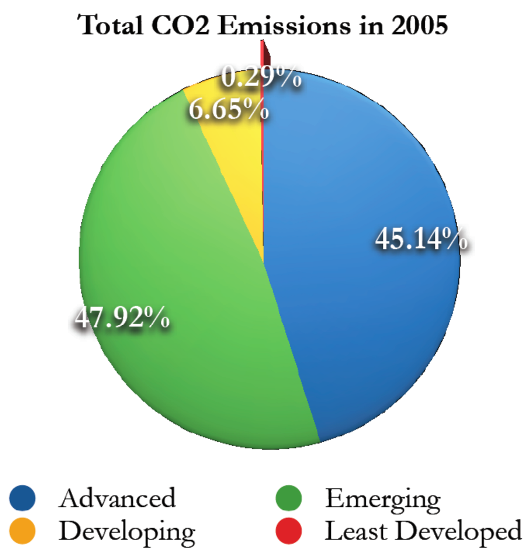

Figure 1: The contribution of each development group to total CO2 emissions in 2005

On average, advanced economies have the highest emissions per capita followed by emerging, developing, and least developed countries (Figure 2). There are however, some significant outliers among developing countries. Qatar emitted 68 metric tons per capita in 2004 followed by Kuwait, the United Arab Emirates, Trinidad and Tobago, Brunei, and Bahrain, all with CO2 emissions over 20 tons per capita.

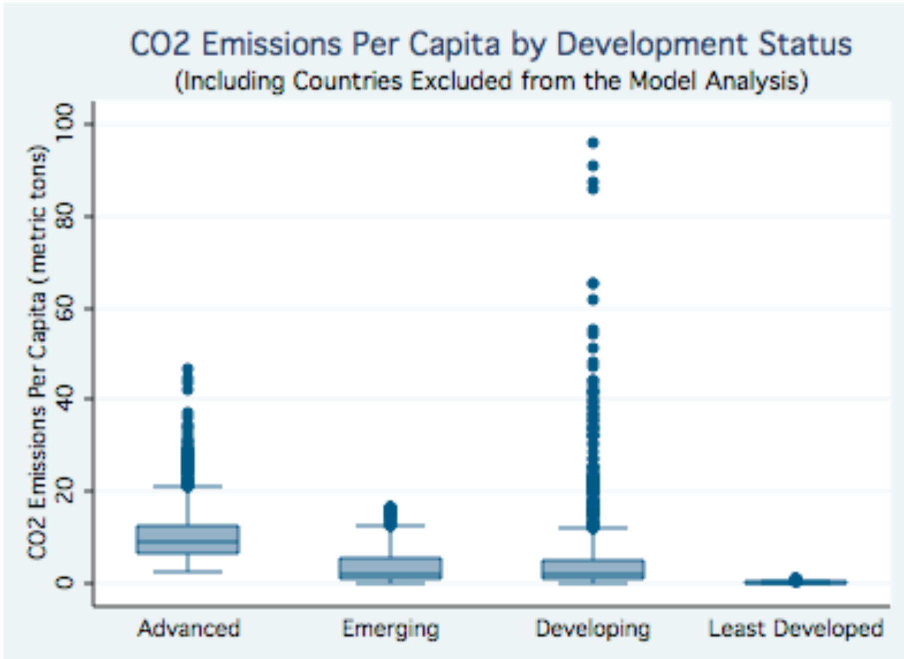

Figure 2: Box plot of CO2 emissions per capita for each development group including data for countries that were removed for model analysis.

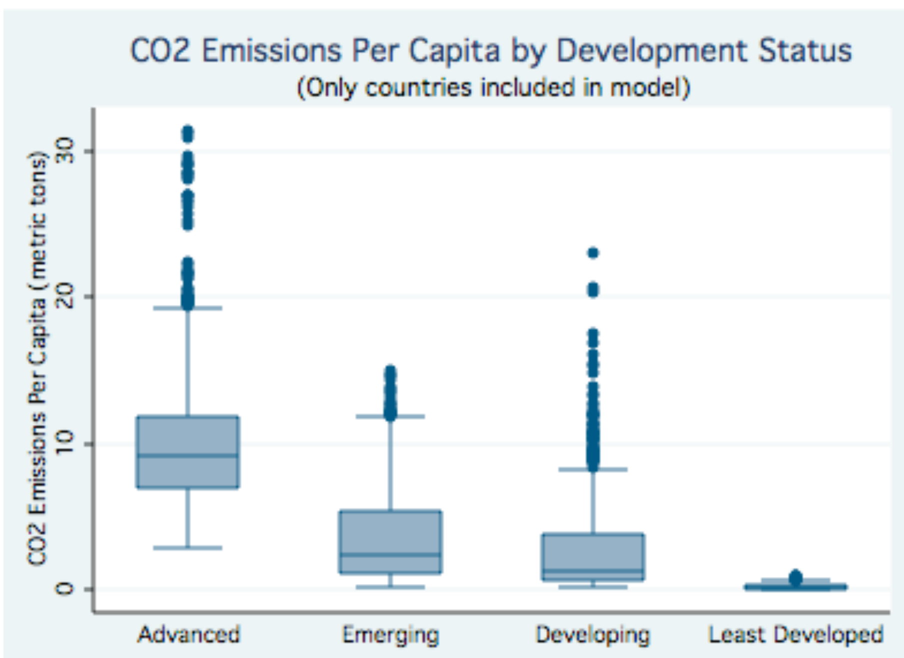

Figure 3: Box plot of CO2 emissions per capita for each development group for countries that are included in the panel regression model.

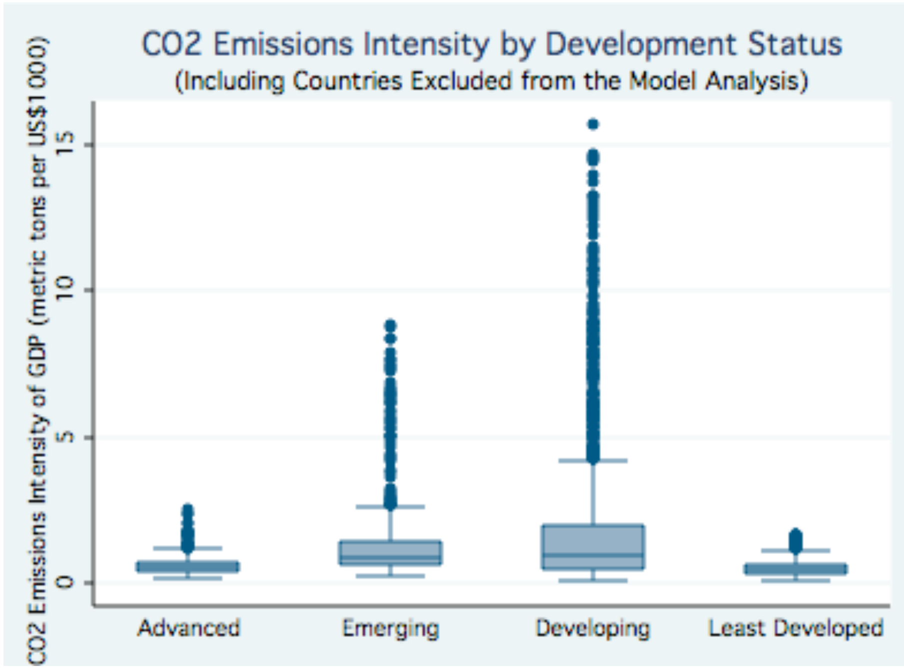

Figure 4: Box plot of CO2 emissions intensity of GDP for each development group including data for countries that were removed for model analysis.

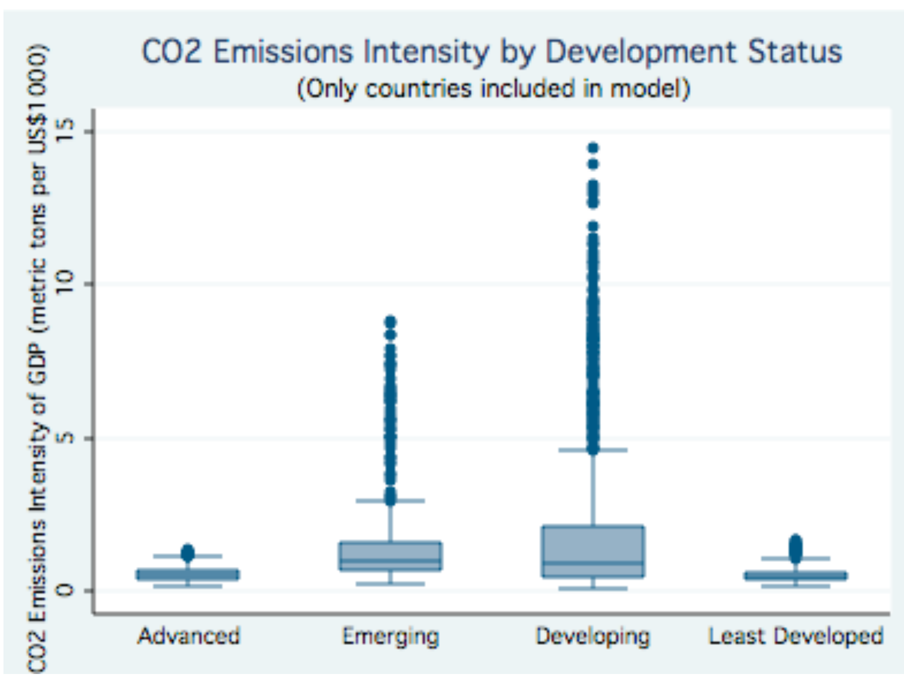

Figure 5: Box plot of CO2 emissions intensity of GDP for each development group for countries that are included in the panel regression model.

Emissions intensity of GDP is lowest for advanced economies, followed by least developed countries, developing countries, and emerging countries (Figure 3). This pattern can be at least partially attributed to the large disparities in GDP. However, other factors, such as energy efficiency and fuel use, also have an impact. Note that the carbon dioxide emissions intensity of GDP follows the inverted U-shape of a Kuznets curve, while the emissions per capita steadily increases with more development.

Existing Methods and Previous Studies

The IPAT identity is a widely known accounting method to parsimoniously break down the environmental impacts of a society (Commoner 1971, York et al 2003, Raupach et al. 2007). This method posits that the impact (I) is the result of the multiplicative effects of population (P), affluence (A), and technology (T). When applied to greenhouse gas emissions, this method is known as the Kaya Identity:

$$C=\left(\frac{C}{E}\right)\left(\frac{E}{GDP}\right)\left(\frac{GDP}{P}\right)*P$$

where C is carbon dioxide emissions, E is energy use, and P is population.

The decomposition method has been widely used to explain energy use and emissions as the result of three major explanatory factors: the economic activity in each sector, the sectoral energy or emissions intensity, and structural shifts in the economy (Luukanen and Kaivo-oja 2002, Ang and Liu 2007). The method deconstructs economic activity by sector and analyzes how these factors interact to make up the total emissions or energy use of the economy. It is used to track the effectiveness of energy efficiency measures, to evaluate the impact of fuel switching, and to gain insight on how various sectors contribute to overall emissions.

One of the most widely studied and discussed trends in carbon dioxide emissions is the Environmental Kuznets Curve (EKC). While many panel data studies have found this concave relationship between emissions and GDP, others have rejected the EKC for carbon dioxide emissions. One such study was a nonparametric analysis, which finds a monotonic relationship, not a convex relationship between GDP and emissions (Azomahou et al. 2006). Using econometric analysis with panel data, Galeotti and Lanza analyze the relationship between carbon dioxide emissions and GDP (1999). They evaluate Annex-I and non-Annex-I countries and estimate an EKC to forecast future emissions.

Energy use is both an input and an output in economic activity (McKibben et al. 2007). Thus energy use, thus carbon dioxide emissions, and GDP share an important relationship. However, many additional factors determine the nature of the relationship—it is overly simplistic and inaccurate to track emissions based on the growth of GDP alone. Under the same GDP growth path, emissions can diverge on a number of different paths depending on the sector composition of economic growth (McKibben et al. 2007).

While certain models assume convergence in emissions and energy use, in terms of energy intensity and emissions per capita, as economies become more developed, this assumption is not supported by empirical evidence (McKibben et al. 2007). Instead, natural resource endowments play a strong role in the emissions pathways of individual countries precluding unconditional convergence. The natural resource endowment helps to determine the fuel source mix of energy production, which is a major factor in the emissions intensity of energy.

This study draws from the underlying ideas of sectoral decomposition, the Kaya identity, and econometric analysis of panel data. By combining these approaches, more depth of analysis of the identifiable factors underlying carbon dioxide emissions is sought. In addition to examining GDP, population, and energy as in the Kaya identity, fuel sources, economic structure, and population distribution are also considered.

Methods

The purpose of this study is to identify differences in factors underlying emissions in economies at very different points in economic development. In order to analyze as many nations as possible, the model draws on the concepts underlying existing methods but is simplified to attempt to pinpoint the most significant sources of emissions without becoming overly data-intensive.

A fixed effects panel regression model is created to analyze panel data from 1971 to 2006. The fixed effects model calculates average coefficients for each factor and allows each country to have unique y-intercepts. The fixed effects approach subtracts the panel-level averages from each term in the model. Characteristics that do not vary with time are thus removed from the model (Baum 2006). The general form of a fixed effect model is as follows:

$$y_{it} - \bar{y}_{it} = (x_{it} - \bar{x}_{it})\beta + (z_i - \bar{z}_{it})\delta + u_i - u_i + \varepsilon_{it} - \bar{\varepsilon}_{it}$$

where x_{it} is a vector of variables that vary across individual countries and across time, β is the vector of coefficients for x, z_i is the vector of variables that vary over countries but do not vary with time, δ is the coefficient vector for z, u_i is the country-level effect, and ε_{it} is the error term. The above equation removes the fixed effects for each country and leaves the time varying variables and the error term:

$$\tilde{y}_{it} = (\tilde{x}_{it})\beta + \tilde{\varepsilon}_{it}$$

Applying this general model to carbon dioxide emissions per capita will enable the analysis of the impact of each factor on emissions while controlling for most other variables, both within the model and the error term. The general model is as follows:

$$CO2pc_{it} = \beta_0 + \beta_G\left(GDPpc_{it}\right) + \beta_{G2}\left(GDPpc_{it}\right)^2 + \beta_E\left(Prdenergy_{it}\right) + \sum_f \beta_f Elect_{itf}$$
$$+ \sum_p \beta_f FuelProd_{itp} + \sum_s \beta_{its} \%GDP_{its} + \beta_R R_{it} + \beta_{it} TrnsptEng + \theta_i + \gamma_t + \varepsilon_{it}$$

where $GDPpc_{it}$ = GDP (US$2000), $Prdenergy_{it}$= productivity of energy (total primary energy supply (kt oil equivalent) divided by GDP), $Elect_{it}$ = percentage of total electricity output from each fuel where f={coal, oil, natural gas}, $FuelProd_{it}$ = annual fuel production where p ={oil, coal}, $\%GDP$ = percentage of value-added GDP from each economic sector where s = {industry, agriculture}, R_{it} = percent of total population residing in rural areas, $TrnsptEng_{it}$= energy use in transportation (kt oil equivalent), θ_i = nation level fixed effects, γ_t = time dummy variables, and ε_{it} = time varying error term.

Aggregate variables, such as population, oil and coal production, and transport energy are scaled to annual population. Efficiency is accounted for by dividing GDP by total primary energy supply, this produces a term called the productivity of energy. Sources of electricity chosen are those that have the greatest contribution to carbon dioxide emissions. The economy is divided into three major sectors: industrial, agricultural, and services. In this model, the percentage of GDP in the industrial sector and agricultural sector are used as independent variables. The services sector variable is not included to prevent collinearity. The effects of urbanization is included in the model with the percentage of population in urban areas.

First these models are run without differentiating between development groups. Then dummy variables for each development group are created and interacted with each coefficient in the model to establish the separate coefficients for each development group. To focus in directly on the the differences in the relationship between GDP and emissions, a third model run collapses the GDP per capita relationship (linear and quadratic terms) back into aggregate coefficients for the entire group. Comparisons made among these models lead to better clarity about how these relationships change among development groups.

Country Level Data

Data for this analysis was compiled from existing international databases. Data on carbon dioxide emissions, total primary energy supply[1], percentage of electricity from each fuel source, energy production, and energy used in transport is gathered from the International Energy Agency. The World Development Indicators Database is the source for population, percentage of the population in rural areas, and value added by industry as a percentage of GDP (World Bank 2007).

The International Energy Agency database provides data on carbon dioxide emissions using both the tier 1 sectoral approach and the reference approach, total primary energy supply, energy production, imports and exports. The reference approach calculates emissions directly from fuel use, while the sectoral method is a bottom up approach that calculates emissions from each of the following sectors: energy, industrial processes (including cement manufacturing), solvent and other product use, agriculture, land use change and forestry, and wastes (IPCC 1996). This analysis uses the IPCC Tier 1 Sectoral approach carbon dioxide emissions data published by the International

[1] Total Primary Energy Supply aggregates production, imports, exports, stock changes, and subtracts energy in international bunkers.

Energy Agency (IEA 2008). These data do not include non-energy fuel use. Emissions for international transport are not included in country totals. They also do not account for biomass fuel emissions. If biomass fuels are sustainably harvested, then the emissions should net out to zero. However, if more biomass is burned than is regrown, then this assumption fails and the emissions reported to not fully reflect the anthropogenic emissions of a given country. Fugitive emissions from energy production are calculated, including flaring of natural gas. The broad-based Sectoral approach reduces the concern of endogeneity, which would occur in the Reference Approach where the CO2 emissions (the dependent variable) are directly calculated using a linear combination of a number of the independent variables.

Unfortunately, consistent data is not available for all countries for the entire sample period between 1971 and 2006. This creates an unbalanced panel. If the absence of a country from the sample year is not related to the error term in the model, then an unbalanced panel does not pose any major problems. However, if the countries are missing data because of some time-varying event that might also impact their carbon dioxide emissions but is not accounted for in the explanatory variables, then the coefficient estimators may be inconsistent.

One major source of unbalance is the breakup of the Soviet Union. A large number of countries appear in 1990 that were unaccounted for before, as the Soviet Union is not included in the analysis due to incomplete data. This could cause a problem, but since beginning the overall sample period at 1990 would not remove these issues and dropping all Soviet-bloc countries would reduce the explanatory value of the model, I instead make the assumption that this will not effect the model outcome. Further analysis could generate more certainty on this assumption.

Another source of imbalance appears to be conflict. A number of countries were missing a string of years in the middle of the sample period, such as Kuwait, which does not have data for 1990 to 1994. Clearly, a war within a nation's borders is likely to impact emissions in various ways unrelated to the explanatory variables. Furthermore, it is possible that lax reporting to international statistical agencies could relate to temporary political issues that may cause inconsistencies in the model.

To remove these potential inconsistencies, I dropped all countries with a gap of a year or more in the data. I also removed countries with 16 or fewer data points. I chose 16 as a benchmark because the Soviet Bloc countries all have 17 years of data. With these corrections, the panel is still unbalanced, but is far less likely to have serious sample attrition correlation with the error terms.

Nation	Years Included	Nation	Years Included	Nation	Years Included
Albania	1980-2005	Finland	1971-2006	Oman	1971-2004
Algeria	1971-2005	France	1971-2006	Pakistan	1971-2006
Angola	1985-2006	Gabon	1971-2006	Germany	1971-2006
Argentina	1971-2006	Georgia	1990-2006	Paraguay	1971-2006
Armenia	1990-2006	Germany	1971-2006	Philippines	1971-2006
Australia	1972-2006	Ghana	1971-2006	Poland	1990-2006
Austria	1971-2006	Greece	1971-2006	Portugal	1971-2006
Azerbaijan	1990-2006	Guatemala	1971-2005	Romania	1981-2006
Bangladesh	1980-2006	Honduras	1971-2006	Russia	1990-2006
Belarus	1990-2006	Hong Kong	1980-2006	Saudi Arabia	1971-2006
Belgium	1971-2006	Hungary	1971-2006	Senegal	1971-2006
Benin	1973-2005	Iceland	1973-2005	Singapore	1975-2006
Bolivia	1971-2006	India	1971-2006	Slovakia	1985-2006
Botswana	1981-2006	Indonesia	1971-2006	Slovenia	1990-2006
Brazil	1971-2006	Iran	1971-2006	South Africa	1971-2006
Brunei	1974-2006	Ireland	1971-2005	Spain	1971-2006
Bulgaria	1980-2006	Italy	1971-2006	Sri Lanka	1971-2006
Cameroon	1971-2006	Japan	1971-2005	Sweden	1971-2006
Canada	1971-2003	Jordan	1975-2006	Syria	1985-2006
Chile	1971-2006	Kenya	1971-2006	Tajikistan	1990-2006
China	1971-2006	Korea, South	1971-2006	Tanzania	1990-2006
Colombia	1971-2006	Kyrgyzstan	1990-2006	Thailand	1971-2006
Congo	1971-2006	Latvia	1990-2006	Togo	1971-2005
Costa Rica	1971-2006	Lithuania	1990-2006	Trinidad and Tobago	1984-2006
Cote d'Ivoire	1971-2006	Macedonia	1990-2006	Tunisia	1971-2006
Croatia	1990-2006	Malaysia	1971-2006	Ukraine	1990-2006
Czech Republic	1990-2006	Mexico	1971-2006	United Arab Emirates	1975-2005
Democratic Republic of Congo	1971-2006	Moldova	1990-2006	United Kingdom	1971-2006
Denmark	1971-2006	Mongolia	1985-2006	United States	1971-2005
Dominican Republic	1971-2006	Morocco	1980-2006	Uruguay	1983-2006
Ecuador	1971-2006	Mozambique	1980-2006	Uzbekistan	1990-2006
Egypt	1971-2006	Nepal	1971-2006	Venezuela	1971-2004
El Salvador	1990-2006	Netherlands	1971-2006	Vietnam	1985-2006
Estonia	1990-2006	New Zealand	1971-2002	Zambia	1971-2006
Ethiopia	1981-2006	Norway	1971-2006	Zimbabwe	1971-2005

Table 1: Countries and time period included in the analysis.

Development Status

The designation of development status is determined by merging a few different existing classifications. Many analyses use the distinction of OECD and non-OECD countries. However, this analysis focuses on the differences between developed, emerging, and developing countries. Included among OECD countries are Mexico and Turkey, which are generally categorized as emerging economies and Slovakia, which is usually classified as a developing country. Moreover, a number of advanced economies are not included in the OECD such as Hong Kong, Israel, and Singapore.[2]

The International Monetary Fund divides nations into two categories: advanced economies and developing and emerging markets (IMF 2007). This analysis follows their classification for advanced economies. In the IMF classification, emerging markets include countries of all development levels from emerging to least developed, so further distinctions are employed. The category of emerging economies is based upon the MSCI Emerging Markets Index (MSCI Barra 2008). Least developed countries are classified using the United Nations designation (UN 2008). All others fall in the category of developing countries. After these bins were created based on these external categories, a few changes were made to better reflect the high level of development of a few small, wealthy countries that were categorized as developing countries. Additionally, countries like Slovenia, South Korea, and Portugal that are now categorized as advanced economies are designated emerging countries since they made the transition from developing to advanced during the study period. Table 2 details the classifications used in the model.

[2] Hong Kong is a special administrative region of China, but has independent data and significant sovereignty over domestic matters that relate to energy, so is included among the country analysis separate from China.

Advanced	Emerging	Developing		Least Developed
Australia	Argentina	Albania	Kyrgyzstan	Angola
Austria	Brazil	Algeria	Latvia	Bangladesh
Belgium	Chile	Armenia	Libya	Benin
Brunei	China	Azerbaijan	Lithuania	Democratic Republic of Congo
Canada	Colombia	Belarus	Macedonia	Ethiopia
Denmark	Czech Republic	Bolivia	Moldova	Mozambique
Finland	Egypt	Botswana	Mongolia	Nepal
France	Hungary	Bulgaria	Oman	Senegal
Germany	India	Cameroon	Panama	Tanzania
Greece	Indonesia	Congo	Paraguay	Togo
Hong Kong	Jordan	Costa Rica	Romania	Zambia
Iceland	Malaysia	Cote d'Ivoire	Slovakia	
Ireland	Mexico	Croatia	Sri Lanka	
Italy	Morocco	Dominican Republic	Syria	
Japan	Pakistan	Ecuador	Tajikistan	
Netherlands	Philippines	El Salvador	Trinidad and Tobago	
New Zealand	Poland	Estonia	Tunisia	
Norway	Portugal	Gabon	Ukraine	
Singapore	Russia	Georgia	Uruguay	
Spain	Saudi Arabia	Ghana	Uzbekistan	
Sweden	Slovenia	Guatemala	Venezuela	
United Arab Emirates	South Africa	Honduras	Vietnam	
United Kingdom	South Korea	Iran	Zimbabwe	
United States	Thailand	Kenya		

Table 2: Development classification groups over the time period of 1971 to 2006.

Summary Statistics for Models Variables

Variable	All Countries	Advanced	Emerging	Developing	Least Developed
CO_2 Emissions per Capita (tons of CO_2 per million people)	3,473,352 (572,704)	9,100,190 (1,043,529)	1843338 (475,988)	811,053 (215,784)	266,437 (134,009)
GDP per Capita (US$ 2000)	4,927 (704)	12,616 (813)	2,301 (573)	1,674 (369)	360 (73)
Productivity of Energy ($ per ton of oil equivalent TPES)	3,405 (573.2)	4,113 (365)	2,668 (450)	4,017 (807)	951 (208)
Number of Countries	62	18	18	21	5

Table 3: Means and standard deviations of key variables for 1971.

Variable	All Countries	Advanced	Emerging	Developing	Least Developed
CO_2 Emissions per Capita (tons of CO_2 per million people)	4,529,848 (87,422)	10,200,000 (169,353)	3,542,006 (119,381)	2,561,647 (83,674)	192,992 (9,743)
GDP per Capita (US$ 2000)	6,757.2 (154.4)	19,704 (244.7)	3,434 (114.1)	1,989.9 (50.7)	314.4 (8.6)
Productivity of Energy ($ per ton of oil equivalent TPES)	2,712.1 (39.6)	4,694.1 (67.1)	2,407.3 (54.2)	2,057.5 (63.0)	996.5 (33.9)
Number of Countries	101	22	24	44	11

Table 4: Means and standard deviations of key variables for 2005.

Results and Discussion

Fully Aggregated Model

When all development groups are run together in one model with carbon dioxide emissions per dollar of GDP, all independent variables are significant (Table #). When the model is run separately for each development group, the coefficients change significantly, not only in magnitude, but in some cases, also in sign. This strongly supports the hypothesis that there are inherent differences in the contribution of various factors among different levels of economic development.

Under a quadratic functional form for GDP per capita, the model appears to confirm the EKC hypothesis, with a large, positive linear coefficient and a small, negative quadratic coefficient. Electricity variables all have large positive variables, which is expected, with the exception of natural gas having a larger coefficient than oil powered electricity. This points to possible indirect effect as a straightforward decomposition of carbon emissions would result in coefficients that follow from the average efficiencies and carbon dioxide emissions per unit of electricity produced. If this were the case, the order would likely be coal, oil, then natural gas. However, more data on efficiencies would be needed in order to be ascertain whether this is indicating an indirect effect or whether the average efficiencies of each type of electricity generation outweigh the carbon ratio of the fuel.

Oil production per capita also has a surprising, negative coefficient. Many major oil producing countries have high subsidies on fuels, resulting in very high use. However, this variation could be accounted for in other terms, such as the productivity of energy or the transportation energy per capita. The correlation between transport energy per capita and oil production per capita is 0.3929, and is 0.1904 between productivity of energy and oil production per capita. Coal production, on the other hand, has a high coefficient.

The percentage of value-added in the economy in agriculture is positive, but smaller than the percentage of value-added in industry, while the services sector is dropped to avoid perfect collinearity. There is a high correlation between the percentage of GDP generated by agriculture and percentage of the population living in rural areas (Correlation=0.7366), so this could affect the magnitude of the coefficient. If services are included and agriculture is dropped, the coefficient for services is -33,515.3 and the coefficient for industry is 13,414.8 (both with p-values < 0.0001).

Variables	Coefficients
GDP per capita	280.3***
GDP per capita squared	-0.0059***
Productivity of Energy (GDP/Energy Consumption)	-217.2***
Coal-Powered Electricity (% Total Electricity Output)	21,464.9***
Natural Gas-Powered Electricity (% Total Electricity Output)	14,795.6***
Oil-Powered Electricity (% Total Electricity Output)	13,161.7***
Oil Production per Capita (kg oil equivalent)	-39.9***
Coal Production per Capita (kg oil equivalent)	870.0***
Agricultural Sector (% of GDP)	34,175.3***
Industry Sector (% of GDP)	47,175.1***
Rural (% of Population)	-49,747.0***
Transport Energy per Capita (kg of oil equivalent per person)	5,285.0***
_Constant	1,814,084***
SSR	1.58E+15
SST	7.79E+16
Adjusted R-Squared	0.9787

Table 5: Panel regression coefficients for fixed effects model of carbon dioxide emissions per unit of GDP without differentiation between development groups.
***P-value < 0.001
**P-value < 0.01
*P-value < 0.05
† P-value < 0.10

Disaggregated Model: Distinguishing Between Development Stages

First, each variable in the general model is interacted with dummy variables to allow the coefficients for each variable to differ among the four development groups. In the first iteration, GDP per capita and GDP per capita squared are also differentiated by groups. Then, to isolate the change in the

GDP per capita and carbon emissions relationship, the GDP per capita coefficients are collapsed back into one group. From here, we can make comparisons between these two models.

In the fully aggregated model (Table #), the relationship between GDP per capita and CO2 emissions is:

$$CO2_{it} = 280\left(\frac{G_{it}}{P_{it}}\right) - 0.0059\left(\frac{G_{it}}{P_{it}}\right)^2 + X'\beta + \varepsilon_{it}$$

where $X'\beta$ represents all other control variables.

In the partially aggregated model, where all variables but GDP per capita are disaggregated, the linear term becomes steeper, while the quadratic term is essentially unchanged.

$$CO2_{it} = 406\left(\frac{G_{it}}{P_{it}}\right) - 0.006\left(\frac{G_{it}}{P_{it}}\right)^2 + X'\beta + \varepsilon_{it}$$

With the fully disaggregated model, the relationship changes for each development group. For advanced economies, the relationship is similar to the aggregated models. Yet, the other development groups show significantly different relationships. Emerging economies display a strongly linear relationship, and the quadratic term is insignificant. This is an important finding as it suggests that emerging countries, including countries like South Korea and Slovenia who are now often categorized as advanced economies, show no concavity in the relationship between GDP per capita and CO2 emissions per capita. Developing countries show a convex relationship, meaning that emissions decline early on in development and then begin to increase with income. The least developed countries do not show significant relationships for any variables, likely due to the small sample size. In future analyses, they could be included with developing economies.

	Advanced Economies	**Emerging Economies**	**Developing Economies**	**Least Developed**
GDP per capita	234.0***	461.5***	-967.1***	860.4
GDP per capita squared	-0.004***	-0.005	0.152***	-0.355
Productivity of Energy (GDP/Energy Consumption)	-845.7***	-675.4***	-49.9***	-113.4
Coal-Powered Electricity (% Total Electricity Output)	51125.6***	7043.6*	-301.9	2350.6
Natural Gas-Powered Electricity (% Total Electricity Output)	44871.4***	6315.0*	10356.0***	-98.4
Oil-Powered Electricity (% Total Electricity Output)	31181.5***	6308.4*	15044.1***	669.5
Oil Production per Capita (kg oil equivalent)	-31.08***	-49.0**	-31.9**	33.9
Coal Production per Capita (kg oil equivalent)	615.9***	495.6**	4,851.4***	5,125.4
Agricultural Sector (% of GDP)	-2223.8	37353.1***	45654.9***	510.4
Industry Sector (% of GDP)	40713.2***	54471.0***	44470.3***	1758.2
Rural (% of Population)	-9049.3	-47831.1***	-36111.0***	563.1
Transport Energy per Capita (kg of oil equivalent per person)	4074.0***	3501.0***	6549.6***	2215.2
_Constant	-356171.6			
SSR	9.63E+14			
SST	7.79E+16			
Adjusted R-Squared	0.9864			

Table 6: Fully disaggregated panel regression coefficients for carbon dioxide emissions per capita.
***P-value < 0.001
**P-value < 0.01
*P-value < 0.05
† P-value < 0.10

	All Countries	Advanced Economies	Emerging Economies	Developing Economies	Least Developed
GDP per capita	406.10***				
GDP per capita squared	-0.006***				
Productivity of Energy (GDP/Energy Consumption)		-939.6***	-658.4***	-131.7***	-87.0
Coal-Powered Electricity (% Total Electricity Output)		50115.7***	7537.4*	-3425.6	2517.9
Natural Gas-Powered Electricity (% Total Electricity Output)		41685.3***	4915.1	8788.7***	345.1
Oil-Powered Electricity (% Total Electricity Output)		33879.5***	5714.6*	13870.3***	687.3
Oil Production per Capita (kt oil equivalent)		-337.6***	-286.4*	-213.2*	7.1
Coal Production per Capita (kt oil equivalent)		611.5***	495.6**	4666.7***	5149.8
Agricultural Sector (% of GDP)		19789.3	35512.8***	60598.3***	-286.0
Industry Sector (% of GDP)		32936.3***	54117.7***	44794.2***	1888.5
Rural (% of Population)		-28566.63†	-46769.4***	-28420.9***	-816.2
Transport Energy per Capita (kg of oil equivalent per person)		3752.6***	4171.8***	6785.2***	2200.2
_Constant	291491.7				
SSR	1.10E+15				
SST	7.79E+16				
Adjusted R-Squared	0.9845				

Table 7: Partially aggregated panel regression coefficients for carbon dioxide emissions per capita.
***P-value < 0.001
**P-value < 0.01
*P-value < 0.05
† P-value < 0.10

To evaluate whether disaggregating among development groups is a better overall fit, an F-test is performed on the sum of squared residuals:

$$F = \frac{(SSR_R - SSR_{UR}) / q}{SSR_R \; / (n - k - 1)}$$

The F-statistic for the fully aggregated model compared to the fully disaggregated model is 8.59, which calls for a rejection of the null hypothesis that the reduction in the residuals is due to solely the increase in explanatory variables. On the contrary, the disaggregated model is a better for for the data. For the partially aggregated model (aggregating GDP per capita terms) compared to the fully aggregated model, the F-statistic is 124.8, thus the unrestricted model is preferred.

These F-tests show that the disaggregated models are more effective at efficiently minimizing the residuals. The individual t-tests for each establish the statistical significance of individual regressors. Now, Wald tests are used to test linear hypotheses about the coefficients of the aggregated model, namely whether coefficients for different developing groups are statistically significant. Post-estimation Wald tests are run for $\beta_{G1} + \beta_{G2}$ from each development group. The GDP per capita coefficients for all developing country groups are significantly different from one another. Pairwise comparison tests show differences for all pairs except for any pairs with least developed countries. Once again, this group appears to suffer from low data availability resulting in a small sample size.

These statistical tests show that the relationships between GDP per capita and carbon dioxide emissions are different among development groups and that a model specification that allows for different slopes for each development group lead to better estimation.

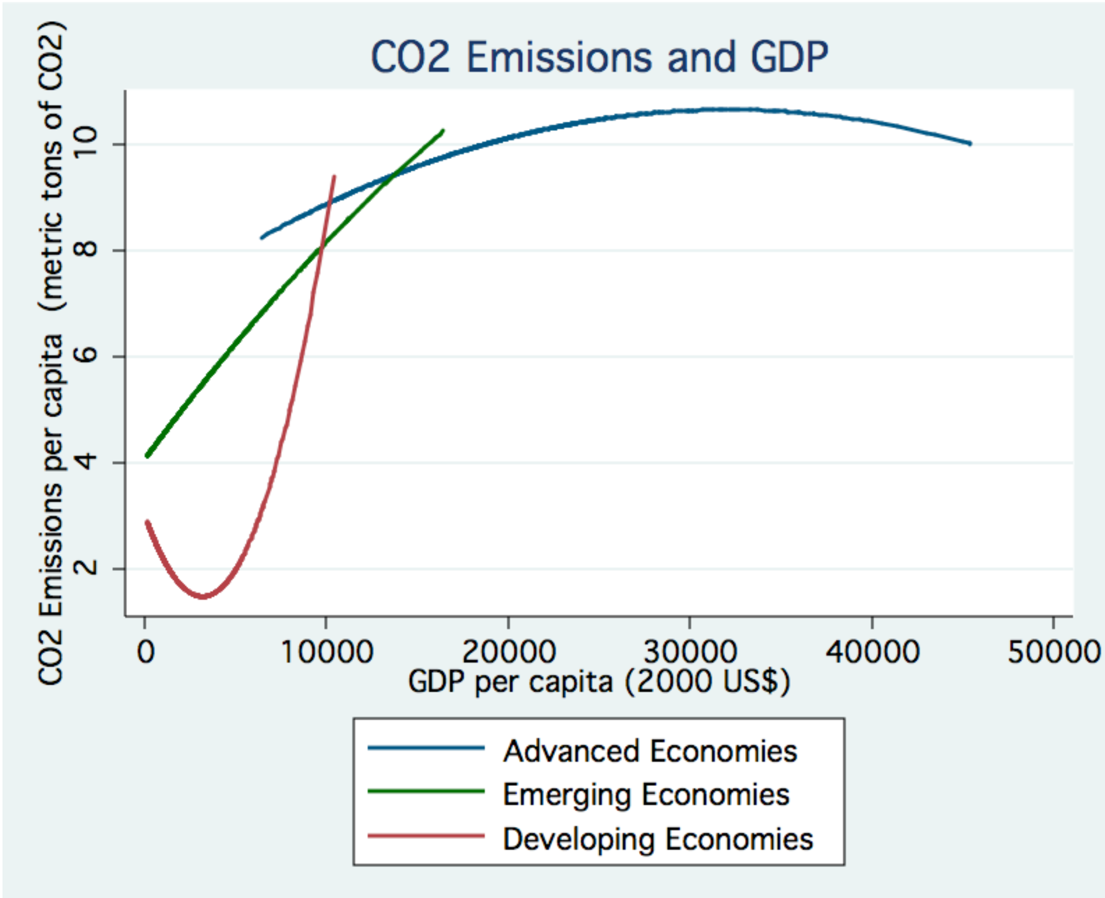

Figure 6: Predicted relationship between per capita GDP and per capita carbon emissions for each development group.

Conclusions

It is difficult to strike a balance between simplicity and accuracy in models that explain complex and far-reaching problems such as carbon dioxide emissions. On the other hand, data intensive decomposition methods can become infeasible on a global scale and also have low widespread explanatory power. This analysis presents a simple methodology that seeks this balance and contributes insight to the specific differences in the relationship between general contributing factors and emissions for different levels of economic development.

Boiling down the greenhouse gas issue to a simple relationship with GDP ignores other essential contributive factors and does not provide effective direction for policy planning. GDP has a complex relationship with carbon dioxide emissions. The results of the model show that there is indeed a major difference in these relationships. These distinctions must be recognized in order to create an accurate picture of carbon dioxide emissions in the past and into the future. This is an essential first step to answer the question of where emissions mitigation potential exists at each stage of economic development.

The urgent nature of climate change demands that we act to reduce our emissions across the globe. However, as we begin to take action in developed countries, the vast uncertainties that remain in evaluating the best and lowest cost ways of reducing emissions in the developing world must be examined and resolved. It is imperative to understand the nature of the relationship between the cost structures in developed, developing, and emerging countries before we set the trajectory global climate policy to depend on an unexamined assumption. This study has shown that it is important to approach these factors differently depending on the development status of each nation. Further analysis could reveal important information about the relative costs of GHG emissions mitigation around the world and could inform the international policy debate on reducing global emissions. If we can answer these questions, we can focus our efforts to reduce the largest quantity of emissions for each dollar spent on greenhouse gas mitigation across the globe.

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