The Effect of Economic Development on CO2 Emissions

A Multivariate Panel Analysis:

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Friday, December 3, 2022

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Introduction

The question we wish to investigate is what is the effect of economic growth on CO_2 emissions?

In this question we will seek to find a relationship between the size of the country, developmental state or projected growth, and the amount of greenhouse gas emissions the country releases over various time periods. We believe that this is both an economically and statistically important question because it focuses on a subject with real world impacts. It also affects economic environments because there are countries whose entire economy depends on the health of the global climate and knowing the effects of large countries on greenhouse gasses could potentially be important to policy makers attempting to make their country prosper. This question is important to us because of the inequitable effect of CO_2 emissions on the world. Countries like Pakistan with a very small carbon footprint have been getting affected by climate change very harshly which can be seen in the recent floods in the country. We also want to investigate growth rates and their effects on a country's ability to curb climate change. We find this question interesting as well because we wanted to find out if a country with a fast growth rate will be able to properly stave off climate change or will the growth crowd out environmental efforts.

Literature Review

In the article "The Nexus Between Carbon Emission, Energy Consumption, Economic Growth and Changing Economic structure in India: A Multivariate Cointegration Approach"

(2018) Authors Chandrima Sikdar and Kakali Mukhopadhyay highlight the intersection between quite a few economic indicators and their effects on carbon emissions in India. In the first section Sikdar and Mukhopadhyay demonstrate that India has begun moving from a largely agriculturally driven economy to a more diverse economy with many different sectors. This transition from agriculture to a more service based economy is usually paired with a boom in industry and manufacturing, followed by a slowdown of these markets as the economy matures and transitions into marketing more services instead. This might produce trouble for a linear model since the effect changes with respect to itself as well as with time, meaning that overtime as an economy matures the growth rate of the CO2 emissions might go down because of the transition of income from a more environmentally intense sector to a less environmentally intense sector like the service sector. Sikdar and Mukhopadhyay pull their data from various Indian governmental departments as well as World Bank financial data. The model they use is a linear logarithmic model. From this logarithmic model they found that "primary energy consumption, per capita GDP and trade openness are statistically significant variables explaining variations in CO2 emission levels over long run" (Sikdar & Mukhopadhyay, 2018). Although they found that co2 emissions are less responsive to factors such as GDP per capita and trade openness. They also found that the elasticities of co2 emissions and primary energy consumption are larger in the long run than the short run, indicating that the more primary energy consumption that occurs the more co2 will be emitted, this result is not surprising considering that the more energy you need will require more fuel and burning more fuel creates more carbon emissions.

In the article "The effects of high technology export and per capita income on carbon emission: An investigation on G20 countries" authors Nazife Ozge Beser and Semanur Soyyigit discuss how technological development level and technological change are important economic growth indicators and how in turn CO_2 emissions increase in parallel to technological development (Beser, Nazife Ozge, et al, 2019). The article highlights how greenhouse gas emissions appear to be more prevalent in developed countries and how the increasing threat of global warming and climate change caused the realization of the relationship between economic growth, energy consumption and CO_2 emission (Beser, Nazife Ozge, et al, 2019). The article analyzes the G20 countries except Russia within the scope of years 1992 to 2014, Russia was excluded due to lack of data (Beser, Nazife Ozge, et al, 2019). The article uses a combination of time series analysis, dynamic panel regression analysis, panel data analysis, panel causality test, Engle-Granger cointegration, GMM panel estimator and Granger causality test methods.

In the article "Beta decoupling relationship between CO_2 emissions by GDP, energy consumption, electricity production, value-added industries, and population in China" the author Rabnawaz Khan uses Beta Decoupling Techniques to look at the effects of GDP, energy consumptions, electricity production, value-added industries, and population on CO_2. Khan chose China for this study because the country has been developing sustainably at a rapid pace while being the largest producer of carbon emissions on the planet. He argues that China is sustainable, strengthening its energy output, constantly changing their energy consumption structure, and is taking environmental circumstances into consideration when creating new developmental policies using both Beta Decoupling Techniques and the STIRPAT model (Khan, 2021). The author uses various data sources to prove his claim and looks at other data points that should be taken into consideration like car sales within China. Data points like these are important to take into consideration as they cover a range of topics within his research topic as car sales will have an impact on energy consumption, value added industries and population. By utilizing Beta Decoupling Techniques and the STIRPAT models on his various data sources, Rabnawaz Khan concludes his paper with two recommendations; 1) it is important to re-imagine growth and control energy development by the amount of energy available. Khan says that the nation has to invest its resources towards the improvement of energy utilization, energy conservation, energy transformation, and consumption (Khan 2021). 2) it is important for every country to take action against CO_2 emissions by taking energy demand into account when planning new industries and developments (Khan, 2021).

Model

Throughout this project we attempt to investigate whether or not there would be a significant effect of economic growth (measured by GDP) on greenhouse gas emissions (measured by CO_2 emissions). We classified our countries as rich and poor in order to analyze our question further and to see if there is a difference in correlation between large economies vs small economies in terms of CO_2 emissions.

H0: Economic growth factors have no effect on greenhouse gas emissions

H1: Economic growth leads to higher greenhouse gas emissions

Dependent Variable: cumulative co2 emissions

Regressors: GDP, GDP^2, GDP^3, GDP^4, Population, Rich and Year

For our model, we estimated the effects of GDP, GDP^2, GDP^3, GDP^4, population on CO2 emissions across countries globally between 1950 to 2018 and between rich vs poor countries. We predict that our model will display a non-linear relationship through an inverted u-shaped curve. We estimate a positive relationship between CO2 emissions and GDP in the early stages of an economy. But after a certain point there would be an inflection point in our graph where the marginal rate of change of CO2 emissions will be equal to 0. After that point, the relationship will become negative, showing an inverse relationship between GDP growth and CO2 emissions. This is because we predict that nations with smaller economies might have trouble curbing CO2 emissions as they have to focus more on manufacturing and cannot expend as much money into environmental efforts as large economies can. As an economy is developing in the early stages they might heavily depend on burning fossil fuels to facilitate growth meaning a stronger positive relationship in the beginning with diminishing marginal returns to scale later on as the economy is more developed and relies less on fossil fuels. Eventually, there will be increasing marginal returns to scale for highly developed economies but in a negative relationship.

Since we predicted that there might be a nonlinear model present we also wanted to estimate regressions with polynomials for GDP in order to pin down the best fit. We begin with a linear regression for our model initially, but because of our initial hypothesis we move on to a non-linear model in order to evaluate the results for several different degrees of polynomial functions. This is because, we also predicted that as GDP changes over time we might find that a non-linear model is required in order to capture the effect of GDP fluctuating over time. We started with a 5th degree polynomial estimation and sequentially dropped insignificant/bad-fitting models until a significant effect was found.

We constructed a multivariate model by regressing CO2 emissions on GDP while eliminating omitted variable bias by controlling for several additional regressors in our model. e.g. we wanted to control for methane and nitrous oxide in our model in order to pin down the true effects of gdp on CO2. We found that by controlling for methane and nitrous oxide we could isolate any effect that gdp has on those greenhouse gasses in order to get closer to a true estimation. Our model also meets the OLS assumptions as much as is required to estimate the precise and accurate effect of GDP on CO2 emissions. We will be using robust regression to avoid any heteroskedasticity present in our data.

Data

We obtained our data from Our World in Data (OWD) and The World Bank. The data from OWID is i.i.d. with a large sample size (n > 30). The data that we used from The World Bank categorized countries as High Income ($13,205 OR MORE), Upper Middle ($4,256 TO $13,205 GNI per capita), Lower Middle ($1,086 TO $4,255 GNI per capita), or Low Income ($1,085 OR LESS GNI per capita) (WorldBank). The variables that we chose to focus on for our model are: cumulative_co2, population, gdp, methane, nitrous_oxide, flaring_co2, coal_co2, consumption_co2, gas_co2, trade_co2, primary_energy_consumption, rich, total_ghg, scaled_gdp, real_cum_co2, classification, and year. In order to analyze our data properly, we had to make some changes to the data. To start, we joined carbon emission data from Our World in Data and economic indicators from the World Bank based on the country's iso_codes. We did this so that we could add the variable classification from the world bank into the data we obtained from OWID. After joining the two datasets, all null values for gdp were dropped as null values could have a significant impact on our analysis. A few variables were also created to assist in analysis such as gdp_per_capita, and country_group. The variable gdp_per_capita was created by dividing gdp by population. country_group was generated to give every country a unique int id. In order to further look at the effect on gdp overtime we also created a variable gdp_growth by calculating how much the country grew from the previous year. Finally, in order to see whether there are any differences in poor vs rich countries, we created the boolean value rich to indicate whether a country is rich or not. We classified a rich country as any country that is classified as High Income or Upper Middle.

Variable	Description	Units
cumulative_co2	Sum of annual emissions	Million Tons
gdp	Gross Domestic Product of a given Country	USD
population	Population of country	N/A
methane	Amount of methane released	Million Tons
nitrous_oxide	Amount of Nitrous Oxide released	Million Tons
flaring_co2	Amount of CO2 flared (process of burning excess natural gas at the production)	Million Tons
consumption_co2	Amount of CO2 comsumed	Million Tons
gas_co2	Amount of CO2 gas released	Million Tons
primary_energy_consumption	Gross crude oil used by a country	Million Tons

total_ghg	Amount of Greenhouse gasses released	Million Tons
classification	Obtained from The World Bank and classifies countries into 4 distinct categories	High Income ($13,205 OR MORE) Upper Middle ($4,256 TO $13,205 GNI per capita) Lower Middle ($1,086 TO $4,255 GNI per capita) Low Income ($1,085 OR LESS GNI per capita)
rich	Any country with a classification of High Income or Upper Middle	Boolean value that is set to 1 if True and 0 if False
year	Year at which Data Point was recorded	N/A

Summary Statistics of Variables used:

Variable	Obs	Mean	Std. dev.	Min	Max
cumula~e_co2	13,357	5016.839	36204.42	.004	1625014
gdp	13,479	2.89e+11	2.18e+12	5.54e+07	1.14e+14
population	13,479	3.48e+07	1.92e+08	25006	7.63e+09
methane	4,673	54.94177	303.3555	.01	8489.97
nitrous_ox~e	4,673	19.78311	110.3976	0	3087.4
flaring_co2	3,273	5.983659	19.40233	0	422.856
consumptio~2	3,413	299.8308	1605.346	.197	36646.14
gas_co2	6,038	44.62951	237.2508	0	7457.572
primary_en~n	7,159	845.0916	4922.821	.097	161772.6
total_ghg	4,672	291.6789	1748.47	-186.55	49368.04
classifica~n	0				
rich	13,479	.6425551	.4792652	0	1
year	13,479	1968.688	39.40363	1820	2018

<u>Results</u>

Our model demonstrates that the relationship between GDP and CO_2 emissions is significant and striking. For rich countries, the coefficient on population is small and insignificant. This is surprising since we would expect more people to generate more CO_2, but from the data this is an unrelated factor, this could be due to the fact that CO2 emissions stem not from the individual, but rather other entities present in an economy (Corporations, Institutions, Energy production). Something not surprising in the data is that we found a positive and significant relationship between the coefficients on the GDP terms and CO2. We found that in rich countries the relationship between CO2 and GDP is non-linear and quadratic. This shows that as GDP fluctuates in a rich country the effect on its output of CO2 fluctuates as well. This effect can be pictured by plotting the marginal effects of gdp on CO2. This can be pictured in the graph below which increases at a diminishing rate pictured by the slight bend in the fitted line. This was achieved by starting with a 5th power polynomial and sequentially dropping insignificant terms until a significant result was reached.

Rich:

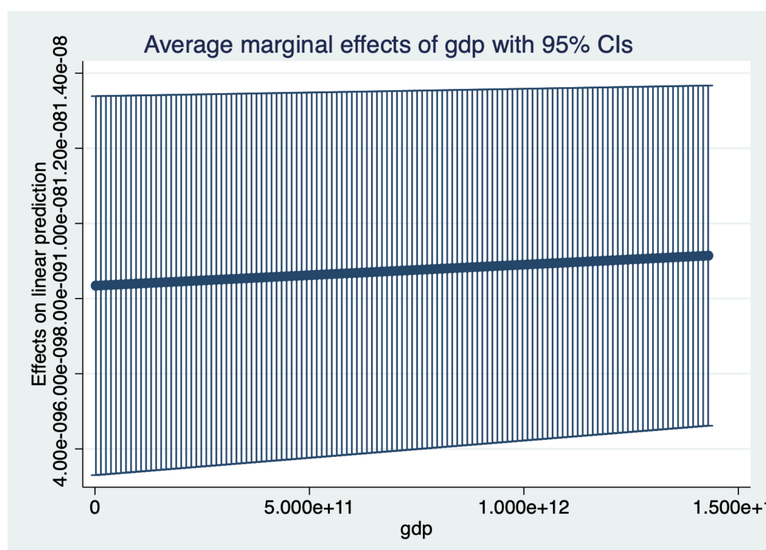
```
Fixed-effects (within) regression               Number of obs     =      2636
Group variable: country_gr~p                    Number of groups  =        91

R-sq:  Within  = 0.9631                         Obs per group: min =        27
       Between = 0.6621                                        avg =      29.0
       Overall = 0.6629                                        max =        29

                                                F(31,90)          =         .
corr(u_i, Xb)  = 0.4255                         Prob > F          =         .

                              (Std. err. adjusted for 91 clusters in country)
```

cumulat~e_co2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
population	.0001171	.0001148	1.02	0.310	-.0001109	.0003452
gdp	8.34e-09	2.57e-09	3.24	0.002	3.23e-09	1.35e-08
c.gdp#c.gdp	2.80e-22	1.04e-22	2.68	0.009	7.22e-23	4.87e-22
methane	-41.33502	28.02827	-1.47	0.144	-97.01807	14.34804
nitrous_oxide	-212.7506	88.92878	-2.39	0.019	-389.4231	-36.07801
year						
1991	39.63409	51.3898	0.77	0.443	-62.4607	141.7289
1992	52.58619	77.12241	0.68	0.497	-100.6309	205.8033
1993	87.24524	125.8499	0.69	0.490	-162.7776	337.2681
1994	146.6872	124.2038	1.18	0.241	-100.0654	393.4397
1995	267.8561	112.883	2.37	0.020	43.5942	492.1179
1996	354.8557	151.3751	2.34	0.021	54.12276	655.5887
1997	204.8756	118.6226	1.73	0.088	-30.78882	440.5401
1998	270.492	111.268	2.43	0.017	49.43872	491.5453
1999	223.938	154.2296	1.45	0.150	-82.46591	530.342
2000	126.5024	190.3183	0.66	0.508	-251.5981	504.603



In poor countries, the relationship is not quite as striking but is still quite interesting. We found that as opposed to rich countries, poor countries do not have the same non-linear relationship that we observed previously. In fact we found that in poor countries as GDP increases its effect on CO_2 can be pictured in a cubic form. As above, this was achieved by sequential dropping of higher power terms until a significant result was achieved. This is surprising since we wouldn't really expect poor countries to be much different in that regard. This could be due to a variety of factors including an unobserved relationship in our data that could mediate the relationship between time, GDP, and CO_2 or some other form of bias produced by the data.

Poor:

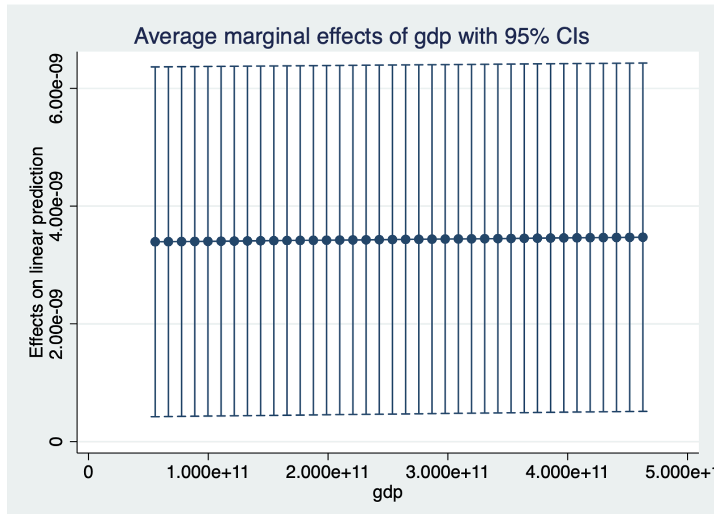
```
Fixed-effects (within) regression               Number of obs     =      2036
Group variable: country_gr~p                    Number of groups  =        71

R-sq:  Within  = 0.9969                         Obs per group: min =        6
       Between = 0.9974                                        avg =     28.7
       Overall = 0.9643                                        max =       29

                                                F(31,70)          =         .
corr(u_i, Xb)  = 0.8966                         Prob > F          =         .

                                  (Std. err. adjusted for 71 clusters in country)
```

cumulative_co2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
population	.0000545	.0000422	1.29	0.201	-.0000297	.0001387
gdp	3.38e-09	1.52e-09	2.23	0.029	3.59e-10	6.41e-09
c.gdp#c.gdp	9.63e-23	9.67e-24	9.96	0.000	7.70e-23	1.16e-22
c.gdp#c.gdp#c.gdp	-3.83e-37	4.12e-38	-9.30	0.000	-4.65e-37	-3.01e-37
methane	-9.092927	18.88312	-0.48	0.632	-46.75412	28.56826
nitrous_oxide	-115.7663	82.23513	-1.41	0.164	-279.7791	48.24646
year						
1991	197.5919	129.0467	1.53	0.130	-59.78371	454.9674
1992	198.4708	116.3496	1.71	0.092	-33.58109	430.5226
1993	186.1193	99.70538	1.87	0.066	-12.73686	384.9754
1994	293.364	160.4445	1.83	0.072	-26.63245	613.3605
1995	300.8816	159.5749	1.89	0.064	-17.38048	619.1437
1996	232.0125	151.1302	1.54	0.129	-69.40723	533.4322
1997	294.6497	182.8239	1.61	0.112	-69.98106	659.2804
1998	316.1382	159.09	1.99	0.051	-1.156766	633.4331
1999	288.7799	154.5969	1.87	0.066	-19.5539	597.1136
2000	590.9925	329.7678	1.79	0.077	-66.70874	1248.694
2001	273.7313	160.7616	1.70	0.093	-46.89764	594.3602



Global:

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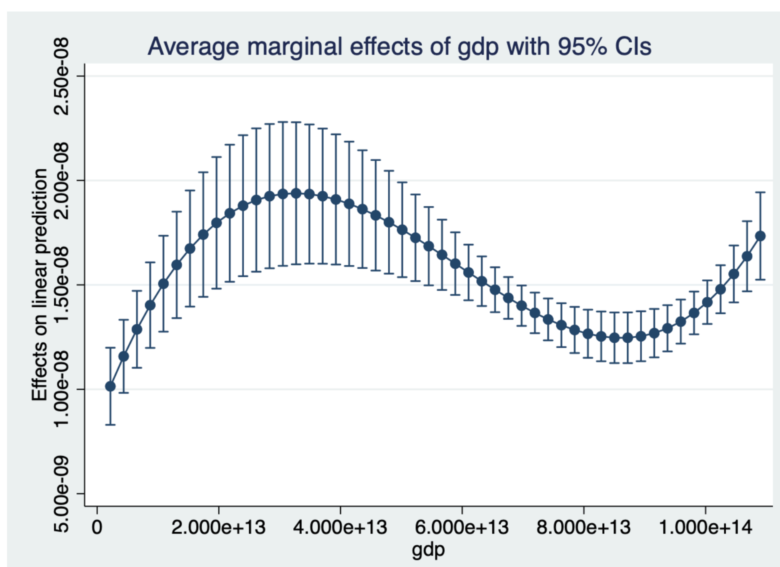
Fixed-effects (within) regression               Number of obs     =      4672
Group variable: country_gr~p                    Number of groups  =       162

R-sq:  Within  = 0.9873                         Obs per group: min =        6
       Between = 0.9643                                        avg =     28.8
       Overall = 0.8049                                        max =       29

                                                F(31,161)         =         .
corr(u_i, Xb)  = 0.7212                         Prob > F          =         .

                                 (Std. err. adjusted for 162 clusters in country)
```

cumulative_co2	Coefficient	Robust std. err.	t	P>|t|	[95% conf.	interval]
population	-.0000392	9.13e-06	-4.30	0.000	-.0000573	-.0000212
gdp	8.56e-09	1.11e-09	7.74	0.000	6.38e-09	1.07e-08
c.gdp#c.gdp	3.80e-22	8.52e-23	4.46	0.000	2.12e-22	5.48e-22
c.gdp#c.gdp#c.gdp	-5.36e-36	1.29e-36	-4.15	0.000	-7.91e-36	-2.81e-36
c.gdp#c.gdp#c.gdp#c.gdp	2.26e-50	5.59e-51	4.04	0.000	1.15e-50	3.36e-50
methane	-26.59295	22.00925	-1.21	0.229	-70.05699	16.87109
nitrous_oxide	-136.4865	52.53361	-2.60	0.010	-240.2303	-32.74274
year						
1991	91.91624	40.65744	2.26	0.025	11.6256	172.2069
1992	166.2196	53.85479	3.09	0.002	59.86677	272.5725
1993	241.6221	58.70896	4.12	0.000	125.6832	357.561
1994	370.6016	92.97884	3.99	0.000	186.9862	554.217
1995	466.736	120.9856	3.86	0.000	227.8125	705.6594
1996	499.8275	143.0535	3.49	0.001	217.3243	782.3307
1997	543.5065	145.5652	3.73	0.000	256.0432	830.9697
1998	620.6431	159.8413	3.88	0.000	304.9873	936.2989
1999	622.2224	177.3856	3.51	0.001	271.9199	972.5249



Globally we found that there is a non-linear relationship between the variables. From similar methods as above we determined that as gdp changes globally, initially the effect is as predicted, but as gdp grows and varies the effect of its magnitude experiences a peak where a countries economic size has the greatest effect on CO2. As economies develop the effect diminishes to a trough before rising slowly again. We believe that this effect is due to developing nations attempting to grow so they use less efficient/costly means to do so, but as they grow they can invest more into efficient capital and green energy. Not producing higher than the maximum could be indicative of efficient energy production, green-carbon-absorbing space, green energy, or nuclear power being present in an economy which are not only signs of a developed nation but would also contribute to less CO2 emitted. We assumed our sample data to be i.i.d and large ($n > 30$) which helps mitigate threats to internal validity. Also due to the nature of our research question we do not have to worry about the threat of reverse causality in our data because it's unlikely that CO2 emissions would determine GDP. In terms of external validity, we are not confident that this research has much use outside of an environmental/economic sense since the results of these tests would most likely be used to inform policy decisions and change environmental protocols based on global economic conditions.

Conclusion

We can see that Economic Growth does have an effect on CO2 Emissions. The three models we used display how this effect varies from country to country depending on the size of their economies. The data tells us that countries with larger economies do not have a linear relationship between Economic Growth and CO2 Emissions, while countries with smaller ones do. One explanation for this is that countries with larger economies can invest more into new energy sources, whether it produces CO_2 emissions or not. Another explanation for this is that these countries would be able to invest more money into making our current systems more efficient so that they produce more energy output per unit of CO_2 emitted. In countries with smaller economies, the linear relationship is not too surprising. As these countries grow, they search for new industries that could contribute to their economies. Many of these industries that smaller economies attract are often manufacturing based which leads to more emissions being released. This relationship in countries with small economies is similar to what was discussed in "The Nexus between Carbon Emissions, Energy Consumption, Economic Growth and Changing Economic Structure in India," by Chandrima Sikdar and Kakali Mukhopadhyay where it is mentioned that the transition in India's Economy from Agricultural to Service based led to an increase in manufacturing, which in turn led to more emissions being released. Globally, we see that as a country with a small economy grows, GDP affects CO_2 emissions at a diminishing rate until they reach a point of peak CO_2 emissions. When countries hit this peak they can invest more into new technologies, green energy, and the creation of new environmentally friendly policies. This in turn leads to the country's emissions dropping to a minimum before going back up, but the amounts of CO_2 emitted will never hit their initial peak again. In the future, we could improve our model by adding variables on manufacturing numbers (Plants, Factories, and Refineries), rules and regulations passed by countries, and energy sources (Nuclear, Coal, etc.).

Citations:

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