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The Effect of Economic Growth on CO2 Emissions

Parker Jackson

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George Fox University

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Abstract

This study looked at the effect of economic growth on the CO_2 emissions of each U.S. state. Data from all 50 states and Washington D.C. was collected from multiple sources across the years of 1990 to 2017. This data was tested using Ordinary Least Squares (OLS) regressions to test the hypothesis that there was a positive causation between the growth of the economy and an increase of CO_2 Emissions. The results of this study were that there was a negative relationship between the growth of the economy, based on GDP per state, and the amount of CO_2 emissions produced. However, for a state, which may not have the resources to consider decreasing the energy consumption, there was a positive causation between economic growth based through the population and the total CO_2 Emissions. The theory was developed that GDP increases to a point where the amount of energy consumed does not matter, because there are more solutions available to mitigate CO_2 Emissions.

Keyword: Economic Growth, Emissions, GDP, Energy

JEL Classifications: O44, Q53, E2

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Introduction

Over the past several decades, the U.S. has been in a state of economic expansion and July 1st, 2019 became the longest stretch of economic expansion in U.S. history (Economy, 2019). During this growth, the population, average income, and GDP have all increased as new jobs have been developed and new technologies have driven innovation. Entire new markets have been created and the wealth and resources of the nation have increased exponentially. With this ever growing economy comes an ever growing need to power it. Energy consumption is also at an all time high, the United States produced approximately 101 quadrillion British thermal units (Btu) of energy in just the year 2019 alone (U.S. Energy Information Administration, 2020 May). This huge number can be compared to 100 times the number of ants currently living globally. The source of this energy varies from renewable energy, to coal, all the way to nuclear, but the main producer of energy today is fossil fuels. Since they mainly consist of carbon and hydrogen and are the cheapest to collect, they are burned in order to create heat which is in turn used for energy (U.S. Energy Information Administration, 2020 August). However, one of the large byproducts of this reaction is CO_2 which has started a controversial debate on how global emission affects our climate.

From the United States Environmental Protection Agency, the global CO_2 emissions have risen steadily since the early 1900s and have increased about 90% since 1970 (Global Greenhouse Gas Emissions Data, 2020). With the climate patterns changing and the weather reaching new extremes, more questions have begun to be asked on how our economy affects our environment and if measures can be taken to decrease the amount of CO_2 emission we produce. Since the economy shows no sign of slowing down, this begs the question: is there causation between economic growth and the amount of emissions we produce? This study attempts to answer that question as it investigates the possibility of a causal relationship between the growth of the economy and CO2 emission within each state of the United States. The growth of the economy is defined as a growth in GDP, average income, population, energy consumption, and a decrease in unemployment.

The prediction for this study is that there is a positive relationship between the growth of the economy and CO2 emissions, so as an economy grows, so does emissions. This does not transpose results onto nations in which fossil fuels are not a main source of energy production, but as for the United States an implication can be made that the causation between the growth of the economy and emissions was due to an increased need for energy. Thus, it was also predicted that the energy consumed would play a large role in total CO2 emissions as this would conversely imply that an increased need for energy means a growing economy.

Data Overview

Each independent variable is separated by year from 1990 - 2017 and covers all 50 states and the District of Columbia for a total of 28 periods and 51 cross sectional units used in a panel model. The data was gathered from multiple different sources which include the Bureau of Economic Analysis (BEA), Iowa State University (ICIP), and the U.S. Energy Information Administration (EIA). The variables are defined under specific ranges which are as follows:

CO2 Emissions - measured in yearly state emissions in each state per million tonnes

GDP - total annual gross domestic product per state in millions of USD

Unemp - the average annual rate of unemployment per state given as a percentage

Income - the yearly average income per state

EnergyCon - the yearly average energy consumption per state measured in Btu

Pop - is the annual total population per state

Table 1 was created to show the summary statistics for all independent variables used in the regressions. These summary statistics are represented in the units corresponding to the independent variable listed. Table 2 and Table 3 are a combination of regressions run to test the hypothesis. Table 2 is the results of a base linear regression to test the relationships of the independent variables as well as a square non-linear regression to test long term statistical significance. Table 3 is the results of 4 different regressions run through fixed effects panel models. With high f-statistics, these regressions are used to further test the veracity of the hypothesis with a more accurate model.

Methodology

The data was analyzed through Ordinary Least Squares (OLS) regressions in Gretl using Panel Models with fixed effects and robust standard errors. In theory, there is a relationship between each independent variable (GDP, Unemp, Income, EnergyCon, Pop) and the dependent variable (CO2 Emissions). Since economic growth can be defined as the increase in GDP, unemployment, income, and population, then our variables have a theoretical relationship with the amount of CO2 Emissions. Whether this relationship is significant or is positive or negative is discussed in further detail in the results. Thusly, the model that is used for the regressions will follow an exact or slightly modified representation of the relationship of the independent variables with the dependent variable. The model that we will be using to estimate is:

$$CO2Emissions = \beta_0 + \beta_1 GDP + \beta_2 Unemp + \beta_3 Income + \beta_4 EnergyCon + \beta_5 Pop + ... + u_i$$

Where β represents the coefficients of each independent variable. This relationship is what is further used to discuss economic significance once there is proven statistical significance.

Results

The regressions that were run are shown in Table 2 and Table 3 in the appendix. A total of 6 different regressions were run, 5 of which were non-linear which includes a sum of square non-linear. The regression in Table 2 column (1) shows significance at the 1% level for EnergyCons, but the coefficients vary dramatically in size and some of which are very small. This variation brews a suspicion that the regression may be non-linear and after creating a base regression (5), the standard error of the regression decreases, which implies that our model is closer to the actual data. Using a Panel model with fixed effects gives an F-statistic of 433.29 and a td_Chi-square of 516 for our base linear regression. These large statistical tests infer that states are fundamentally different for each model so both fixed effects and time dummies should be used in the analyzed regressions. Regressions (2), (3), (4), (5), and (6) are non-linear panel models with fixed effects and time dummies included due to the high F-statistic and td_Chi-square.

To start off, the base regression in column (5) shows significance for 4 different variables. The first is ln_EnergyCons which shows significance at the 1% level and it indicates that for every 1% change in energy consumption, the total CO2 emission will increase by 0.721%. The second is ln_GDP which shows, also at the 1% significance level, that for every 1% increase in the GDP measured in millions of dollars, then total CO2 emissions will decrease by -0.405%. Thirdly is ln_Pop which, following the trend, is significant at the 1% level; it indicates that for every 1% change in population, then CO2 emissions will increase by 0.473%. Lastly, ln_Unemp shows that for every percent increase in unemployment then CO2 emissions will decrease by -0.0619%, and this is significant at the 1% level. Since each independent variable is measured in different units, each variable has to be tested for economic significance separately.

Out of the 4 independent variables, it can be said that ln_EnergyCons, ln_GDP, and ln_Pop are all economically significant but ln_unemployment is not. A change of -0.0619% of CO2 Emissions is not economically significant, as unemployment does not change drastically and its increase would actually decrease emissions. Since the purpose of an economy is to decrease unemployment, then this relation is having a counter effect. In terms of economic significance for ln_EnergyCons, a positive increase of 0.721% per 1% increase in Btu is noteworthy. Since the United States consumed an estimated 100 quadrillion Btus of energy in the year 2019, then 1% of that would be 10 trillion Btus of energy. So with a 1% increase in energy consumption would result in a 7 trillion unit increase in CO2 emissions. Therefore, this large positive correlation can be used as a method to possibly reduce the total amount of CO2 emissions emitted as lowering the total energy consumed will have a large impact on emissions. This information provides the inverse relationship that a decrease in energy consumption will result in a decrease in emissions. As for GDP, there is a negative correlation unlike proposed in the hypothesis. This can be seen as a 1% increase in GDP causes a -0.410 decrease in CO2 emissions. However, this relationship is not always the case, as GDP is not statistically significant outside of energy consumption as seen in regressions in column (2) and (4) of Table 3. A relationship can also be seen in the sq_ln regression in Table 2 column (6), whereas as time goes on GDP has a greater negative effect on CO2 emissions. So the economic significance of the relationship between GDP and CO2 emissions is that as the GDP within a state increases, then it begins to reach a point where the amount of wealth of the state starts to combat the amount of energy being consumed. This effect can be seen in regression (3) in Table 3. If energy consumption is taken out of the picture, then there is a decrease in the amount of relevant information as seen by the adjusted R^2 which decreases by -0.1875. There is only significance between what relates to an individual person as to the amount of CO2 emissions, so a 1% increase in ln_Income and ln_Pop causes a 0.667% and 0.770% increase in emissions respectively. Thus, GDP is not significant in this regression, since the only dependency is on the population and income of each person, which are both focused on singular people instead of being focused on the economy as a whole which compiles each person through energy consumption. A similar relationship can be seen in regression (5) to a lesser extent, as an increase of 1% in ln_Pop increases CO2 emissions by 0.473. Therefore, the population of a state can be considered as economically significant and each individual has their own impact on emissions, but if the GDP is high enough to decrease emissions and lower the amount of consumption, then the impact of an individual person is lessened because it is included in total energy consumption. An important relationship to see in regression (6) is that all of the statistical significance is maintained from regression (5). This implies not only is there strong statistical significance, but the economic significance carries a strong correlation between each of the variables.

Considering the research hypothesis that economic growth has a positive causation with CO2 emissions, we can conclude that the hypothesis is not entirely true. A state may not have enough resources available to combat emissions and thus will have a relationship like that in regression (3). However, a state with enough resources to consider the amount of energy being consumed will also have enough resources to decrease the total emissions through the growth of their economy. Each individual still produces emissions, and this effect increases with income, but once an economy has more power over a state than an individual person, then individuals do not affect the total CO2 emissions as much as previously. This impact may be due to a state being able to invest more into sustainable energy sources or receive alternative energy from areas outside the state that are better equipped to create energy that does not produce as much CO2 emissions. Since the regressions show a 68.14% adjusted R^2, there is still data outside the collected data if a more definitive decision was to be made. However with 99% confidence, it can be said that the amount of energy consumed, total GDP, and total population all have economic significance in the total amount of CO2 emission produced in each state of the United States.

Summary

Since CO2 emissions are continually increasing alongside our economy, they have to be considered at some point when addressing future sustainable energy. At first glance, it appears that the growth of the economy is causing an increase in the total amount of CO2 emissions, but after running regression (5), this can be seen as not the case. An economy that is growing will eventually grow to a point where it can consider the amount of energy it is consuming and where that energy is coming from. This consideration, in turn, decreases the amount of CO2 emission being produced as projects are implemented to mitigate total emissions output. There is enough significance to consider the energy each state consumes and the economic standing of that state measured by the GDP. So, it seems that GDP is a good way to properly negate increasing CO2 emissions. Since decreasing the amount of energy consumed, decreasing population, etc. seem to be unreasonable for a large state, then increasing the GDP seems to be a great way to lower carbon emissions. Not only that, many areas of the economy will benefit from increasing GDP vs decreasing the other economically significant variables. Even at an individual level, there is a significant impact of the general population on CO_2 emissions. All of which can be considered when innovating new ideas to help decrease emissions. Creating solutions to lower each individual's impact on emissions, such as clean energy, will decrease the amount of impact from the population and might also decrease the impact of energy consumed in addition to the decrease created by GDP. Progress has already been made in markets such as transportation, with vehicles such as the Tesla models, to reduce the amount of emissions a person produces. By creating these models and viewing the data with a mindset to improve, even more progress can be made to a more sustainable future.

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Appendix

Table 1

Summary Statistics of Independent Variables

Variables	Mean	Median	S.D.	Min	Max
CO2_Emissions	108	77.3	111	2.62	718
EnergyCons	1.86E+03	1.38E+03	2.02E+03	126	1.34E+04
GDP	2.35E+05	1.30E+05	3.15E+05	1.15E+04	2.83E+06
Income	3.36E+04	3.25E+04	1.14E+04	1.34E+04	7.92E+04
Pop	5.69E+06	3.90E+06	6.38E+06	4.54E+05	3.94E+07
Unemp	5.62	5.3	1.84	2.3	13.7

Note: CO2_Emissions is measured in units per million tonnes, EnergyCons is measured in Btu, GDP in millions of dollars, Income in average income, Pop in number of people, Unemp in the rate of unemployment.

Table 2

Regression Results

Dependent Variable: CO2Emissions		Dependent Variable: sq_ln_CO2Emission	
Regressor	(1)	Regressor	(6)
EnergyCons	0.0500*** (0.0254)	sq_ln_EnergyCons	0.407*** (0.0440)
GDP	-1.9e-05 (1.412e-05)	sq_ln_GDP	-0.696** (0.0317)
Income	0.000166 (0.00016)	sq_ln_Income	0.0427 (0.0497)
Pop	2.478e-07 (1.99e-06)	sq_ln_Pop	0.0825* (0.0449)
Unemp	-0.243 (0.308)	sq_ln_Unemp	-0.112** (0.0432)
Constant	15.021* (8.9003)	Constant	-15.76 (9.825)
Summary Statistics			
R^2	0.9977	R^2	0.9975
Adjusted R^2	0.764	Adjusted R^2	0.7127
SER	5.427	SER	0.4266
F-Statistic	365.393	F-Statistic	451.484
td_Chi-square	146.075	td_Chi-square	516.007

Table 3

Regression Results continued

Dependent Variable: ln_CO2Emissions

Regressor	(2)	(3)	(4)	(5)
ln_EnergyCons	0.747*** (0.102)	0.683*** (0.0889)		0.721*** (0.0963)
ln_GDP	-0.102 (0.0814)		-0.216 (0.147)	-0.405*** (0.138)
ln_Income		-0.158 (0.151)	0.666*** (0.210)	0.279 (0.191)
ln_Pop		0.0898 (0.131)	0.770*** (0.197)	0.473*** (0.164)
ln_Unemp		-0.0519** (0.0206)	-0.00039 (0.0309)	-0.0619*** (0.0213)
Constant	0.694 (0.615)	-0.316 (1.93)	-11.51*** (2.824)	-6.085** (2.50)
Summary Statistics				
R^2	0.9971	0.9971	0.9957	0.9973
Adjusted R^2	0.6562	0.6603	0.4939	0.6814
SER	0.05774	0.05744	0.0701	0.0556
F-Statistic	520.964	400.739	782.555	433.249
td_Chi-square	286.605	363.642	763.495	516.007