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# The Impact of Renewable Energy Investments on the U.S Growth Rate of GDP per Capita

## Introduction

Renewable and alternative energy have been frequent topics of interest in the media, especially with regards to political campaigns that promise to tackle global warming. In June 2017, the United States withdrew from the Paris Climate Agreement, a voluntary effort between 200 nations to reduce greenhouse gas emissions to combat climate change.[1] President Trump justified this decision with the claim that the accord would bring "permanent disadvantage" to the United States, including negative economic impacts such as job losses and exorbitant costs— consequences that may not seem worth the collective effort.[2] As implied by President Trump, the major benefit of switching from traditional energy consumption, such as fossil fuel and natural gases, to utilizing "clean" energy focuses solely on the environment. However, if we are able to show that renewable energy can produce economic benefits, perhaps it may provide a better argument for championing alternative energy sources and incentivize countries to tackle climate change. In 2014, around 81% of the world's primary energy was produced by oil, natural gas, and coal.[3] This is a significant concern, since oil and gas reserves are estimated to deplete by 2042, and coal reserves by 2112 (Singh and Singh, 2012).[4]

To ascertain whether transitioning towards renewable energy can produce economic benefits, we created a model to estimate the potential relationship. Using data FRED (Federal Reserve Economic Data) and the US Energy Information Administration, we see that both GDP per capita and the production of renewable energy have been increasing with time (Figures 1 and 2).

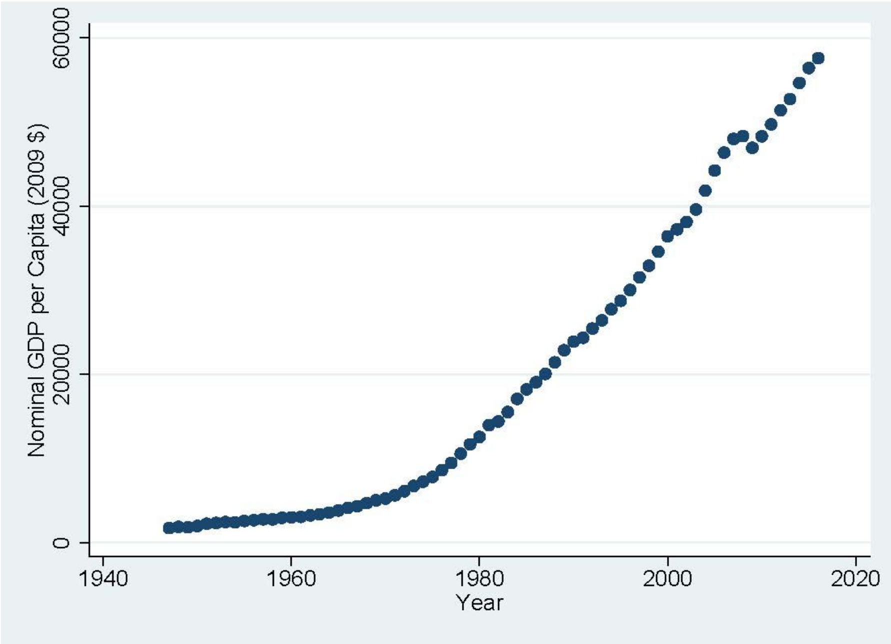



*Figure 1: Nominal GDP per Capita (2009 $) over time. Data retrieved from FRED (Federal Reserve Economic Data).*

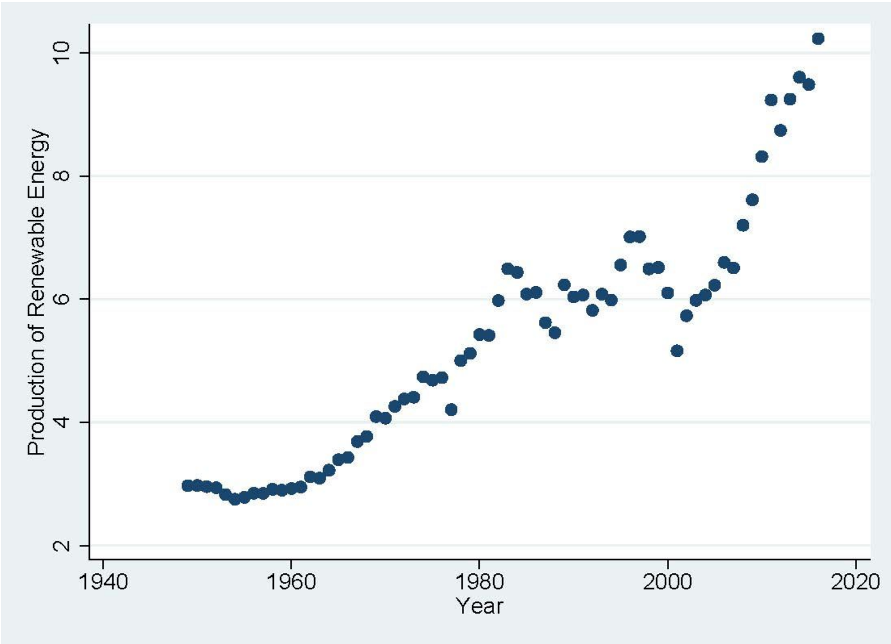



*Figure 2: Production of Renewable Energy over. Data retrieved from the US Energy Information Administration.*

Wiesmith and Golde (2015) suggest that investing in renewable energy will have positive impacts on standards of living. However, the consequences are mixed: social benefits outweigh social costs, whereas private costs outweigh private benefits.[5] They state that investing in renewable energy will lead to improvements of rural areas by promoting domestic production of energy, thereby bolstering GDP per capita. According to Pollin, Heintz and Garrett-Peltier (2009), spending on clean energy will have a greater impact on job creation in the United States, compared to spending the same amount of money on high-carbon fuel.[6] This is because investing in renewable energy requires a large portion of its investment to hire people and buy capital. They also state that investing in non-renewable energy requires considerable spending on imports, which negatively affects GDP. By investing in renewable forms of energy, energy production becomes more domestic and will thus boost GDP.

We hypothesize that investments in renewable energy will have a greater positive impact on GDP per capita than investments into traditional forms of energy. Investing in renewable energy will decrease the need for importing non-renewables, expand employment levels and create further social benefit by increasing social welfare and reducing negative externalities, such as pollution. However, due to the lack of accessibility for investment data, we decided to use data on renewable energy production instead. The quantification of energy production can be interpreted as a result of investments. By measuring the effect of renewable energy production on GDP per capita, and comparing it to the effect of traditional energy production, we will be able to uncover economic benefits that may provide a greater incentive for countries to adopt renewable energies.We chose to focus our study on the United States of America, given that the United States is a leading example of a developed country with a strong capitalistic market. Measuring the impact of renewable energy investments in the United States could carry over to other countries that operate under similar market structures.

We find that the investing in renewable energy does not produce any significant increase in GDP per capita and that the modeled relationship we captured indicate inaccuracies from the varying significance of control variables and exceptionally high R-squared values.

**Empirical Methodology**

$$GDPPC = \beta_0 + \beta_1 renewable + \beta_2 traditional + \beta_3 nuclear + \gamma_4 X_1 + \delta_5 X_2 + \varepsilon_6 X_3 + u$$

In order to assess the impact of renewable energy production on the growth rate of GDP per capita (*GDPPC_g*), we first began with a simple linear regression with the % change in renewable (*renewable_g*), traditional (*traditional_g*), and nuclear (*nuclear_g*) energy production [1]. Nuclear energy production was added because it does not belong in renewable nor traditional forms of energy. We expect all three slope coefficients to be positive because the production of energy, regardless of form, should have risen from investments, which contribute to GDP. In consideration of the other factors known to contribute to GDP, we added control variables $X_1$ for consumption (*consumption*), government spending (*gspending*), net export (*nexport*), and investment (*investment*). The investment data includes energy investments. Unfortunately, since we were unable to find data on energy investments, we could not create a non-energy investment variable. *Consumption*, *gspending*, *nexport*, and *investment* are contributors to GDP in the short run macroeconomic theory of the Keynesian Cross, and are predicted to have a positive coefficient. To be uniform with the dependent variable, the newly introduced variables are also in % change format.

Additionally, we decided to include the growth rate of the labor force (*labor_growth*) and population (*pop_growth*) as another set of control variables $X_2$. We predict the coefficients of both variables to be positive because an increase in the labor force would lead to an increase in output according to the long run Solow Growth Model, and a greater population would create more participants in the economy and boost GDP.

In the final set of control variables $X_3$, we controlled for any unobservable factors that may influence our independent variables by using a time trend variable, *year*. Furthermore, we decided to include a one year lagged dependent variable, $GDPPC_{-1}$, as another control in our regression. The intuition behind the lagged control is that since the best indicator of today's GDP is last year's GDP, utilizing a lagged control would show the relationship between our explanatory and dependent variable while taking into account the rising trend of GDP and any potential omitted variable problems.

Throughout the process of modeling the regression, we wondered whether the relationship would change if we dealt with nominal values of the variables instead of percentage values. Thus, we will also run the same regression with nominal values, and the log form of nominal values— looking out for any differences between the growth rate regression and the logged nominal value regression. In the logged nominal value regression, data with negative nominal values, such as *nexport*, could not be logged and decreased our number of observations. To solve this problem we left *nexport* in its growth rate form to continue serving as a control. Furthermore, we were worried about the potential multicollinearity between total population and total labor force, and decided to remove *total_labor* in order to reduce multicollinearity whenever nominal regressions were conducted. We have also considered leaving *total_labor* within the regression because one could make the claim that total population and total labor force differ due to the labor force being more sensitive to economic factors such as the business cycle or unemployment rate. However, we do not believe that these factors are enough to make the difference significant, and have confirmed this by checking the correlation between the two variables, which came to be a striking 98.7% (Append. 1).

Additionally, we considered adding an additional time dummy interaction variable, *renewable* * $Y_{15}$, which would signify whether the production of renewable energy in 2015, the year of the Paris Climate Agreement and the finalization of the Clean Power Plan, had a significant effect on GDP per capita. However, because our data only goes up to 2016, any significance found on the interaction variable's coefficient would not be reliable. On the other hand, we did want to explore the possibility of energy production from the year before having an impact on GDP per capita, and so we created an additional one year lagged variable for all three energy explanatory variables in both our original regressions. The intuition behind the lagged model is that the production of energy in one year will influence the amount of investments received in the next year.

Lastly, we utilized robust standard errors to account for any potential heteroskedasticity in all our regressions. We would not encounter any time-invariant errors in our data as we only have one cross-sectional unit (the United States of America) and are not using panel data.

**The Data**

As a general representation of economic benefits, we chose GDP per capita as the dependent variable, *GDPPC*. Data was collected as GDP per capita from FRED (Federal Reserve Economic Data). To calculate the growth rate, the formula below was utilized:

$$GDPPC\_g = \frac{GDP\ Per\ Capita_2 - GDP\ Per\ Capita_1}{GDP\ Per\ Capita_1}$$

The independent variables, *renewable* and *traditional* measures the production of renewable and traditional energy, respectively. Data was collected from the US Energy Information Administration. The data ranges from 1949-2011, and is subdivided into 'Fossil Fuels' (consisting of Dry Natural Gas, Coal, Crude Oil, and NGPL/Natural Gas Plant Liquids), and 'Renewable Energy' (consisting of Hydroelectric, Wind, Solar, Geothermal and Biomass). All data is in quadrillion Btu (British thermal units). Therefore, we measure the independent variables as:

$$renewable = Hydroelectric + Geothermal + Solar + Wind + Biomass$$

$$traditional = Coal + Natural\ Gas\ (dry) + Crude\ Oil + NGPL$$

The control variables of *consumption*, *gspending* (government spending), *investment* (gross private domestic investment) and *nexport* (net export) are collected from FRED. Each of these variables have been transformed to reflect their respective growth rates using the same formula as *GDPPC*.

Data on the labor force growth rate was collected as total labor force (1000's) from FRED. To calculate the growth rate, the formula below was utilized:

$$labor\_g = \frac{total\ labor\ force_2 - total\ labor\ force_1}{total\ labor\ force_1}$$

The data on total U.S population (1000's) was collected from the World Bank. The same formula as *labor_g* was applied for *pop_growth*.

The final control variable is *Nuclear*, which measures the production of nuclear energy in quadrillion BTU. Data was collected from the US Energy Information Administration and ranges from 1949-2011. *Nuclear* accounts for the effect of nuclear energy production on *GDPPC*, and is incorporated into the model since nuclear energy is not characterized as renewable or traditional. A detailed descriptive statistics of the variables are listed on the following table:

Table 1 presents summary statistics for the data set. The top half of the table reports data on Nominal GDP figures, GDP per capita, the constituent components of GDP and their annual growth rates (consumption, investment, government spending and net exports). The second half of the table reports data on the production of three different forms of energy (traditional, renewable and nuclear) and their annual growth rates, along with the total US population and the annual population growth rate. Production of renewable energy (average growth rate of 2.03%) is growing approximately twice as much as production of traditional energy (average growth rate of 1.31%). Interestingly, the production of nuclear energy is growing at an annual average of 19.87%, much larger than the production of renewable and traditional energy.

*Table 1: Descriptive Statistics of Variables*

| Variable | # Observations | Mean | Median | St. Dev. | Min | Max |
|---|---|---|---|---|---|---|
| *NominalGDP* | 70 | 20097.64 | 14182.5 | 17964.55 | 1734 | 57591 |
| *GDPPC* | 69 | 0.053 | 0.048 | 0.032 | -0.029 | 0.137 |
| *consumption* | 70 | 13219.96 | 8677.5 | 12278.87 | 1124 | 39645 |
| *consumption_ growth* | 69 | 0.053 | 0.053 | 0.027 | -0.0253 | 0.105 |
| *gspending* | 57 | 2278.83 | 1735.5 | 1973.94 | 148.9 | 6269.7 |
| *gspending_gr owth* | 56 | 0.069 | 0.069 | 0.036 | -0.006 | 0.170 |
| *nexport* | 70 | -158.556 | -24.25 | 235.955 | -770.9 | 16 |
| *nexport_grow th* | 69 | -0.028 | 0.006 | 3.439 | -21 | 13.438 |
| *investment* | 70 | 958.984 | 606.1 | 955.865 | 37.1 | 3093.6 |
| *investment_g rowth* | 69 | 0.072 | 0.073 | 0.114 | -0.225 | 0.445 |
| *total_labor (1000s)* | 69 | 0.015 | 0.014 | 0.010 | -0.004 | 0.042 |
| *labor_growth* | 69 | 0.015 | 0.0139 | 0.010 | -0.004 | 0.042 |
| *traditional* | 68 | 53.039 | 56.63 | 9.301 | 28.748 | 70.207 |
| *traditional_g rowth* | 67 | 0.013 | 0.011 | 0.039 | -0.073 | 0.133 |
| *renewable* | 68 | 5.324 | 5.443 | 1.951 | 2.754 | 10.233 |
| *renewable_gr owth* | 68 | 0.021 | 0.011 | 0.059 | -0.154 | 0.189 |
| *nuclear* | 59 | 4.476 | 4.754 | 3.306 | 0.002 | 8.455 |
| *nuclear_grow th* | 58 | 0.199 | 0.052 | 0.423 | -0.082 | 2.333 |
| *total_pop* (1000s) | 57 | 249960.3 | 244499 | 42766.97 | 180671 | 323127 |
| *pop_growth* | 57 | 1.050 | 0.981 | 0.226 | 0.693 | 1.702 |

## Empirical Results

*Table 2: Regression Analyses on GDP per capita*

| *Variable* | [1] Growth Rate (N = 56) | [2] Growth Rate w/ 1 Yr Energy Lag (N = 56) | [3] Nominal (N = 57) | [4] Nominal w/ 1 Yr Energy Lag (N = 57) | [5] ln(Nominal) (N = 57) | [6] ln(Nominal) w/ 1 Yr Energy Lag (N = 57) |
|---|---|---|---|---|---|---|
| *renewable* | 0.0000362 (0.0121) | — | 95.536 (72.556) | — | 0.0146 (0.100402) | — |
| *traditional* | 0.0167 (0.026) | — | -2.955 (11.664) | — | 0.0538 (0.01901)*** | — |
| *nuclear* | -0.0015 (0.0022) | — | 354.343 (118.71)*** | — | 0.000553 (0.00213) | — |
| *renewable_1* | — | 0.00489 (0.119) | — | 71.820 (51.593) | — | 0.0134 (0.00918) |
| *traditional_1* | — | 0.0398 (0.0226)* | — | -25.353 (8.885)*** | — | 0.0167 (0.0154) |
| *nuclear_1* | — | 0.00072 (0.00177) | — | 225.484 (69.571)*** | — | 0.00415 (0.00237)* |
| *consumption* | 0.545 (0.0853)*** | 0.563 (0.0638)*** | 0.734 (0.135)*** | 0.723 (0.108)*** | 0.6802 (0.0778)*** | 0.578 (0.0754)*** |
| *gspending* | 0.140 (0.0458)** | 0.141 (0.0413)*** | 0.718 (0.477) | 0.614 (0.357)* | 0.0764 (0.0295)** | 0.0848 (0.0273)*** |
| *nexport* | -0.00037 (0.000142)** | -0.00039 (0.0000126)*** | 0.350 (0.462) | 0.557 (0.292)* | -0.000183 (0.000134) | -0.000162 (0.000191) |
| *investment* | 0.145 (0.0200)*** | 0.148 (0.0171)*** | 2.415 (0.516)*** | 2.450 (0.413)*** | 0.0952 (0.0172) | 0.1077 (0.0157)*** |
| *total_pop* | -0.00355 (0.00471) | -0.0022 (0.00454) | -0.0349 (0.0172)** | -0.0518 (0.0139)*** | -0.00546 (0.132) | -0.141 (0.146) |
| *total_labor* | 0.0814 (0.146) | 0.0564 (0.123) | — | — | — | — |
| $GDPPC_{-1}$ | -0.0564 (0.0564) | 0.0659 (0.0487) | 0.201 (0.0431)*** | 0.209 (0.0386)*** | 0.119 (0.0557) | 0.181 (0.0586)*** |
| *year* | -0.0000682 (0.0000848) | 0.00000 (0.0001) | 113.433 (61.577)* | 202.422 (41.373)*** | -0.00296 (0.00136) | -0.00067 (0.00157) |
| $R^2$ | 0.9766 | 0.9766 | 0.9999 | 1.000 | 1.000 | 1.000 |

$$GDPPC = \beta_0 + \beta_1 renewable + \beta_2 traditional + \beta_3 nuclear + \gamma_4 X_1 + \delta_5 X_2 + \varepsilon_6 X_3 + u$$

Standard Errors in parentheses.

* denotes significance at the 0.10 level

** denotes significance at the 0.05 level

*** denotes significance at the 0.01 level

Table 2 presents the results of four regressions ran on GDP per capita. In the growth rate regression [1], a coefficient estimate of 0.000036 for *renewable_g* suggests that a 1% increase in production of renewable energy leads to a 0.000036% increase on average in the growth rate of GDP per capita, which seems to be a practically small effect. Interestingly, a 1% increase in production of non-renewable energy (*traditional*) leads to an average of 0.0167% increase in GDP per capita, which is a greater effect, relative to renewable energy production. However, all energy variables are statistically insignificant even at the 10% significance level. Our controls for GDP (*consumption*, *investment*, *gspending*) are all significant with sizeable estimates, showing that they are important contributors to GDP per capita. Though we get significant estimates for nuclear energy while using nominal values, we cannot conclusively state that increasing production nuclear energy increases GDP per capita, since two of the model's controls are insignificant (namely *gspending* and *nexports*) . Assuming that the factors of GDP in macroeconomic theory should have an significant effect on GDP, this implies that the regression does not accurately capture the relationships we are trying to study.

Introducing a time lag for the three forms of energy changed some of the results of the initial regressions. Even though these results suggest that the production of renewable energy one year ago does not produce a significant change in GDP per capita today, regression [2] shows that production of traditional energy one year ago increases next year's GDP per capita by around 0.04%, which seems to be a practically sizeable effect, and is significant at the 10% level. When we decided to use lagged energy forms for the nominal values regression from regression [2], we found that all variables were significant at least at the 10% level, with the exception of *renewable*, further showing that production of renewable energy a year ago does not produce any significant increase in GDP per capita today. Interestingly, coefficients of -25.353 for *traditional* and 225.484 for *nuclear* suggest that a quadrillion BTU unit rise in traditional energy and nuclear energy from a year ago decreases GDP per capita by $25.35 and increases GDP per capita by $225.48 respectively. Both variables are significant at the 1% level, but with a $R^2$ of 1.000, the results might not be trustworthy. Since the regressions with nominal values had some insignificant controls, we decided to run the models in a log-log form. We created a histogram for the residuals of GDP per capita (see Append. X) and after judging them to be roughly normally distributed, we ran regression [3] and [4] again, this time using log forms for all energy variables and controls (regressions [5] and [6]). Using log forms of all variables still shows *renewable* to be insignificant, and even though *traditional* is significant in regression [5], only two of the controls are significant, and alongside an $R^2$ of 1.000, the regression results cannot be trusted.

During the estimation procedure, we encountered issues of multicollinearity, especially when trying to control for both population and labor force in the regression models with nominal values. To solve for this, we elected to remove *total_labor* from the regression (for both the nominal values regression and the corresponding log regressions) while keeping *total_pop*. Additionally, there may be further multicollinearity between *investment* and energy production variables, since renewable, traditional and nuclear energy are all proxies for investments into those respective types of energy.

Endogeneity may also exist, as there may be other factors that can affect GDP per capita within our error term. However, given the high $R^2$ values in all our regressions, we believe that our control variables are sufficiently behaving as controls.

To account for possible heteroskedasticity, all standard errors reported in Table 2 are robust standard errors.

## Conclusion

Alternative energy is a topic of great focus within today's political climate. However, the majority of benefits promised by using alternative energy has been skewed towards environmental responsibility. On the other hand, since the transition towards renewable energy will lead to job creation and domestic energy production, we believe that the production of renewable energy will have a significant effect on GDP per capita in the United States. To do so, we controlled for factors that directly contribute to GDP, such as consumption, government spending, net exports, and investment, and for factors that may have an impact on GDP per capita, such as the population and labor force. We ran regressions for both growth rates and nominal values, and showed that an increase in renewable energy production does not have a significant impact on GDP per capita. The control variables display varying levels of significance over our regressions, indicating a potential inaccuracy in capturing the relationship between the explanatory variables and the dependent variable. In accordance to this, the exceptionally high R-squared values of regressions question the significance of our results.

Although we are unable to report statistical significance on GDP per capita for the United States, future analysis on the impact of renewable energy on the economy should focus on multiple countries, especially those that have already implemented plans to tackle climate change in their respective countries, such as those in the European Union. By extending the scope of this study into multiple countries, the impact of renewable energy will be estimated with greater accuracy. Additionally, future studies could also quantify the impact of renewable energy on the climate of the countries mentioned above, to confirm that renewable energy does have a significant impact on the climate before anything else.

**Acknowledgements**

We would like to thank Professor Graham for his mentorship, and Grinnell College Economics department for the opportunity for us to conduct this study.

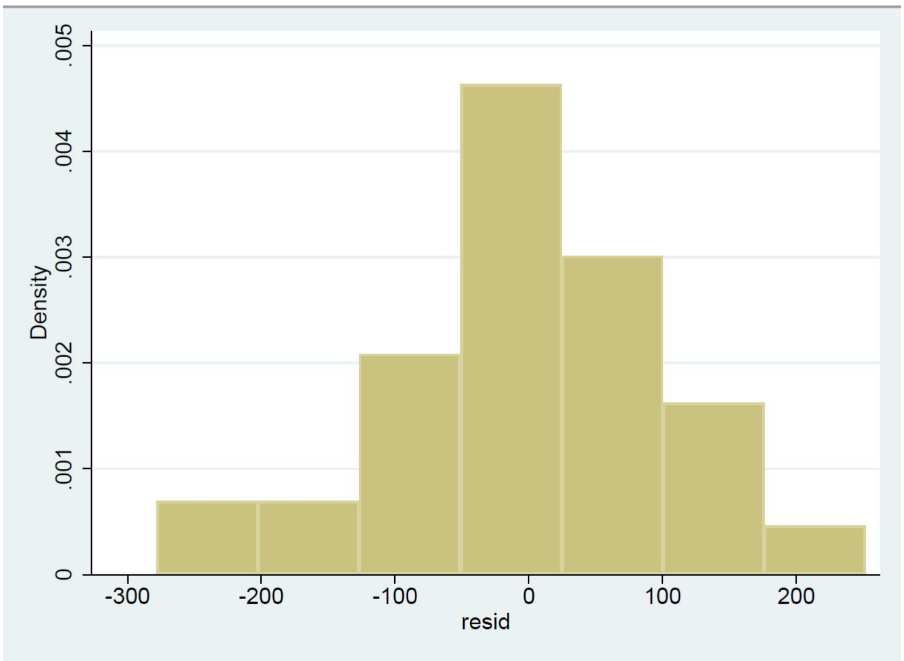
**Appendix**

*Appendix 1. Correlation between total_pop and total_labor.*

```
. corr total_labor Population1000s
(obs=57)

             | total_~r Po~1000s
-------------+------------------
 total_labor |   1.0000
Popula~1000s |   0.9869   1.0000
```

*Appendix 2. Histogram of residual values for Nominal GDP per capita*



**References**

[1] Chakraborty, B. (2017, June 01). Paris Agreement on Climate Change: US withdraws as Trump calls it 'unfair'. *Fox News*. Retrieved from: http://www.foxnews.com/politics/2017/06/01/trump-u-s-to-withdraw-from-paris-climate-pact-calls-it-unfair-for-america.html

[2] IEA Statistics OECD/IEA 2014. Fossil Fuel Energy Consumption (% total). *The World Bank*. Retrieved from: https://data.worldbank.org/indicator/EG.USE.COMM.FO.ZS

[3] Pollin, R., Heintz, J., Garret-Peltier, H. (2009 June). The Economic benefits of investing in clean energy. *Department of Economics and Political Economy Research Institute*. Available: https://cdn.americanprogress.org/wp-content/uploads/issues/2009/06/pdf/peri_report.pdf

[4] Singh, B.R., Singh, O. (2012 March 14). Global trends of fossil fuel reserves and climate change in the 21st century. *Intech*, *Fossil Fuel and the Environment, Chapter 8.* Available: https://www.intechopen.com/books/fossil-fuel-and-the-environment/global-trends-of-fossil-fuel-reserves-and-climate-change-in-the-21st-century

[5] Varinsky, D., Mosher, D., Schwartz, A. (2017, June 01). 5 Claims Trump used to justify pulling the US out of the Paris agreement— and the reality. *Business Insider*. Retrieved from: http://www.businessinsider.com/fact-check-trump-reasons-for-leaving-paris-agreement-2017-6/#a-negative-economic-impact-on-the-us-3

[6] Wiesmith, H., Golde, M. (2015). Social-economic benefits of renewable energy. *Technical University Dresden, Germany*. Available: http://www.seedengr.com/Socio-economic%20benefits%20of%20Renewable%20Energy.pdf

[7] Woolridge, J (2012). Appendix G, *Introductory Econometrics*.