Statistical Analysis of the Relationship between Ecologcial Footprint of Consumption and GDP for 174 Nations

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Abstract

The ability of a country to utilize its natural resources for economic prosperity has always been a vital component of any nation. However, an overall disregard for the sustainability of those resources has resulted in the Earth being at a net deficit in terms of the amount of resources ecosystems are able to to regenerate with respect to comsumption. This analysis aims to further understand the relationship between the economic strength of a country (measured by its GDP) and its environmental impact (measured by its ecological footprint). Furthermore, to measure differences in this relationship between countries running at an ecologcial deficit with respect to their domestic biocapacity and countries operating in ecological reserve. Using the statistical resampling techniques of permutation tests, a Jackknife estimator and non parametric bootstrapping with 2014 data from the Global Footprint Network, a strong correlation between GDP and ecologcial footprint was observed. However no difference in this correlation or average GDP was found between countries in ecological deficit versus those not. These results suggest that if the goal of reducing our global ecological footprint is to be achieved through national initiatives these solutions must be economically practical but are indeed possible as already demonstrated by several countries.

Contents

1 Introduction

Tackling the issues of natural resource over-consumption and sustainability have become more urgent than ever. As a species we are currently consuming more natural resources anually than the earth is able to regenerate for each year [1]. Though we have not yet exhausted our total supply of these resources, the pattern of over consumption means that we are increasingly having to tap into previously unaccessed sources. As a result we are running at a global deficit in a manner which cannot continue in perpetuity. While the natural resources of the planet a whole are being depleted, this over-consumption is not evenly distributed across countries and in fact we are able to measure the ecological balances of specific nations.

1.1 Ecological Metrics

One important measure for assessing the ecological impact of a country is through its **Ecological Footprint of Consumption** (EF_c), measured in global hectares. Simply stated the EF_c indicates the total amount of resource producing, or biologically productive area required to service all the needs of a population as well as abosrb the waste created within a given country, city, region etc [2]. It incorporates various factors such as the area needed for the production of primary goods, the space required for carbon dixode sequestration due to fossil fuel burning as well as accounting for the support of existing built infrastructure [2]. In addition to domestic resource requirements the EF_c also factors in the effects of imports and exports as they carry their own implicit ecological cost or benefit. A more detailed visualization of the factors which go into the EF_c are illustrated in Figure 1 [3].

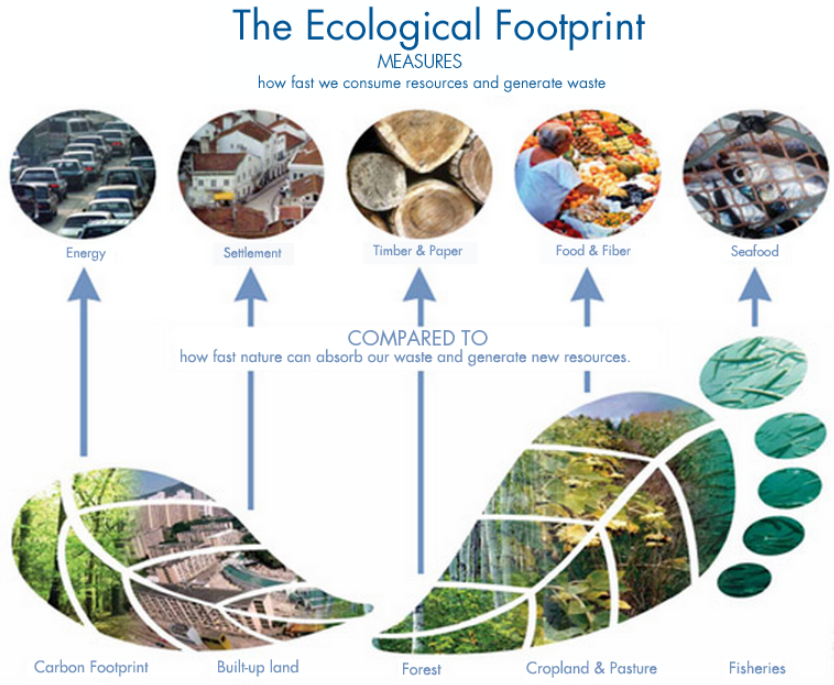


Figure 1: Ecological Footprint Calculation

In relation to the ecological footprint of a country it is also necessary to understand the concept of *Biocapcity*. This refers to the total amount of renewable resource producing space contained within a given region which for our purposes will always be a country. Hence, if a country is consuming natural resources at a greater rate than its various ecosystems are able to regenerate, its ecological footprint will be greater than its biocapacity. In this case we we say the country is in **ecologcial deficit** and can be called an **ecological debitor** [2]. Conversely, if the biocapacity of a country exceeds its ecologcial footprint of consumption we term the country an **ecological creditor** and say the country has an **ecological reserve** [2].

1.2 Data Set

The data set used in the proceeding analysis was sourced from the Global Footprint Network, a non-profit organization that tracks the ecological impact of over 200 countries, territories and regions. The data is collated from various UN and other international agency data sets as well as studies published in peer-reviewed science journals [2].

The data set contains a multitude of different metrics but for the purposes of this analysis I will focus on the ecological footprint of various countries and how it relates to their GDP. In order to ensure fair comparisons between countries I have chosen to use the per capita measures for both ecolological footprint and GDP (USD). As part of the comparison a distinction will also be made between ecological creditor nations and ecological debitor nations meaning the biocapacity per capita of each nation will be taken into account. While the full data set spans multiple decades the 2014 data was isolated for this study as it is the most recent year for which data is present. After removing countries for which any of the metrics of interest did not exist the final data set was reduced to 174 nations.

2 Objectives

The purpose of this analysis is to determine if there is a relationship between the GDP of a country and its ecological footprint. In particular a distinction will be made between ecological creditor and ecological debtor nations in an effort to investigate if and how that specific relationship is different between the two groups.

With the aid of statistical resampling techniques the specific problem statements being addressed are:

1. Is there a difference between the average GDP of an ecological debitor nation vs the average GDP of an ecological creditor nation?
2. How strong of a correlation is there between GDP and ecological footprint for the entire sample of countries studied?
3. Is the strength of the correlation between GDP and ecologcial footprint significantly different between ecologcial debtor and ecological creditor nations?

The motivation for performing this analysis is to understand whether the unsustainable use of natural resources within a country is an inevitable consequence of maintaining a prosperous economy. GDP is an oft quoted metric for assessing the economic prosperity of a country as it tracks value added to an economy an a yearly basis [4]. It should be noted that there are many complex factors that contribute to the economic strength of a nation and GDP does not capture the complete picture but provides a useful metric for analysis.

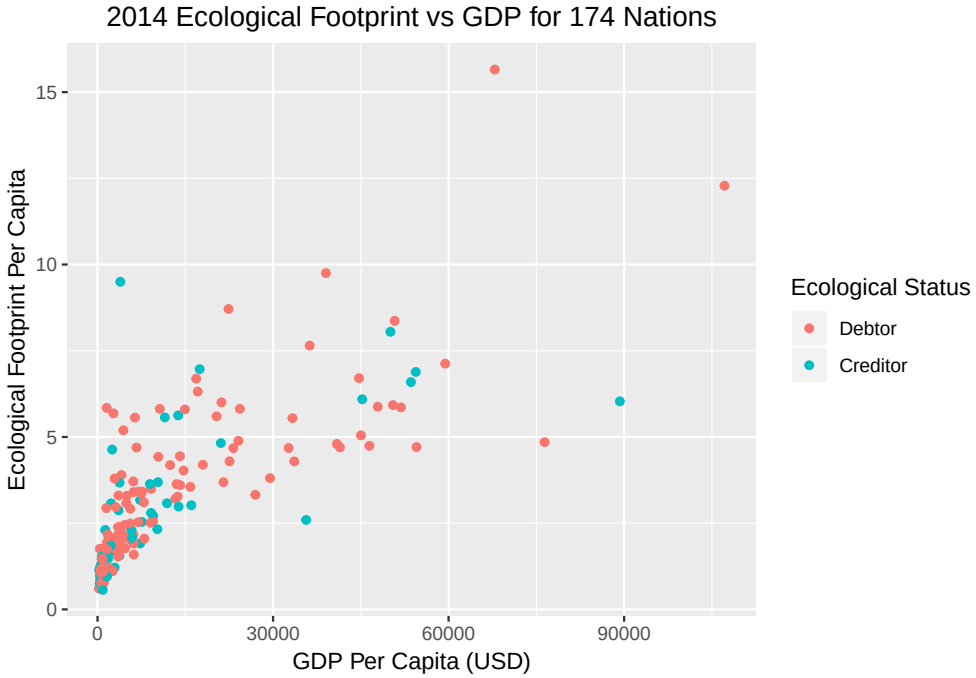
3 Hypotheses

Based on a review of past studies and similar analysis I believe that there is a significant correlation between the ecological footprint of a country and its GDP. An increase in both metrics was tracked for multiple European countries over several years as part of a joint 2007 report released by the Global Footprint Netork and World Wildlife Fund [5]. However I postulate that the there is no statistically significant difference in this relationship or GDP by itself between ecologcial debtor and creditor nations. My hypothesis on this is based on the fact that I believe it is possible for a country to effectively utilize its natural resources in a non environmentally harmful way while still maintaining economic growth. Several major European countries with strong economies are already some of the highest ranking nations in terms of the Environmental Performance Index which tracks a multitude of environmental performance indicators [6]. In addition, some of those same countries are also ecological creditor nations by the Global Footprint Network standard.

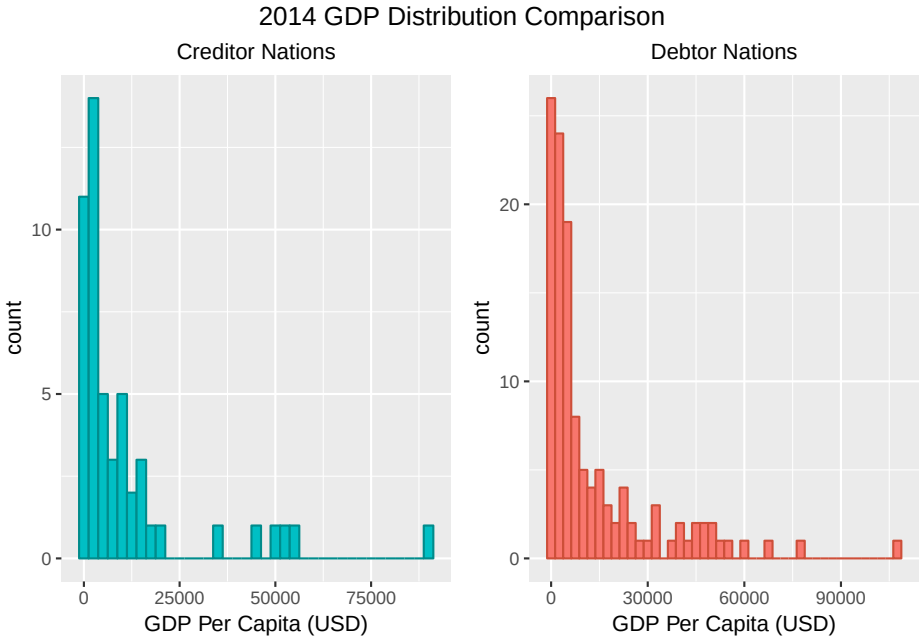
4 Analysis

4.1 Initial Data Insights

From a basic x-y scatter plot of the complete data set we can see that there appears to be an overall trend of increasing ecological footprint of consumption with GDP. However, no clear differences between creditor and debtor nations immediately stand out.



Visualizing the distribution of GDPs for creditor and debtor nations shows that they follow a similar pattern with the data being very right skewed in both cases.



4.2 Average GDP Comparison

To determine if there is a statistically significant difference in the average GDP of ecologcial debtor nations compared to ecological creditor nations I have chosen to use a standard permutation test. The quantity being measured for this test is the difference in median GDP between the two groups. The reason for using median over mean in this case is due to the fact that the data is heavily right skewed as a result of a few countries with extremely large GDPs. Hence, in order to avoid having these outliers skew the overall results the median GDP is a better representation of the the average GDP value.

The null hypothesis for this test is that there is no difference in the median GDPs of ecological debtor vs creditor nations.

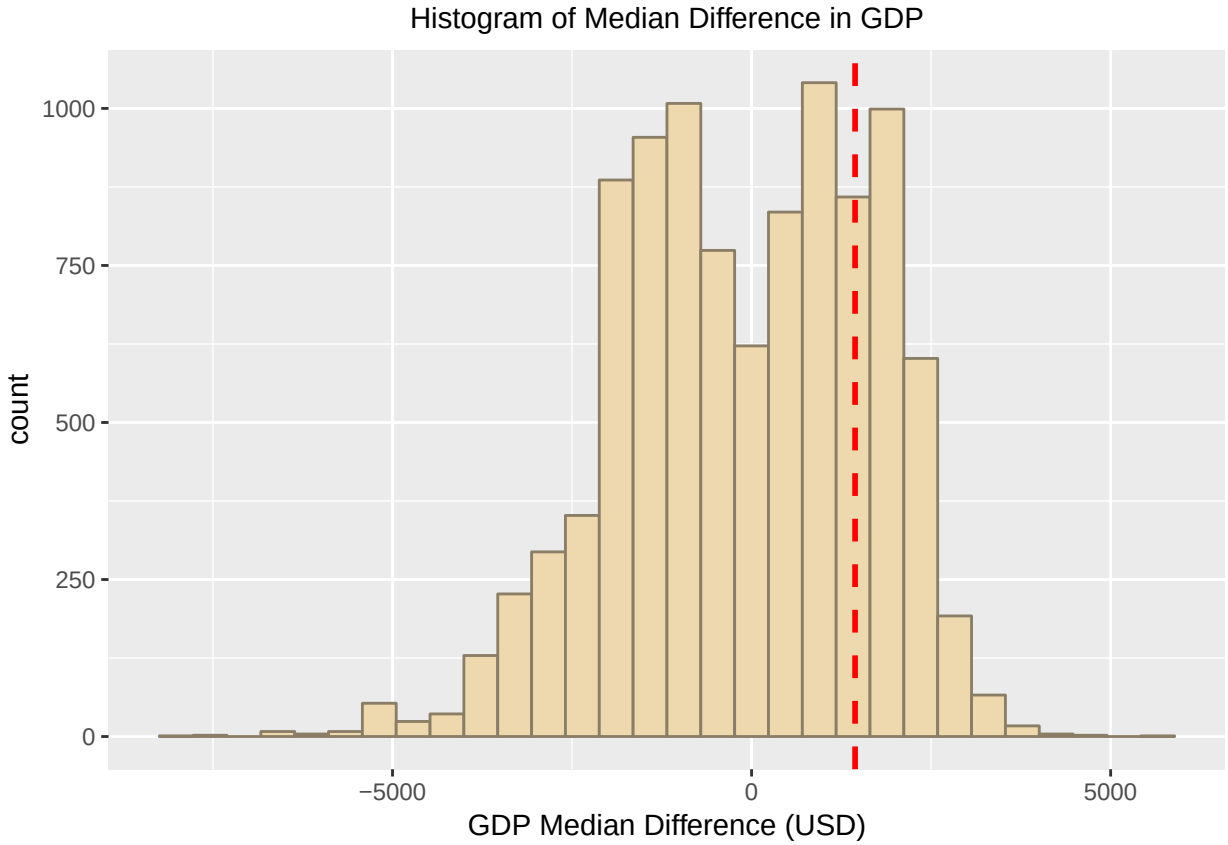
$H_0 : Med(X_D) = Med(X_C)$

The alternate hypothesis for the test is that the median GDP of ecological debitor nations is greater than that of ecological creditor nations.

$H_1 : Med(X_D) > Med(X_C)$

4.2.1 Results

Performing the permutation test with 10,000 rearrangements generated a distribution of median differences illustrated below. The median difference calculated from the original data is indicated by the dashed red line on the graph.



The calculated $p - value$ was 0.2376 which indicates we cannot reject the null hypothesis i.e. there is no statistically significant difference between the median GDP of ecologcial debtor nations compared to the median GDP of ecological creditor nations.

4.3 Ecological Footprint vs GDP Correlation

To analyse the relationship between ecological footprint and GDP for the entire data set I used the Jackknife method to estimate the Pearson correlation coefficient.

The Jackknife estimate for a parameter, θ, is given by:

$$\bar{\theta^*} = \frac{1}{n}\sum_{i=1}^{n}\hat{\theta^*_{(i)}}$$

Where:

n is the original sample size
$\hat{\theta^*_{(i)}}$ is i^{th} pseudovalue of the parameter which is calculated using the following formula

$$\hat{\theta^*_{(i)}} = n\hat{\theta} - (n-1)\hat{\theta_{(i)}}$$

Each value of $\hat{\theta_{(i)}}$ is calculated by removing the i^{th} data point from the original sample and calculating the parameter of interest (in our case correlation coefficient) from the new modified data set. $\hat{\theta}$ in the equation above represents the value of the parameter calculated from the original data set.

4.3.1 Results

With the Jackknife method the resulting estimate for the Pearson correlation coefficient with a 95% confidence interval is: **0.7477 ± 0.0977**

This result indicates that there is a strong positive correlation between the ecologcial footprint of a country and its GDP.

4.4 Comparison of Correlation Coefficient for Creditor vs Debtor Nations

For the final part of the analysis I investigated whether there was a difference in the strength of correlation coefficient (GDP vs ecological footprint) between the debtor and creditor nations. To do this I used a non parametric bootstrap method with 10,000 bootstrap samples.

The null hypothesis for this test is that there is no difference in the correlation coefficent for GDP vs ecological footprint between ecological debitor and ecological creditor nations.

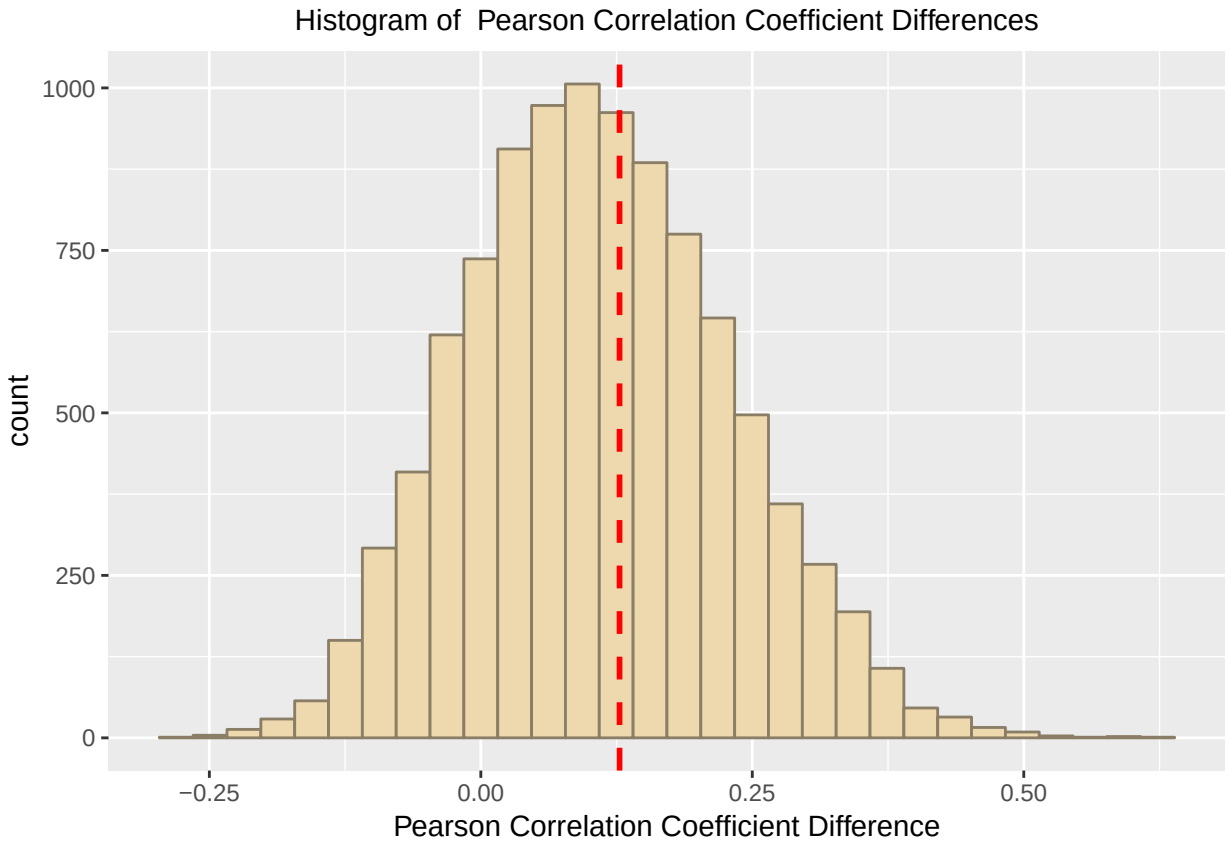
$H_0 : \rho_d = \rho_c$

The alternate hypothesis is that the correlation coefficient for ecological debitor nations is larger than that for ecological creditor nations.

$H_1 : \rho_d > \rho_c$

4.4.1 Results

The distribution of the bootstrap estimates for the correlation coefficient is shown in the histogram below with the coefficient value calculated from the raw data indicated by the dashed red line.



Due to the slightly long tails of the correlation coefficient distribution, the 95% confidence has been calculated using the simple method rather than the quantile method. A 95% interval calculated using the simple method is given by the following formula:

$$[LCL = 2\hat{\theta} - \hat{\theta^*}_{97.5}, UCL = 2\hat{\theta} - \hat{\theta^*}_{2.5}]$$

Where:

$\hat{\theta}$ is the true sample estimate of a parameter
$\hat{\theta^*}_{97.5}$ is the bootstrap estimate of the parameter at the 0.975 quantile
$\hat{\theta^*}_{22.5}$ is the bootstrap estimate of the parameter at the 0.025 quantile

Using this formula with the results from the non-parametric bootstrap test, the estimate of the difference in Pearson correlation coefficient is: **-0.0962 ± 0.4613**

From this result we can see that a zero difference in correlation coefficient lies within the 95% confidence interval meaning we cannot reject the null hypothesis. This implies that there is no statistically significant difference between the correlation coefficients of ecological debitor and creditor nations.

5 Findings and Interpretation

Overall the results from the statistical tests show that while there is a strong positive correlation between the GDP of a country and its ecological footprint, there is no statistically significant difference in terms of that correlation or median GDP between ecological creditor nations and ecological debtor nations.

From these results we can say that when considering strategies for lowering the ecological footprint of a country it is not possible to neglect economic concerns. As stated previously GDP is not a complete assessment

of a country's economy but assuming it provides one reasonable indicator for economic strength this analysis indicates that it is very heavily tied to the the environmental impact of a country.

While it is true that countries with a larger ecological footprint tend to have larger GDPs the results also suggest that there are many countries effectively managing their resources in ways that prevent overconsumption without being at an economic disadvantage.

6 Conclusions

The ability of many countries to balance their economic prosperity and ecologcial sustainability has been and will continue to be for a long time a challenging issue. These two concepts are inextricably linked and so while it is currently more important than ever to address environmental challenges associated with over consumption and pollution, the economic feasibility of solutions is an vital consideration. Several countries have already demonstrated a capability to maintain strong economies while not running an ecologcial deficit and so may provide frameworks for other countries to adapt moving forward. It is worth noting that not all countries are equal in their biocapcity and hence certain nations are less susceptible to overshooting their natural resource regeneration limits.Therefore looking at each country's ability to reduce its ecological footprint would need to be done on a case by case basis taking into account the individual biocapacities and population requirements.

References

1. Gabe Bullard. 2015 We've Consumed More Than the Earth Can Produce This Year. *National Geographic News*.

2. Global Footprint Network. In press. Data and Method - Global Footprint Network.

3. Global Footprint Network. In press. Ecological Footprint - Global Footprint Network.

4. Global Footprint Network. In press. FAQ - Global Footprint Network.

5. Global Footprint Network, World Wildlife Fund. 2007 Europe 2007 : Gross Domestic Product and Ecological Footprint.

6. Shubha Lakshmi. 2018 Top 5 Environmentally Sustainable Countries in the World. *BuzzOnEarth*.

Code Appendix

NB: The variable name for GDP has '2010' due to the fact that the GDP measurement used is an inflation adjusted metric measured against 2010 GDP.

Permutaion Test Comparing Population Medians

```
nr <- 10000 #Number of permutationss
st <- numeric(nr) #Array to store difference in medians
n1 <- nrow(defNations) #Number of debitor nations
n2 <- nrow(resNations) #Number of creditor nations
totalLen <- n1 + n2 #Total number of countries analysed

#Difference of median GDP from original data set
sttrue <-
  median(defNations$PERCAPITAGDP_2010_USD) - median(resNations$PERCAPITAGDP_2010_USD)

#Initialising counter
cnt <- 0

#Vector storing complete set of GDP values to sample from for permutaions
vect <- c(defNations$PERCAPITAGDP_2010_USD, resNations$PERCAPITAGDP_2010_USD)

for (i in 1:nr) {
  d <- sample(vect, totalLen)
  defp <- d[1:n1]
  resp <- d[(n1+1):totalLen]
  st[i] <- median(defp) - median(resp)
  if(st[i] > sttrue){
    cnt = cnt + 1
  }
}
```

Jackknife Estimator for Correlation Coefficent

```
theta <- cor(EFdata$PERCAPITAGDP_2010_USD, EFdata$EFCON_PERCAP)
thetai <- numeric(totalLen)
pseudov <- numeric(totalLen)

for (j in 1:totalLen) {
  thetai[j] <- cor(EFdata$PERCAPITAGDP_2010_USD[-j], EFdata$EFCON_PERCAP[-j])
  pseudov[j] <- totalLen*theta - (totalLen - 1)*thetai[j]
}

coeff_est <- mean(pseudov)
```

Non-parametric Bootstrapping Correlation Coefficient Difference

```
nb <- 10000 #Number of bootstrap samples

#Difference in correlation coefficients from original samples
corDiffTrue <- cor(defNations$PERCAPITAGDP_2010_USD, defNations$EFCON_PERCAP) -
  cor(resNations$PERCAPITAGDP_2010_USD, resNations$EFCON_PERCAP)
```

```r
zdef <- seq(1, n1)
zres <- seq(1, n2)
corDiffb <- numeric(nb)

for (i in 1:nb) {
  zdefb <- sample(zdef, n1, replace = T)
  zresb <- sample(zres, n2, replace = T)
  corDiffb[i] <-
    cor(defNations$PERCAPITAGDP_2010_USD[zdefb], defNations$EFCON_PERCAP[zdefb]) -
    cor(resNations$PERCAPITAGDP_2010_USD[zresb], resNations$EFCON_PERCAP[zresb])

}


#95% confidence interval for correlation coeffcient using Simple method
LCL <- 2*corDiffTrue - quantile(corDiffb, 0.975)
UCL <- 2*corDiffTrue - quantile(corDiffb, 0.025)
```