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## HSO201A Research Paper

Estimating Economic Growth using Deep Learning

# Abstract

The economic growth rate of countries is usually computed in terms of GDP per capita, which is largely influenced by macroeconomic factors, as depicted by certain case studies and papers. The aim of our paper is to present a model that predicts economic growth as the real GDP per capita, as well as changes in the real GDP of a country. We will be using data from the Data Bank for World Development Indicators of the World Bank. Post this, we will use python for data analysis, and then build a deep learning model using Artificial Neural Networks on the TensorFlow framework using the Keras library. We will also try to reason the findings by the correlation matrix and scatter plots and compare them with the previously done research and find similar patterns.

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# Introduction

Gross Domestic Product (GDP) is the final value of the goods and services produced within the geographic boundaries of a country during a specified period of time, normally a year. The real GDP is an important indicator of the economic performance of a country.

Economic growth can be defined as the increase in the inflation-adjusted market value of the goods and services produced by an economy over time. It is generally measured as the per cent rate of increase in real gross domestic product, or real GDP. The economic growth rates of countries are usually computed in terms of the real GDP per capita. Conventionally, our standard of living is measured by the number of goods and services accessible, thus we may even say that economic growth leads to an increase in our general standard of living.

However, research into the field of economic growth tells us that growth cannot occur in isolation. There exists a dependency of growth to a multitude of variables. It is a widely accepted notion between scholars that the GDP of a country acts as a good indicator of economic growth; the higher the GDP of an economy, the more vigorous its growth. There exist many macroeconomic factors that directly influence the GDP of a country and its growth rate as well.

Shiva S Makki’s and Agapi Somwaru’s published works[[1]](#footnote-0) in the American Journal of Agricultural Economics states how factors like foreign direct investment, trade, labour force, etc, directly influence the economic growth in developing countries. We roughly see a similar relation apply to other countries with different development levels as well.

On the basis of these hypotheses, we aim at building a model that estimates the real GDP per capita of a country, as well as the changes in real GDP per capita of a country based on relevant macroeconomic factors, using artificial neural networks -- barring the name of the country and the year.

# Literature Review

Many publications suggest a correlation between change in GDP per capita of a country with a myriad of macroeconomic factors. Such macroeconomic evidence not only provides dominant support for how macroeconomic factors have a positive influence on a country’s economic growth, but also tells us the significance these factors hold in determining the state of development of a country. Each of these variables have been chosen from different sectors like Education, Finance, Health, Infrastructure, Poverty, Environment. All of these factors have different intensities of significance when it comes to their influential power over altering the GDP per capita of a country.

Below we aim to describe in brief how each of these variables affect the GDP per capita of a country:

1. **Population :** Population is an important factor that helps us predict economic growth to a large extent. Broadly, a country with a growing economy would require a growing population as well, so as to maintain a balance between the producers and consumers. Data tells us that the success of Western economies can thus be largely associated with economic growth[[2]](#footnote-1). But we also observe that in countries with low income, population growth may be detrimental to the GDP in the short run, or medium run[[3]](#footnote-2), as growth on individual terms cannot be predicted by the gross domestic production. Thus, an important thing to mention is that a higher population, though may result in a higher GDP, is not indicative of improvement in living.
2. **Foriegn Direct Investment (FDI) :** Many published journals tell us about the importance of FDI on the GDP of a country. Usually, we observe a positive relationship between the two terms.[[4]](#footnote-3) FDI also significantly affects the GDP because ‘investment’ is a non-stationary element of GDP. Thus, estimating GDP is dependent on the total investment of a country. However, as FDI’s influence on the GDP is something that has been deliberated on for quite a while in academia, there also exist some results talk about how FDI affects the GDP positively only in the long run, and negatively in the short run, at least in the cases of developing countries.[[5]](#footnote-4) But we must also take into consideration a very logical argument that a high FDI ultimately results in a high GDP of a country as greater investment tends to bring forth a higher level of goods and services. Furthermore, evidence from both developing and developed countries[[6]](#footnote-5) tell us how FDI, not only promotes economic growth, but also indirectly influences economic growth via certain interaction terms, that interacting with human capital exerts a strong positive effect on economic growth.[[7]](#footnote-6)
3. **GDP Deflator :** As GDP rises and falls, the metric doesn't factor the impact of inflation or rising prices into its results. The GDP price deflator addresses this by showing the effect of price changes on GDP, first by establishing a [base year](https://www.investopedia.com/terms/b/base-year.asp) and, secondly, by comparing current prices to prices in the base year. Simply put, the GDP price deflator shows how much a change in GDP relies on changes in the [price level](https://www.investopedia.com/terms/p/price_level.asp). It expresses the extent of price level changes, or [inflation](https://www.investopedia.com/terms/i/inflation.asp), within the economy by tracking the prices paid by businesses, the government, and consumers.[[8]](#footnote-7)
4. **Gross Savings :** A rise in aggregate savings would yield larger investments associated with higher GDP growth. As a result, the high rates of savings increase the amount of capital and lead to higher economic growth in the country. When talking about the relationship between savings and economic growth, it cannot be denied that an increase in aggregate savings would boost investment and promote economic growth. This is more evident in developing countries where the largest source of financial capital stems from savings deposited in commercial banks. Past experiences have shown that low saving rates have led to deficits in the budget and balance of the country’s account.[[9]](#footnote-8)
5. **Unemployment Level :** There is a clear relationship between the two, and many economists have framed the discussion by trying to study the relationship between [economic growth](https://www.investopedia.com/terms/e/economicgrowth.asp) and unemployment levels. Economist Arthur Okun first started tackling the discussion in the 1960s, and his research on the subject has since become known as [Okun’s law](https://www.investopedia.com/terms/o/okunslaw.asp). Okun’s law investigates the statistical relationship between a country’s [unemployment rate](https://www.investopedia.com/terms/u/unemploymentrate.asp) and the growth rate of its economy. It is intended to tell us how much of a country’s [gross domestic product (GDP)](https://www.investopedia.com/terms/g/gdp.asp) may be lost when the unemployment rate is above its [natural rate](https://www.investopedia.com/terms/n/naturalunemployment.asp). One version of Okun’s law has stated very simply that when unemployment falls by 1%, [gross national product (GNP)](https://www.investopedia.com/terms/g/gnp.asp) rises by 3%. Another version of Okun’s law focuses on a relationship between unemployment and GDP, whereby a percentage increase in unemployment causes a 2% fall in GDP.[[10]](#footnote-9)
6. **Manufacturing value added :** In the paper Manufacturing and economic growth in developing countries, Adam Szirmai and Bart Verspagen analysed the relationship between Manufacturing value added and GDP per capita, for 88 countries, across the time period of 1950-2005. For the overall sample, they found a moderately positive impact of MVA, but when they split their samples for 1950-1970, 1970-1990, 1990-2005, they made a rather interesting observation. In comparison to all the other periods, the 1990-2005 period had the least impact on GDP per capita, i.e., it became less significant as compared to earlier times. Thus, to get the same positive impact in this time period, the labour force needed to be increased. This shows that contribution by MVA is positive towards GDP, although it is decreasing.[[11]](#footnote-10)
7. **Education expenditure :** Education is one of the key factors of promoting economic growth because of its role in enhancing human capital thus productivity. However, adverse macroeconomic conditions and increased competition for scarce public funds have reduced governments’ capacity to expand education expenditure to improve labor productivity. Also, Hanushek and Wößmann (2010) observed that it is not just enrollment rate that counts for economic growth, but rather the knowledge acquired through education. Therefore, policy makers must pay more attention to the quality of education. In effect, policy changes to increase education expenditures in developing countries have a positive impact on per capita GDP. Education improves workers‟ productivity, which in turn has positive effects on per capita GDP.

The findings indicate that expansion in education expenditure in developing countries affects per per capita GDP positively.[[12]](#footnote-11)

1. **Literacy Rate :** Countries with a high literacy rate usually have a high GDP per capita. Nations with low GDP frequently have lower literacy rates since the people in that country have less access to education, and children often have to work to help support the family.[[13]](#footnote-12) For those with low literacy, it is often a struggle to obtain jobs that pay above a living wage. Furthermore, once they are in these jobs, it is difficult to be promoted or get a pay raise, vastly limiting their job mobility. This means that these employees will have more difficulties supporting their families and are more likely to depend on supplemental means of doing so such as welfare or food stamps.[[14]](#footnote-13)
2. **Profit Tax :** A low tax-to-GDP ratio poses significant challenges for the government to spend money on creating necessary infrastructure in the economy and raise investment. A higher tax to GDP ratio means that an economy's tax buoyancy is strong as the share of tax revenue rises in sync with the rise in the country's GDP. India, despite seeing higher growth rates, has struggled to widen the tax base. Lower tax-to-GDP ratio constrains the government to spend on infrastructure and puts pressure on the government to meet its fiscal deficit targets.[[15]](#footnote-14)
3. **Net Migration Rate :** Immigration significantly increases GDP per capita in advanced economies. Both high- and lower-skilled migrants can raise labor productivity, suggesting that the complementarities uncovered in the microeconomic literature are also relevant at the macro level. An increase in the migrant share benefits the average income per capita of both the bottom 90 percent and the top 10 percent earners, suggesting the gains from immigration are broadly shared, even though high-skilled migration contributes to raise the income share of the top 10 percent earners.[[16]](#footnote-15)
4. **Prevalence of Tobacco use :** Tobacco use is one of the leading preventable causes of death, killing more than 7 million people every year. More than its enormous toll of disease, suffering, and death, tobacco use also burdens the global economy with an estimated US$ 1.4 trillion in healthcare costs and lost productivity each year.[[17]](#footnote-16) About 15% of the aggregate health care expenditure in high-income countries can be attributed to smoking. The economic burden of smoking estimated in terms of GDP reveals that smoking accounts for approximately 0.7% of China's GDP and approximately 1% of US GDP. As part of the indirect (non-health-related) costs of smoking, the total productivity losses caused by smoking each year in the US have been estimated at US$151 billion.[[18]](#footnote-17)
5. **Labour Force :** Labour force participation and gross fixed capital formation have a positive relationship with economic growth. When the labour force participation and gross fixed capital formation increases, then the economic growth also increases.[[19]](#footnote-18) As an economy's labor productivity grows, it produces more goods and services for the same amount of relative work. This increase in output makes it possible to consume more of the goods and services for an increasingly reasonable price.[[20]](#footnote-19)
6. **Human Capital Index (HCI) :** HCI is an internationally accepted metric that keeps a track of the basic elements of the human capital in different countries, or economies. It gives us insight into how efficiently a country is able to maximise the true potential of their entire population. More human capital is indicative of a sense of betterment in the overall life of an individual, as well as a higher income level for different countries.[[21]](#footnote-20) Thus, we can say that human capital is an important factor in terms of figuring out economic growth. A positive correlation between GDP and HCI is widely observed as well.
7. **Age Dependency Ratio :** It is the ratio of the number of dependents between the ages 0-14 and over 65, to the total population aged 15 to 64 - which may be referred to as the working class. An increase in the age dependency ratio could result in long term economic problems in the world, as there would exist a decrease in the labour force and an increase in the economically dependent population, thus slowing down the economic growth.[[22]](#footnote-21) Consequently, it has been hypothesised that the age dependency ratio and the GDP of a country are inversely correlated at different stages of development.
8. **Birth** **rate :** It refers to the number of births that occur per thousand people, per year. Majority of the studies concluded that high birth rates negatively affect economic growth. But what we noticed is high birth rates are not necessarily associated with lower economic growth. It could be positively associated when reaching a certain point. High birth rates means that the resources of the economy have to be spread across more people. These people create value, but since resources are decreasing, and They don't create much. Under the research of the National Research council (1986). There are both important positive and negative impacts of population growth. The impact of population on economic growth varies from country to country and, from time to time and situation to situation. [[23]](#footnote-22)
9. **Imports of goods and services :** When a country imports goods, it buys them from foreign producers. The money spent on imports leaves the economy, the importing activity of a country can influence a country's GDP, it's exchange rate,and its level of inflation and interest rates. If imports are greater than exports, then a country has to spend more to import goods and services. Country may run in deficit and make debts. Thus it negatively affects a country's growth. An increase in imports can bring down the GDP of an economy. To balance the trade we add the values of exports. A weaker domestic currency stimulates exports and makes imports more expensive. If exports are growing, but imports are declining, it may indicate that foreign economies are better shape than the domestic economy. [[24]](#footnote-23)
10. **Exports in goods and services :** Exports are the goods and services produced in one country and purchased by the residents of another country. Exports are added to the GDP.Businesses export goods and services where they have a competitive advantage. The more a country exports , the greater its competitive advantage. Exports increase jobs, bring in higher wages, and raise the standard of living of residents. A country uses the foreign currency to purchase its own currency. That decreases the money supply, making the local currency worth more and hence control inflation.[[25]](#footnote-24)
11. **Child mortality rate :** UNICEF defines it as the number of deaths of children under five years of age in a given year per one thousand children. The age parameter may vary among different reports. It has been observed that countries which had stronger GDP growth tended to see greater reductions in child mortality. [[26]](#footnote-25)
12. **Food Production Index :** For low income countries, GDP increase is accompanied by changes towards food consumption patterns with large gaps between supply and actual consumption. Total supply differs by a factor of two between low and high income countries. People in low income countries derive nutritional energy mainly from carbohydrates; the contribution of fats is small, that of protein the same as for high income countries and that of meat and dairy negligible. People in high income countries derive nutritional energy mainly from carbohydrates and fat, with substantial contribution of meat and dairy. Whenever and wherever economic growth occurs, food consumption shows similar change in direction.[[27]](#footnote-26)
13. **New business registered :** New businesses registered by Entrepreneurs are equally important when the economy is doing badly. When unemployment is high and the economy is contracting or stagnating, dynamic entrepreneurship could help turn the economy around. By developing novel products or increasing competition, new firms can boost demand, which could in turn create new job opportunities and reduce unemployment. New businesses are the fresh blood that keeps economies healthy and flourishing even as some individual firms fail.[[28]](#footnote-27)
14. **Industry in USD :** Industry is viewed as leading the sector to economic development. We can have economies of scale by applying advanced technology and division of labour and scientific management. So production and employment will increase rapidly. This will bring economic growth and capital formation. An economy is made from the composition of many different industries like agriculture, service, engineering, manufacturing etc. These industries provide so many benefits to the economy i.e. employment generation, production of goods and services, equal income distribution in the whole economy. [[29]](#footnote-28)
15. **Death rate :** It refers to the number of deaths per thousand people, per year. It's been said that increased job stress due to the better economy may play a role. Some researchers hypothesized that unhealthy lifestyles and road traffic accidents increased during good economic times. During times of economic growth, levels of social support for the elderly may change. Higher employment may mean that people have less time to help care for their older loved ones and those that continue to do so may be more stressed because they are working while caring for another adult.[[30]](#footnote-29)
16. **Life expectancy at birth rate :** It refers to how many years a person may expect to live. By definition, life expectancy is based on an estimation of the average age at which members of a given demographic group will be at death.the economists agree that, when the economic performance of a country — its GDP — is higher than anticipated, mortality rates are often higher than expected. The relationship is evident but the impact size is small. Adults are about 1 percent more likely to die in a year when GDP is about 5 percent above average. The correlation between GDP and economic development is not linear. When a country has a low GDP, the citizens don’t have enough money for essentials to survive. They are forced to buy the cheapest foods which don’t have the proper amounts of nutrients required to live long, healthy lives. Likewise,On the other hand, many countries with low GDP’s have a very high life expectancy. Possibility is that these countries are heavily involved in farming and agriculture. Thus, they have easy, cheap access to healthy food and other essentials to survive while not contributing much to the GDP. [[31]](#footnote-30)
17. **Agriculture, fishing, forestry :** The Agriculture, Forestry and Fishing sector comprises establishments engaged in growing crops, raising animals, harvesting timber, and harvesting fish and other animals from a farm, ranch, or their natural habitats. The agriculture and fisheries and forestry sector provides food and vital raw materials for the rest of the economy. It is itself a significant market for the products and services of the non- agricultural economy. As the sector grows and modernizes, it releases surplus labor to the industry and services sectors.Agriculture provides direct employment for farmers to sustain themselves and their families.This sector is still growing, but not enough to pull out the economy that has entered recession mode since the lockdown-hit first quarter of this fiscal.

The role of this sector to boost up the economy is vital. A country exports products of these sectors and hence the economy of a country rises. [[32]](#footnote-31)

# Objectives

The objective of this research is to use artificial neural networks to predict the economic growth (measured as changes in GDP per capita) of a country, with reasonable accuracy, considering the data of 264 countries over 20 years. To estimate our target variable, we will build 2 models that predict the real GDP per capita, as well as the changes in real GDP per capita, without taking into consideration the name of a country and the year in the feature set.

The name of a country should not affect the results produced, for we will divide the relevant factors of each country with their respective population -- thus decreasing the overall effect of the name of a country. As for all the factors given in USD, we shall make use of the GDP deflator to take inflation into consideration. This will in return decrease the overall effect of taking a particular ‘year’ into consideration. We aim to change the base year of every country to 2005 by dividing the GDP deflator values of each year by the GDP deflator of the year 2005 for each country, so that the GDP deflator has the same base years for all the countries. And in order to convert other nominal variables given in USD to ‘real’ variables, we divide them by the GDP deflator of the corresponding year and country.

Thus, instead of the year and the name of a country, our model will encompass other 20+ macroeconomic factors including gross savings, unemployment rate, education expenditure, profit tax, the amount of foreign direct investment and other factors mentioned in the table of description of variables.

Furthermore, we will split our data into train, validation and test sets in the ratio 80:10:10. We will then use the training data to train our model, the validation data to tune the hyperparameters of the model, and the test data to measure the mean absolute error and the coefficient of determination of our model.

Our main motive will be to train the deep learning model such that it predicts the change in GDP per capita with least possible mean absolute error and analyse the dependence of variables with the real GDP. With the help of our deep learning model, we will thus check whether the changes in real GDP per capita can be predicted as accurately as the real GDP per capita or not -- in order to prove our hypothesis.

# Hypothesis

Studies from several reputed journals depict a correlation between macroeconomic factors and economic growth. The premise of our hypothesis is to bring forth the idea that the GDP, or the changes in GDP of a country, does not depend on the name of the country or the year, but on the actual variables which directly or indirectly affect the GDP. These variables or factors have been chosen from various domains like health, literacy, infrastructure, etc, that are widely known to potentially affect the GDP.

In our study, we worked around two sub hypotheses in order to ascertain the target variable of our model, and to test and verify the central hypothesis of this paper. We conjecture that, our model, that disregards both the year and the name of the country, would not predict “changes in GDP” as well as it would predict only “the GDP'', given we take into consideration exactly the same variables.

We make this conjecture based on the fact that the variables we took into consideration did not give us the expected changes - as we only used data for a particular year, and not the respective net changes for each of the variables. We’ll build models that predict both changes in the GDP and the GDP alone, and note their observations to test the credibility of our conjecture.

To sum up, we hypothesize that the GDP can be predicted more accurately than the changes in GDP by our model, without using the name of the country or the year. Furthermore, we will also try to see the dependency between each of these features with the help of correlation matrices and scatter plots.

# Table of variables

|  |  |  |
| --- | --- | --- |
| **Variable** | **Interpretation** | **Source** |
| GDP per capita | The gross domestic product per capita, or GDP per capita, is a measure of a country's economic output that accounts for its number of people. It divides the country's gross domestic product by its total population. | World Bank[[33]](#footnote-32) |
| GDP Deflator | The GDP deflator gives us a measure of changes in prices of various goods and services that are produced in an economy.  It also helps us compare the real economic activities of two different years. | World Bank |
| The amount of foreign direct investment | A foreign direct investment (FDI) is an investment made by a firm or individual in one country into business interests located in another country. FDI measures the total level of direct investment at a given point in time, usually the end of a quarter or of a year. | World Bank |
| Gross Savings | Gross saving is disposable income less consumption. It can be calculated as gross national income less total consumption, plus net transfers. | World Bank |
| Unemployment Level | % of people from the labour force who are unemployed. | World Bank |
| Labour force | The labor force is the number of people who are employed plus the unemployed who are looking for work. | World Bank |
| Child Mortality Rate (per 1000 live births) | The probability of a child born in a specific year, dying before reaching the age of 5. | World Bank |
| New Business Registered | Business registration certificate issued by the Department of the Treasury or such other form or verification that a contractor or subcontractor is registered with the Department of Treasury | World Bank |
| Education Expenditure (USD) | Represents a part of the government's budget allotted to different educational activities, for any country. | World Bank |
| Age Dependency Ratio | The ratio of the number of dependents aged 0-14 and over 65, to the total population aged 15 to 64. | World Bank |
| Food Production Index | Food production index covers food crops that are considered edible and that contain nutrients. Coffee and tea are excluded because, although edible, they have no nutritive value. | World Bank |
| Industry (in US$) | Group of productive enterprises or organizations that produce or supply goods, services, or sources of income, including construction, value added | World Bank |
| Human Capital Index(HCI)  (Scale 0-1) | HCI score ranges from zero to one and measures the productivity as a future worker of a child born today relative to the benchmark of full health and complete education of a country. | World Bank |
| Imports of goods and services  (in US$) | Represents the value of all goods and other market services received from the rest of the world | World Bank |
| Exports of goods and services | Exports are the goods and services produced in one country and purchased by residents of another country. | World Bank |
| Life Expectancy at Birth (years) | In years, it is the age a person born in that year would expect to live if the average age of death did not change over their lifetime. | World Bank |
| Manufacturing, value added | % of total estimate of net-output of all resident manufacturing activity units obtained by adding up outputs and subtracting intermediate consumption with respect to GDP. | World Bank |
| Prevalence of current tobacco use | % of the population aged 15 years and over who currently use any type of cigarette (except E-cigarette) | World Bank |
| Profit tax | % the amount of taxes on profits paid by the business. | World Bank |
| Population | The total population of a country | World Bank |
| Literacy Rate  (% of people ages 15 and above) | The literacy rate is defined by the percentage of the population of a given age group that can read and write. | World Bank |
| Birth Rate  (per 1,000 people) | The birth rate is the ratio between the number of live-born births in the year and the average total population of that year. | World Bank |
| Net Migration Rate | The net migration rate is the difference between the number of immigrants (people coming into an area) and the number of emigrants (people leaving an area) throughout the year. | World Bank |
| Death Rate  (per 1,000 people) | Death rate is the ratio between deaths and individuals in a specified population during a particular time period. | World Bank |
| Agriculture, forestry, and fishing (in US$) | The branch of manufacture and trade based on the growing and/or harvesting of organic commodities. This includes all livestock and livestock products, food and other agricultural products, forestry and fishery products, and all associated services, value added | World Bank |

# Methodology and methods

The data was collected from the Data Bank for World Development Indicators of the World Bank. We used the features of 20 years (1996-2015) of 264 countries.

GDP per capita was calculated by dividing the GDP by the population of the country. After overviewing the data, we found a lot of missing values in the data. The rows having missing values for the GDP per capita were dropped, as we did not want to impute the target variable. We imputed the missing values using k-Nearest Neighbours with k=20.

The GDP deflator had different base years for different countries, so we changed the base year of every country to 2005 by dividing the GDP deflator values of each year by the GDP deflator of the year 2005 for each country.

All the nominal variables which were in dollars, including the GDP per capita, were converted to real variables by dividing them by the GDP deflator of the corresponding year and country.

A copy of the dataset was made and the change in real GDP per capita was calculated from the real GDP per capita in the 2nd dataset. The change in real GDP per capita could only be calculated for the years having the data of the preceding year also present, so we had to drop the data of the year 1996 in this new dataset.

Every further operation was done separately on the two datasets.

We plotted the target variables (real GDP per capita and its changes) and calculated their mean, standard deviation and mean absolute deviation.

Then we built correlation matrices for the real GDP per capita and its changes to analyse the relationships between the target variables and the features. We tried to reason the findings by the correlation matrix and compare them with the previously done research and find similar patterns. We also visualised the data using scatter plots between the target variables and the features to do the same.

Both the preprocessed datasets were saved so that two different models could be built, one for predicting the real GDP per capita and one for predicting its changes.

The datasets were divided into the feature set (X) and the target variable (y). The feature set can be seen from the table of description of variables above and the target variables were the real GDP per capita and its changes which are indicators of economic growth.

We split our data into train, validation and test sets in the ratio 80:10:10. We used the training data to train our model, the validation data to tune the hyperparameters of the model, and the test data to measure the mean absolute error and the coefficient of determination of our model.

We built a deep learning model using Artificial Neural Networks on the TensorFlow framework using the Keras library. The following network architecture and the hyperparameters were tuned based on the performance of the model on the validation dataset. We built the first model with 23 input units, 4 hidden dense layers having 1024, 512, 256 and 128 units respectively and an output layer having 1 unit which gives the estimated real GDP per capita. The second model had 23 input units, 3 hidden dense layers having 256 units each and an output layer having 1 unit which gives the estimated change in real GDP per capita. We used the Rectified Linear Unit (ReLU) activation function for each unit. We normalised the variables using Batch Normalisation before every layer to make the mean and standard deviation of each layer 0 and 1 respectively to make sure that the model trains well. We also used dropout layers with dropout rate=0.3 between the layers to avoid overfitting.

We used stochastic gradient descent using the Adam optimizer with learning rate=0.01 and a batch size of 128. We used the mean absolute error as the loss function as well as the metric for our model. We also used Early Stopping with min\_delta=0.1, patience=20 and restore\_best\_weights=True in the second model to prevent overfitting. We trained the first model for 500 epochs and the second model for 400 epochs. The second model stopped training after 120 epochs because of Early Stopping to prevent overfitting as the validation loss started increasing.

We evaluated our models on the test data and calculated the mean absolute error and the coefficient of determination for both the models.

# Mathematical Analysis

Formulae needed:

1. Correlation
2. Forward Propagation
3. ReLU activation function
4. Batch Normalization
5. Mean Absolute Error
6. Gradient Descent
7. Backpropagation
8. GDP Deflator
9. k-Nearest Neighbours
10. Coefficient of Determination (R squared)
11. **Correlation[[34]](#footnote-33)** - A correlation is a statistical measure of the relationship between two variables. The measure is best used in variables that demonstrate a linear relationship between each other.

The correlation coefficient is a value that indicates the strength of the relationship between variables. The coefficient can take any values from -1 to 1. The interpretations of the values are:

* -1 : Perfect negative correlation. The variables tend to move in opposite directions (i.e., when one variable increases, the other variable decreases.
* 0 : No correlation. The variables do not have a relationship with each other.
* 1 : Perfect positive correlation. The variables tend to move in the same direction (i.e., when one variable increases, the other variable also increases.

*=*

where,

– the correlation coefficient of the linear relationship between the variables x and y

– the values of the x-variable in a sample

x̅ – the mean of the values of the x-variable

– the values of the y-variable in a sample

ȳ – the mean of the values of the y-variable

1. **Forward Propagation** -

where,

: activation values of the previous layer. Dimension: [number of nodes in layer (l-1), 1]

𝝈 : the activation function being used (relu, sigmoid etc)

: activation values of the current layer. Dimension: [number of nodes in layer (l), 1]

: bias values of current layer. Dimension: [number of nodes in layer (l), 1]

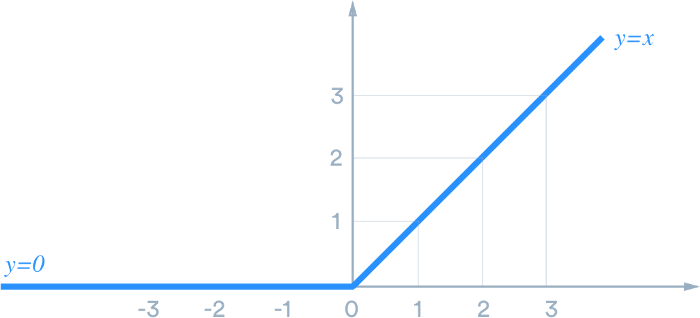
: weights from previous layer to the current layer. Dimension: [number of nodes in layer (l), number of nodes in layer(l-1)]

The information provided by the input layer propagates forward through the hidden layers, and produces the output. The architecture of a neural network consists of depth, width and activation function used. Depth is the number of hidden layers, while width is the neurons in each hidden layer.

1. **ReLU activation function[[35]](#footnote-34)** - The rectified linear activation function or ReLU is a piecewise linear function that will output the input directly if it is positive, otherwise, it will output zero. It has become the default activation function for many types of neural networks because a model that uses ReLU is easier to train and often achieves better performance. The ReLU is the most used activation function in the right now. The function and its derivative both are monotonic.

Formula: f(x)=max(0,x)

Graph :



1. **Batch Normalization** -

*=*

where,

X = activation values from previous layer with dimension : (number of nodes in the layer, 1)

Weights in deep neural networks are very sensitive towards any minor changes. Thus, if there is a high contrast in activations, weights are going to change rapidly and may cause overfitting.That is why batch normalization is a very important technique used in training deep neural networks. As we receive the activations from the previous layer, before going for a forward propagation, we normalize the whole layer by making the mean of the layer = 0, standard deviation = 1. This helps standardize the input before going to the next layer. This helps in training the network faster, makes it easier for training deep neural networks.

1. **Mean Absolute Error[[36]](#footnote-35)** - The Mean Absolute Error(MAE) is the [average](https://www.calculushowto.com/average-value-of-a-function/#def) of all absolute errors. The formula is:

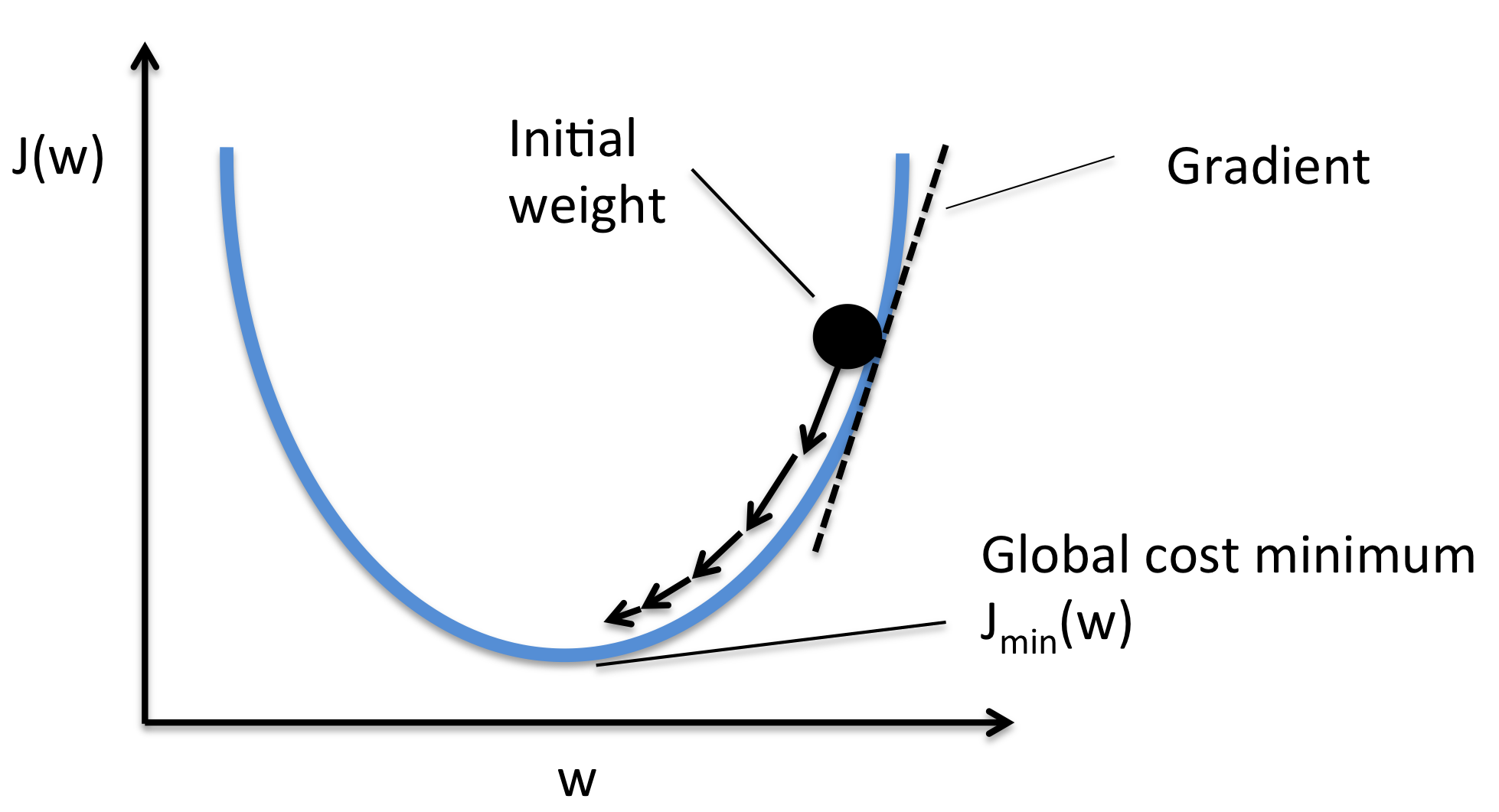
where:

= the number of errors,

∑ = [summation symbol](https://calculushowto.com/what-is-sigma-summation-notation/) (which means “add them all up”),

= the absolute errors.

1. **Gradient Descent[[37]](#footnote-36)** - The concept for gradient descent is very basic. We have a function J(w) which depends on weight w. To get the lowest possible value of J, we first find its gradient, and move along the gradient. We can move in 2 directions, but for our purposes, we will move in the direction where J decreases. The amount of shift we take is dependent on a hyperparameter called learning rate. The learning rate should be tuned with the model, as too low learning rate will take a lot of time to train, and too high learning rate can overshoot the value of J and will never lead to its minimization.



We will be using stochastic gradient descent which takes a small sample of the training data, called a minibatch, and optimizes the hyperparameters using gradient descent.

1. **Back Propagation[[38]](#footnote-37)** - Back-propagation is the essence of neural net training. It is the method of fine-tuning the weights of a neural net based on the error rate obtained in the previous epoch (i.e., iteration). Proper tuning of the weights allows you to reduce error rates and to make the model reliable by increasing its generalization.

Backpropagation is a short form for "backward propagation of errors." It is a standard method of training artificial neural networks. This method helps to calculate the gradient of a loss function with respect to all the weights in the network.

where,

= weighted input

= activations in layer

C = cost function

= weights in layer

= biases in layer

⊙ = dot product

1. **GDP Deflator** - The Gross Domestic Product (GDP) estimates the changes in prices of all the goods and services that may be produced in an economy. It is a measure of inflation that is widely accepted and utilised by economists, as it helps in comparing the inflation-adjusted economic activities or variables from one year to the other. Here, the effect of price changes on GDP is shown by, first, establishing a base year and, secondly, by comparing current prices to prices in the base year.

where,

Nominal GDP = the value of goods and services unadjusted for inflation Real GDP = the value of goods and services adjusted for inflation

1. **k-Nearest Neighbours** - k-NN is a Machine Learning algorithm that can be used for classification and regression predictive problems. KNN helps classify a data point based on how its neighbours are classified. In KNN, the K refers to the number of nearest neighbours that one must include in order to classify a data point. In our model, we use the KNN imputer to impute the NaN values in our data.

In this equation for the Euclidean distance, Xi and Yi refer to the coordinates of the data point.

1. **Coefficient of Determination (R Squared)** - R-squared helps us determine how well our regression line fits out data, with a value that lies between 0 and 1. The given R Squared formula compares the fitted regression to the possible ‘worst’ case model.

Here,

SSres = Sum of squares of residual

Where, yi = variable to be predicted

f(xi ) = predicted value of yi

SStot = Total sum of squares

Where, yi = value of the sample

ȳ = mean value of the sample

# Results

The statistics of the target variables are given below:

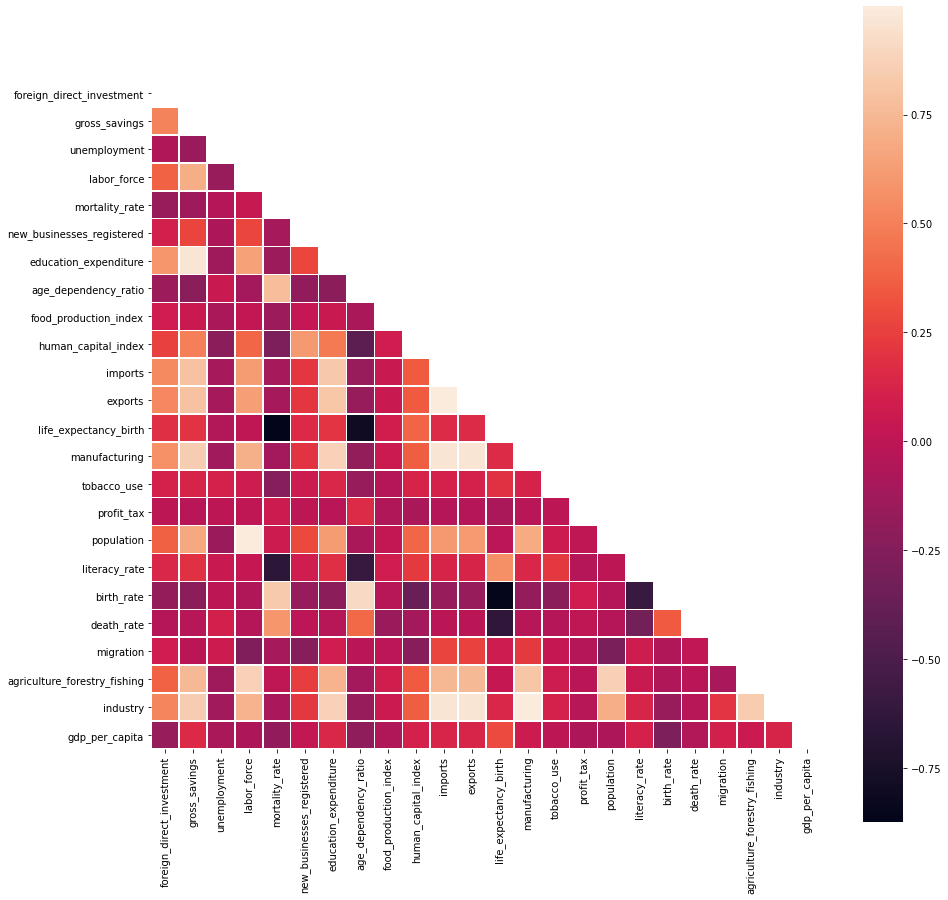
* Real GDP per capita:
  + Mean: 12126.134572076002
  + Standard Deviation: 26568.308328310643
  + Mean Absolute Deviation: 13347.679900928873
* Change in real GDP per capita:
  + Mean: -263.27408286000616
  + Standard Deviation: 10514.52190219185
  + Mean Absolute Deviation: 1376.3827631760414

After preprocessing the data using the above mentioned methods, we trained 2 different models, one for the ‘real GDP per capita’ and another one for ‘change in real GDP per capita’, and we found the following results:

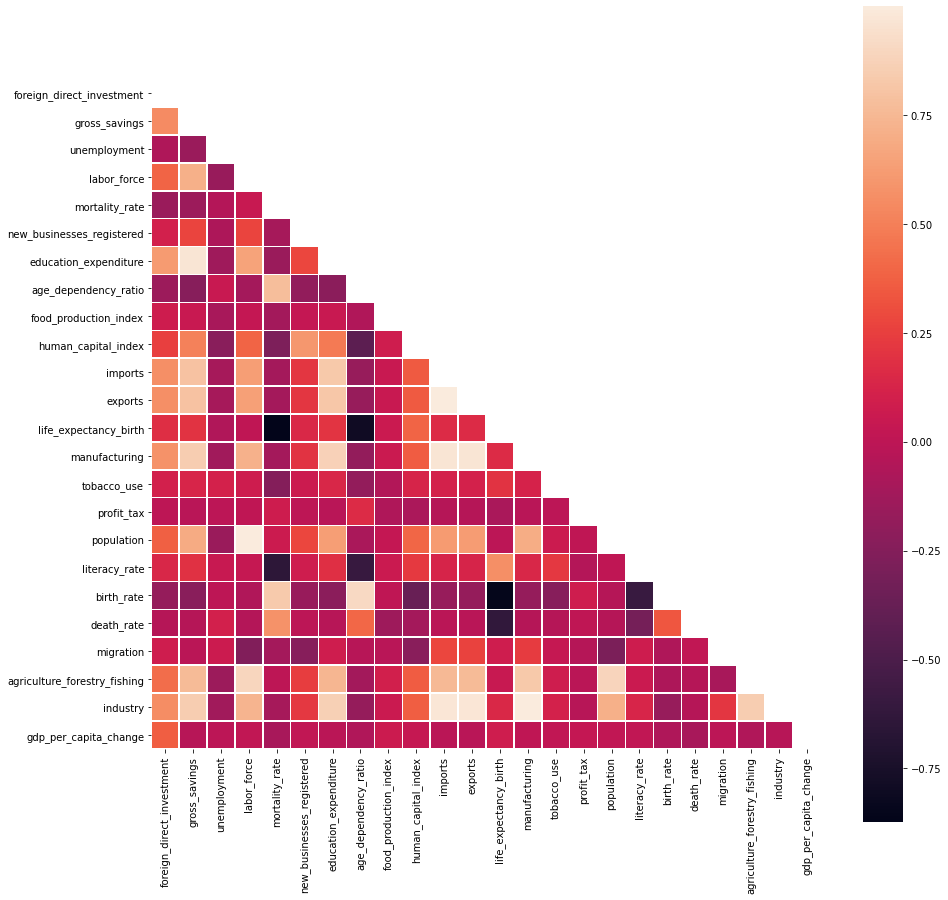
* Real GDP per capita:
  + Mean Absolute Error: 2103.056640625
  + **R-squared value = 0.895**
* Change in real GDP per capita:
  + Mean Absolute Error: 1230.848876953125
  + **R-squared value = 0.109**

As we can see from the R-squared values, our model was able to predict the ‘real GDP per capita’ but was unable to predict the ‘change in real GDP per capita’.

The correlation heatmap between the real GDP per capita and the features is given below:



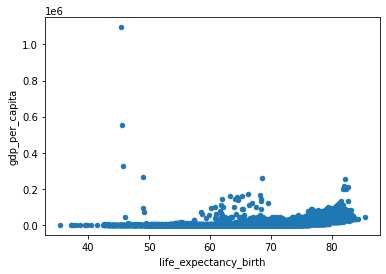
The correlation heatmap between the change in real GDP per capita and the features is given below:



Looking at the correlation heat maps, the real GDP per capita seems to have a strong correlation to life expectency and the change in real GDP per capita seems to have a strong correlation with Foreign Direct Investment.

Most of the scatter plots had a lot of noise in them, and hence no particular trend was seen. We think the source of noise was all the missing data that we had to impute.

For example, the scatter plot of the real GDP per capita vs life expectancy is given below:



The value of our target variable seems to be rising as we increase life expectancy rate after a certain value, but there seems to be a lot of noise in the data.

# Conclusions

The economic growth rate of countries is usually computed in terms of GDP per capita. Significant differences in the real GDP arise due to the varied values of independent macroeconomic variables like birth rate, imports and exports, literacy rate etc, across different countries. The purpose of this paper is to estimate the dependence of economic growth of a country in terms of these independent macroeconomic variables, barring the name of the country and a particular year. Using the dataset from the Data Bank of the World Bank, we further estimated our target variables with the help of the model which was based on artificial neural networks.

After training the data and the model for both real GDP per capita and its changes, the result revealed that there is an effective relationship between different parameters involved and the real GDP per capita of a country. We were be able to predict the real GDP per capita without using the name of the country and the year, and hence we were able to conclude that the real GDP per capita of a country can be estimated by simply using features obtained from various domains which can potentially affect the GDP, irrespective of which country’s or year’s data we are using.

However, our model was unable to predict the ‘change in real GDP per capita’, likely because we did not have the changes of the variables in our dataset which actually determines the changes in real GDP per capita rather than the values of that specific year. This proves that both our hypotheses were correct. The large amount of missing data seems to be the root cause of the error in predicting the real GDP per capita. Hence, we believe that if given the actual values of the missing data, the predictions could be further improved.

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