Unraveling Egypt's Net Migration Patterns: A Time Series Economical and Sociopolitical Analysis

Ramzy Bakir[1], **Seif Hegazy**[2], **Shady Ali**[3]

[1,2,3]Faculty of Computer and Information Sciences; [1,2,3]Egypt University of Informatics; [1]22-101024@students.eui.edu.eg; [2]22-101049@students.eui.edu.eg; [3]22-101195@students.eui.edu.eg

Prof. Mohamed Taher

***Abstract*—*This study investigates Egypt's net migration patterns from 1965 to 2022 using time series analysis and various regression models. By exploring correlations between net migration and economic indicators such as population, GDP, Foreign direct investment, and Unemployment, the research aims to uncover the driving forces behind migration trends in Egypt. Findings indicate a moderate positive correlation between net migration and total population ($r \approx 0.42$) and a negative correlation with GDP growth ($r \approx -0.33$). Other variables show weak correlations. The analysis suggests that regional conflicts influence inward migration, while internal instabilities, such as economic struggles and political unrest, drive outward migration. The study employs advanced regression algorithms, including Gradient Boosting and XGBoost, to predict net migration, achieving R^2 scores of 0.3919 and 0.3544, respectively. These results underscore the complex interplay of factors affecting migration and highlight the need for comprehensive policies to address these dynamics.*

Keywords*—*Egypt, GDP, Population, Net Migration, Inflation, Pearson's Correlation, Time Series Analysis, Regressors, Economics

1. Introduction

Migration has historically been a fundamental force in shaping human societies, civilizations, and cultures. An estimated 286 million people live outside of their countries of birth, including 32.5 million refugees as of mid-2022[27] . This complex process involves the movement of individuals across different regions, driven by a myriad of factors including economic opportunities, geographical conditions, and political developments. Egypt, with its rich history and strategic location, has long played a crucial role in various geopolitical events and has extended her arms to over more than 9 million immigrants, particularly from the Middle East and North Africa (MENA) region due to various regional disputes and conflicts. Concurrently, Egypt itself has experienced periods of instability, ranging from economic to political issues, leading to significant emigration. Notably, Egypt was one of the top 10 countries receiving remittances from 2010 to 2020[25].

Understanding net migration—the balance between incoming immigrants and outgoing emigrants—is essential for analyzing the demographic landscape of a country. Positive net migration occurs when the number of immigrants exceeds that of emigrants, whereas negative net migration indicates a higher number of departures than arrivals. Egypt's position as a pivotal point for both immigration and emigration reflects the dynamic nature of global migration patterns. By examining Egypt's migration data, we can uncover insightful trends that offer a window into the region's social and economic dynamics.

In light of Egypt's dynamic migration patterns and its experience as both a receiving and sending nation, this study aims to analyze the relationship between various economic indicators and net migration in Egypt. By examining trends in areas like GDP, GDP per capita, personal remittances, unemployment levels, and foreign direct investment, we can identify potential correlations between economic conditions and the movement of people. This analysis can provide valuable insights into the factors driving migration in Egypt.

To further explore these relationships, we will employ a machine learning technique called gradient boosting. This method will allow us to build a model that predicts net migration based on the chosen economic indicators. By visualizing the model's results, we can gain insights into whether these economic factors actually lead to increased immigration, emigration, or both in Egypt.

For the following economic indicators we will use in our analysis and modeling:

1. Population total
2. Population growth
3. GDP
4. GDP growth
5. GDP per capita
6. GDP per capita growth
7. Consumer price index

8. Foreign direct investment net inflows
9. Personal remittances received
10. Unemployment total
11. Net migration

We hypothesize the following:

- Is there a linear correlation between any of the mentioned economic indicators and Egypt's net migration?

  $H_0 : r = 0$

  $H_\alpha : r \neq 0$

- Can Egypt's net migration be predicted using a supervised machine learning algorithms on the economic indicators previously mentioned?

  $H_0 : R^2 = 0$

  $H_\alpha : R^2 > 0.35$

2. Related Works

in [22], the author attempts to model the net migration in Philippines from 2000 to 2021. They also explore the net migration relationship with other forces such as unemployment rates, gross domestic product growth rate, labor force participation, and population growth.

Several studies have investigated the relationship between migration and various economic and social factors. Research on Singapore highlights a significant positive correlation between net migration and international trade from 1960 onwards, emphasizing the role of favorable policies and global economic integration in shaping migration patterns [28]. Similarly, Ostojić et al. (2021) analyzed the economic determinants of net international migration using panel data from 136 countries over 30 years. Their findings reveal that unemployment negatively impacts migration, while education and migrant networks positively influence it. Additionally, they identified a complex relationship between GDP per capita and migration, suggesting an inverted-U pattern in economic development stages [16].

In the context of internal migration, a study in Bangladesh utilized census data from 1991 to 2011 to explore internal migration dynamics. The findings indicate that developed and urbanized cities like Dhaka and Gazipur have the highest in-migration rates, while northern and southern districts experience the highest out-migration rates. Significant factors influencing internal migration include activity rate, population density, and literacy rate. The study recommends comprehensive urban planning, decentralization, and rural development to address the challenges posed by high rural-to-urban migration [17].

Furthermore, an analysis of Spain from 1975 to 2013 examined the bidirectional relationship between migration, remittances, and foreign trade using Granger-causality analysis. The study found that export causes migration and vice versa, with net migration and international trade being treated as substitutes. Additionally, it was observed that higher remittances lead to further migration, and the reduction in remittance costs has encouraged international trade [11].

Another study focused on the impact of regional economic growth on migration by age group. The results indicate that economic growth and job creation significantly increase net migration rates across all age groups, with a more pronounced effect on the youth population. Income disparities among the 25-29 age group and land price fluctuations among the 40-64 age group also significantly influence migration patterns, highlighting the importance of regional economic factors in migration decisions [13].

3. Data Methodology

Data Sources: We utilised The World Bank Open Data platform [26] as our main source of data. This platform provides comprehensive data covering a broad spectrum of subjects across 189 member nations, allowing us to explore the various factors influencing migration trends. With its extensive repository of statistical information, it serves as a valuable resource for our analysis. Our study aims to dissect the complex interplay between migration patterns and the multifaceted changes in Egypt's demographic, political, and economic landscape. We decided to keep the integrity of our analysis by using The World Bank Open Data platform as our only source of data to avoid conflicting values, metrics confusion, etc.... We used various research papers and articles detailing political events and economic policies in Egypt throughout the period.

Data Types: we used chose our variables based on other works using them with net migration and ones we predicted to have a contribution value to this studying net migration, our variables are used for two objectives of the time series analysis and modeling it. Here is each indicator in detail according to the World Data Bank [26]:

Variable	Definition	Unit
Population, total	Total population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship. The values shown are midyear estimates	Total
Population growth	Annual population growth rate. Population is based on the de facto definition of population, which counts all residents regardless of legal status or citizenship	Annual %
GDP	GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars. Dollar figures for GDP are converted from domestic currencies using single year official exchange rates. For a few countries where the official exchange rate does not reflect the rate effectively applied to actual foreign exchange transactions, an alternative conversion factor is used	current US$
GDP growth	Annual percentage growth rate of GDP at market prices based on constant local currency. Aggregates are based on constant 2015 prices, expressed in U.S. dollars. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources	annual %
GDP per capita	GDP per capita is gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources. Data are in current U.S. dollars	current US$
GDP per capita growth	Annual percentage growth rate of GDP per capita based on constant local currency. GDP per capita is gross domestic product divided by midyear population. GDP at purchaser's prices is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products. It is calculated without making deductions for depreciation of fabricated assets or for depletion and degradation of natural resources	annual %
Consumer price index	Consumer price index reflects changes in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly. The Laspeyres formula is generally used. Data are period averages	2010 = 100
Unemployment, total	Unemployment refers to the share of the labor force that is without work but available for and seeking employment. Definitions of labor force and unemployment differ by country	% of total labor force (national estimate)
Personal remittances, received	Personal remittances comprise personal transfers and compensation of employees. Personal transfers consist of all current transfers in cash or in kind made or received by resident households to or from nonresident households. Personal transfers thus include all current transfers between resident and nonresident individuals. Compensation of employees refers to the income of border, seasonal, and other short-term workers who are employed in an economy where they are not resident and of residents employed by nonresident entities. Data are the sum of two items defined in the sixth edition of the IMF's Balance of Payments Manual: personal transfers and compensation of employees	% of GDP
Foreign direct investment, net inflows	Foreign direct investment are the net inflows of investment to acquire a lasting management interest (10 percent or more of voting stock) in an enterprise operating in an economy other than that of the investor. It is the sum of equity capital, reinvestment of earnings, other long-term capital, and short-term capital as shown in the balance of payments. This series shows net inflows (new investment inflows less disinvestment) in the reporting economy from foreign investors, and is divided by GDP	% of GDP
Net migration (our target variable)	Net migration is the net total of migrants during the period, that is, the number of immigrants minus the number of emigrants, including both citizens and non-citizens	

Table 1. *Main Variables (economic indicators) used in our paper*

Data Cleaning: Prepossessing and cleaning the data is an important step to ensure the validity and accuracy of the model and our analysis. We found some missing values in the following variables: Foreign direct investment, Personal remittances, Unemployment. We decided to fill those missing values using Linear Interpolation:

$$\frac{y - y_0}{x - x_0} = \frac{y_1 - y_0}{x_1 - x_0}$$

Given two values (x_0, y_0) and (x_1, y_1), Linear Interpolation finds the missing value (x, y) simply by getting the median of the nearest non missing values, typically the median of the first element before and after the (x, y).

Correlations and Testing: We used Pearson's correlation metric and t-testing to check for statistical significance.

4. Modeling Methodology

Egypt's net migration holds significant economic and sociopolitical meanings. Understanding and predicting net migration patterns can provide valuable insights for policy-making and economic planning. To this end, we tested several regression models to identify the most accurate predictors of net migration.

All our variables are labeled as numerical values, necessitating the use of regressor-based models. We initially tested the following models:

- Linear Regression
- Decision Tree Regressor
- Random Forest Regressor
- Gradient Boosting Regressor
- XGBoost

4.1. R-Squared (R^2) Score

The R^2 score, or the coefficient of determination, is a statistical measure that represents the proportion of the variance for a dependent variable that's explained by an independent variable or variables in a regression model. The R^2 score ranges from 0 to 1, where:

- $R^2 = 1$ indicates that the regression predictions perfectly fit the data.
- $R^2 = 0$ indicates that the model does not explain any of the variability of the response data around its mean.

In the context of social sciences and economics, achieving high R^2 scores can be challenging due to the complexity and variability of human behavior. For further reading on acceptable R^2 values economics and human behavior, see [6] and [20].

4.2. Initial Model Performance

The initial test data R^2 scores for the models were as follows:

- Linear Regression: 0.3973
- Decision Tree Regressor: 0.1327
- Random Forest Regressor: 0.1389
- Gradient Boosting Regressor: 0.2152
- XGBoost: 0.2395

We observed that Linear Regression performed best with an R^2 score of 0.3973.

4.3. Feature Engineering and Selection

To improve model performance, we selected statistically relevant features with moderate to strong correlation and p-values less than 0.05. Additionally, we implemented new feature-engineered variables:

4.3.1. *Feature-Engineered Variables.*

$$\text{Feature 1} = \left(\frac{\text{Population growth (annual \%)} \times \text{GDP (current US\$)}}{\text{GDP per capita (current US\$)}}\right)$$

correlation with net migration: 0.4308

p-value: 0.0007355

$$\text{Feature 2} = \left(\frac{\text{Population growth (annual \%)/GDP growth (annual \%)}}{\text{Official exchange rate (LCU per US\$, period average)/Consumer price index (2010 = 100)}}\right)$$

correlation with net migration: 0.5861

p-value: 1.338×10^{-6}

4.3.2. *Selected Features.* The selected features included:

- Population, total
- GDP (current US$)
- GDP growth (annual %)
- GDP per capita (current US$)
- GDP per capita growth (annual %)
- Unemployment, total (% of total labor force) (national estimate)
- Feature 1 and Feature 2 (as defined above)

4.4. Improved Model Performance

With the revised features, the models' test data R^2 scores improved as follows:

- Linear Regression: 0.1829
- Decision Tree Regressor: 0.3542
- Random Forest Regressor: 0.3650
- Gradient Boosting Regressor: 0.4046
- XGBoost: 0.3917

The Gradient Boosting Regressor and XGBoost models performed best, followed by the Decision Tree and Random Forest Regressors.

4.5. Model Fine-Tuning

We proceeded with further fine-tuning of the Gradient Boosting Regressor and XGBoost models due to their superior performance. However, it is essential to note that without hyperparameter tuning, both models appeared to be overfitting the data. In some cases, this led to the models producing nearly identical values for the dependent variable. Hyperparameter tuning aims to optimize the performance of the models by finding the best combination of hyperparameters, thus mitigating the risk of overfitting and improving generalization to unseen data.

4.5.1. *Gradient Boosting Regressor.*

- Best cross-validation R^2 score: 0.5303
- Test R^2 Score: 0.3919

The Gradient Boosting model iteratively fits decision trees to the residuals of previous models. The prediction at step m is given by:

$$F_m(x) = F_{m-1}(x) + \nu \sum_{i=1}^{n} \gamma_{mi} I(x \in R_{mi}) \tag{1}$$

where ν is the learning rate, γ_{mi} is the prediction of the i-th region R_{mi}, and I is the indicator function.

4.5.2. XGBoost.

- Best cross-validation R^2 score: 0.4944
- Test R^2 Score: 0.3544

XGBoost uses an ensemble of trees, optimized using the following objective function:

$$\mathcal{L}(\theta) = \sum_{i=1}^{n} l(\hat{y}_i, y_i) + \sum_{k=1}^{K} \Omega(f_k) \tag{2}$$

where l is a differentiable convex loss function, and Ω is a regularization term controlling model complexity. Each tree's prediction is given by:

$$\hat{y}_i = \sum_{k=1}^{K} f_k(x_i) \tag{3}$$

While R^2 scores above 0.7 are generally considered acceptable, achieving such results in economics and human behavior can be challenging [6], [20].

5. Results

In this section we demonstrate the results of our time series analysis of Egypt's net migration trends over the past half-century (1965-2022) and explores potential correlations with sociopolitical and economic factors. The analysis aims to identify factors influencing migration patterns and quantify these relationships using regression analysis and time series modeling. The graph reveals significant fluctuations in Egypt's net migration rates over the time period, with both positive and negative net migration. We also demonstrate and discuss our machine learning model we used to predict the time series.

Indicator	r value	p value
Population total	0.4173748088137177	0.0011157374758196826
Population growth	0.042833396226888164	0.7495332889878951
GDP	0.2980826708894402	0.02304752525612825
GDP growth	-0.3318186587867672	0.01094073335581462
GDP per capita	0.357496612299195	0.0058686201008801234
GDP per capita growth	-0.33935516511060515	0.009160017940091227
Consumer price index	0.18011514687843297	0.17607159043325407
Foreign direct investment net inflows	0.0014626244707889834	0.9913059959742574
Personal remittances received	-0.21094364649696978	0.11195423904763112
Unemployment total	0.6054667734967716	$4.773918515478313 \times 10^{-7}$

Table 2. *Each economic indicator's correlation and statistical significance with the net migration*

From the table above 2, we can see correlation values in between very weak to moderate values, which indicates that most of the indicators here may not actually play a significant role in the fluctuations in the net migration graph. p values less than $\alpha = 0.05$ indicates that these correlations are statistically significant and are not by mere chance, such values appear in Population total, GDP, GDP growth, GDP per capita, GDP per capita growth, Unemployment total. On the other hand, the variables having a p value of more than $\alpha = 0.05$ indicates that the correlations resulted could be the outcome of random chance without actual significance.

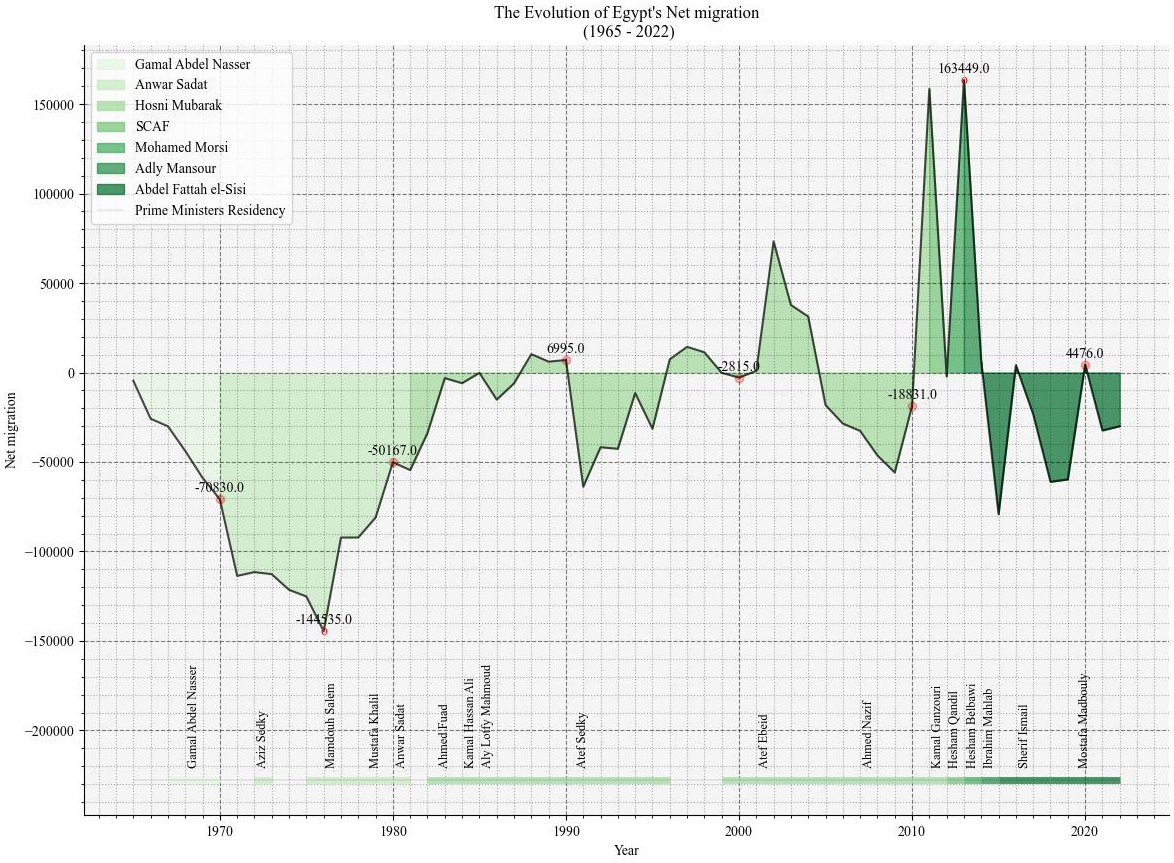


Figure 1. *Net Migration Time series Analysis*

Figure 1 illustrates the evolution of net migration in Egypt from 1962 to 2021, highlighting the periods under various Egyptian presidents. The chart indicates fluctuating migration rates over the decades, with several notable peaks and troughs.

- At the time of Nasser's presidency, net migration was predominantly negative, reaching a low point of -144,535 in the mid-1970s.
- Under Sadat, the trend remained negative but showed some improvement, with a significant dip to around -70,830 in the early 1970s.
- Mubarak's long tenure saw more variability, with net migration improving significantly in the late 1980s to early 1990s, even reaching a positive peak of 6,995. However, this period also included phases of negative net migration, such as -50,167 in the early 1980s and -18,831.0 in the early 2000s.
- During Morsi's brief presidency, net migration marked a significant positive spike, with a peak of 16,349 in 2013.
- Following Morsi, under Mansour, the net migration rates showed a dramatic decline, reverting to negative values.
- Under el-Sisi, the trend has remained unstable, with periods of both negative and positive net migration. The most recent data point in the graph indicates a slight positive net migration of 4,476 in 2020.

The fluctuations in Egypt's net migration over the decades are influenced by a complex interplay of factors. While the leadership of various presidents played a significant role in shaping migration trends, other variables such as economic conditions, social cohesion, political stability, and international disputes also had substantial impacts and

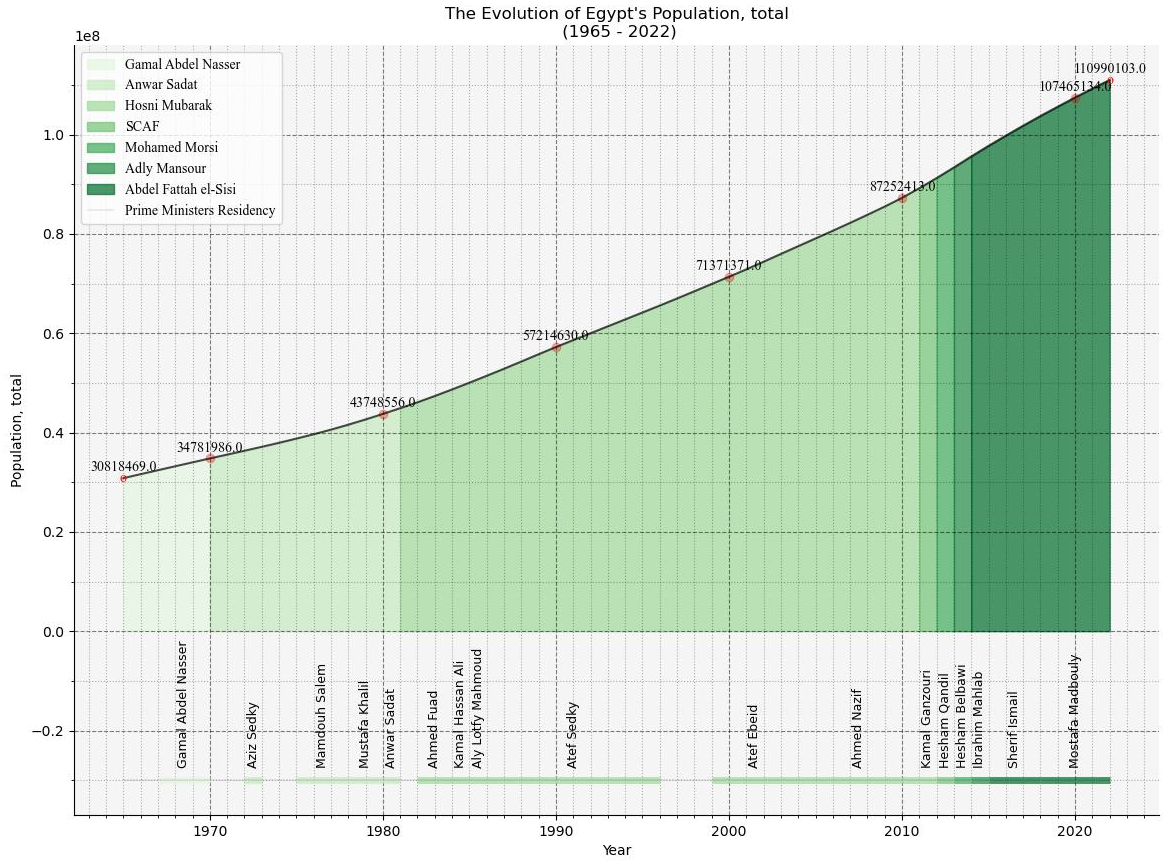


Figure 2. *Population time series Analysis*

The graph of Egypt's Population (1965-2022) 2 reveals a substantial and sustained increase in population over nearly six decades. While there may be fluctuations throughout the period, the overall trend is clearly upward. The population has more than tripled, jumping from around 30.8 million in 1965 to an estimated 87.3 million by 2022. Additionally, the correlation between the total population and net migration during this period is 0.417, with a p-value of 0.00112, indicating a statistically significant positive relationship between these variables.

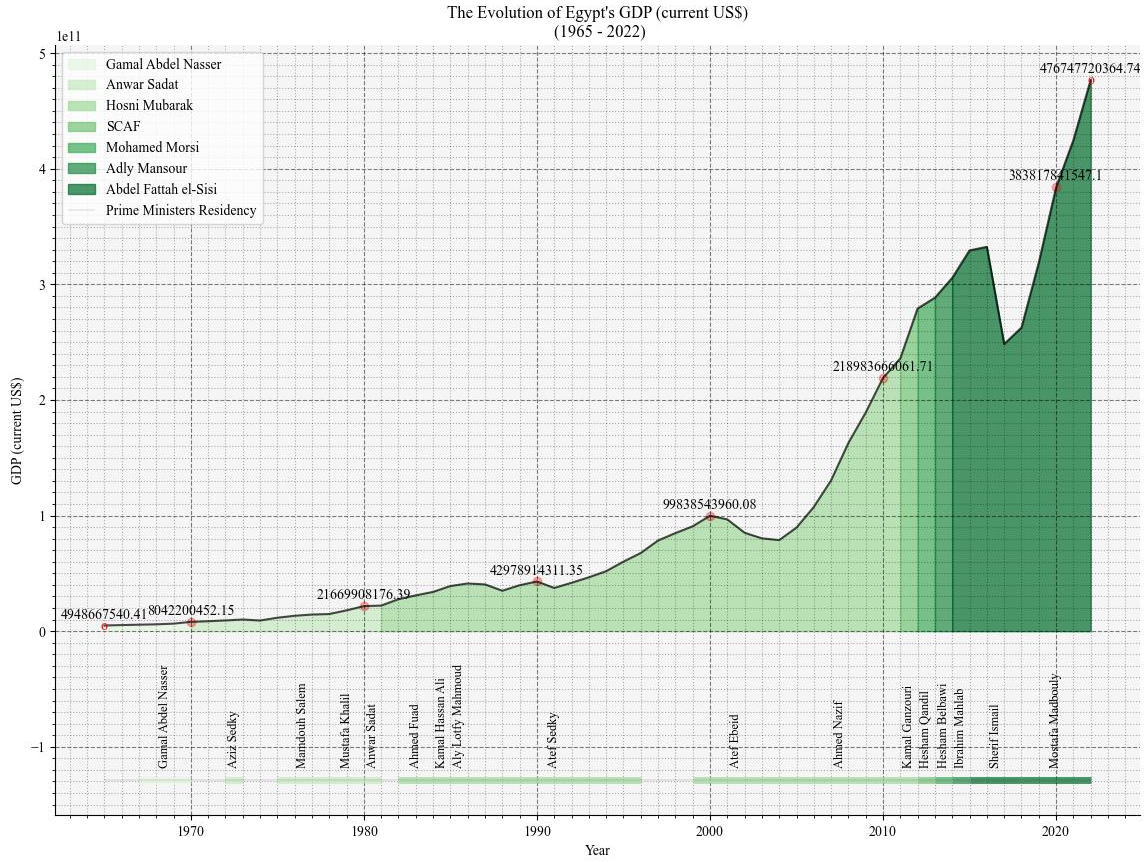
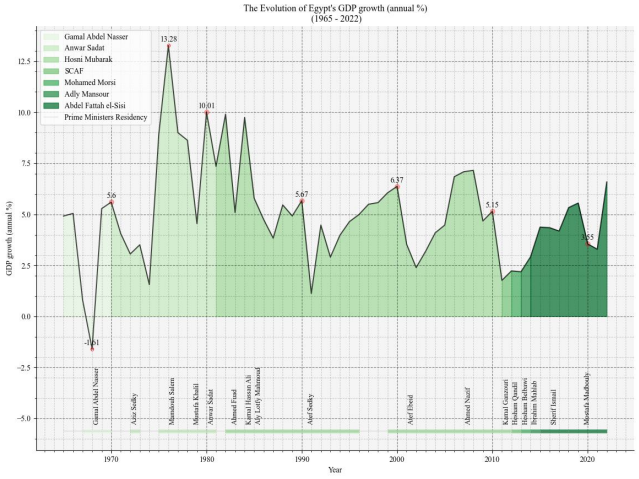
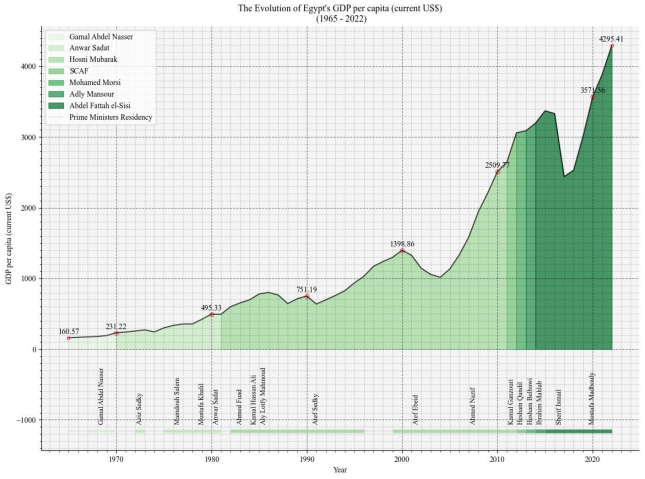


Figure 3. *GDP time series Analysis*

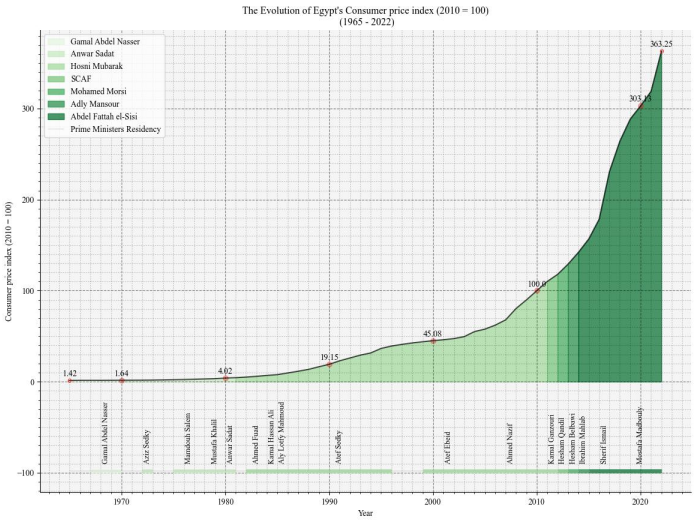
This graph 3 analysis examines the evolution of Egypt's Gross Domestic Product (GDP) in current US dollars from 1965 to 2022, revealing a steady rise in Egypt's GDP from $4.90 billion in 1965 to $21.7 billion by 1980. A period of remarkable growth followed, with the GDP nearly quintupling to $99.8 billion by 2000. The graph shows a dip around 2016 to 2017 due to the devaluation of the Egyptian pound by 48% to meet the IMF's demands, but the GDP appears to have recovered and continued its upward trend, reaching an estimated $476.7 billion by 2022. Additionally, the correlation between GDP (current US$) and net migration during this period is 0.298, with a p-value of 0.0230, indicating a statistically significant positive relationship between these variables.



(a) *GDP Growth*



(b) *GDP per capita (current US)*



(c) *Consumer price index (2010 = 100)*

Figure 4. *GDP growth, per capita, and consumer price index graphs*

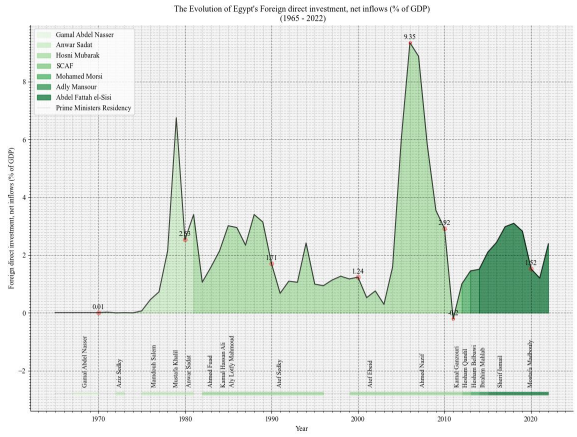
The first graph 4a illustrates that the GDP growth rate fluctuated considerably over this period. There were periods of strong growth, such as from the mid-1990s to the mid-2000s, and periods of decline, such as the early 2010s. The highest GDP growth rate was 13.28% in 1967, under President Gamal Abdel Nasser. The lowest GDP growth rate was -1.61% in 2011, during a period of political unrest. Graph 4b, GDP per capita (current US dollars), takes the total GDP and divides it by the population. This essentially tells us how much "economic pie" each Egyptian gets on average. So, if the GDP (current US dollars) grows but the population increases faster, the GDP per capita (current US dollars) might not rise as much, or even decrease.

Meanwhile, graph 4c, the Consumer Price Index (CPI), unveils a different story - inflation. Imagine a basket of groceries you buy regularly. The CPI tracks how much more (or less) you'd need to spend to buy that same basket over time. While a growing GDP (current US dollars) could suggest more people have money to spend, potentially driving prices up (inflation), it's not a guaranteed outcome. Other factors like government policies or global events can also influence inflation.

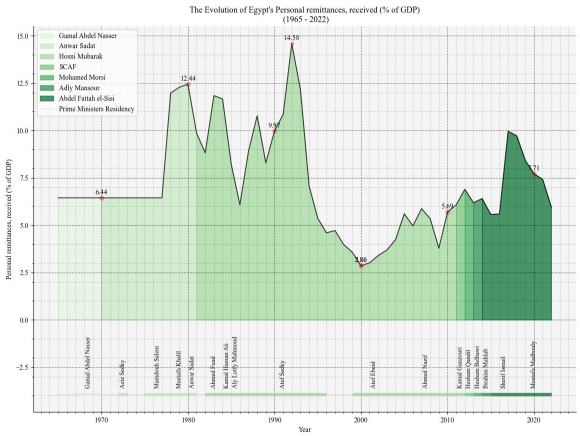
By looking at all three graphs together, we can paint a richer picture of Egypt's economic journey. We can see if the overall economy is expanding (GDP current US dollars), how this translates to average wealth per person (GDP per capita current US dollars), and how inflation has affected the purchasing power of Egyptians (CPI). This multi-faceted approach allows us to move beyond headline numbers and gain a deeper understanding of Egypt's economic well-being.

Additionally, the correlation between GDP growth (annual %) and net migration is -0.332, with a p-value of 0.0109, suggesting a statistically significant negative relationship between these variables. The correlation between GDP per capita (current US$) and net migration is 0.357, with a p-value of 0.00587, indicating a statistically significant positive relationship. However, the correlation between the Consumer Price Index and net migration is 0.180, with a p-value of 0.176, suggesting a weak and

statistically insignificant relationship between these variables.



(a) *Foreign direct investment, net inflows (% of GDP)*

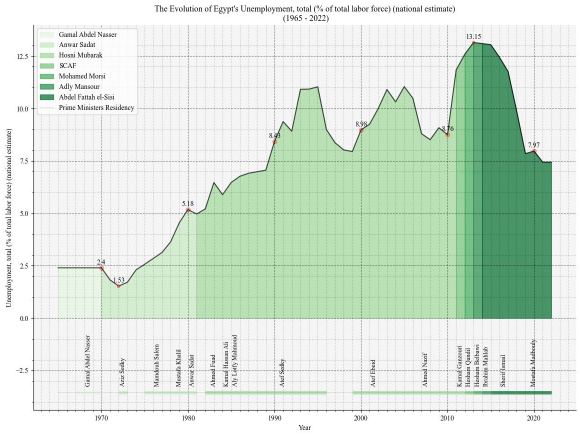


(b) *Personal remittances, received (% of GDP)*

Figure 5. *Foreign direct investment and the personal remittances*

Graph 5a reveals a fascinating journey of foreign direct investment (FDI) in Egypt relative to its GDP. From the mid-1960s to the early 1970s, foreign investment was practically nonexistent. A turning point arrived in the late 1970s with a modest rise, culminating in a significant surge by the early 1980s, reaching a peak of 2.53% of GDP. The 1980s witnessed a period of consolidation with fluctuations between 1% and 2.5%. The 1990s continued this trend with some dips and recoveries. Interestingly, the early 2000s saw a dramatic surge, exceeding 9% in 2007, indicating a period of high investor confidence. However, this exuberance was short-lived, as a sharp decline followed in the late 2000s, dropping to nearly 3% by 2010. The early 2010s witnessed a further plunge, with FDI reaching a historic low of 0.62% in 2011. Fortunately, there has been a recovery since the mid-2010s, albeit with fluctuations, and by 2022, FDI stabilized around 1.52% of GDP. In conclusion, Egypt's FDI landscape has been marked by periods of significant growth followed by fluctuations and corrections. The correlation between foreign direct investment, net inflows (% of GDP), and net migration is 0.00146, with a p-value of 0.991, indicating no significant relationship between these variables.

Examining graph 5b, we observe a dynamic trend in Egypt's personal remittances as a share of GDP over several decades. From the mid-1960s to the late 1970s, remittances remained steady at around 6% of GDP. A turning point came in the late 1970s with a significant surge, reaching a peak of nearly 14.6% by the mid-1980s. The 1980s witnessed fluctuations, but the overall level stayed high. However, the 1990s saw a steady decline, with remittances reaching a low point in the late 1990s. The following decade brought a recovery with fluctuations, experiencing a dip towards the end. Finally, the 2010s were marked by a gradual increase, with remittances reaching a new high in the early 2020s. In essence, Egypt's reliance on remittances has fluctuated over time, with significant peaks followed by periods of decline and recovery. The correlation between personal remittances, received (% of GDP), and net migration is -0.211.



(a) *Unemployment, total (% of total labor force) (national estimate)*

(b) *Relationship Between the unemployment rate and Egypt's net migration*

Figure 6. *Unemployment analysis and it's relationship with the net migration*

This analysis offers a nuanced view of Egypt's unemployment trends from 1905 to 2022. It highlights periods of low rates in the 1970s, followed by steady increases through the 1980s. The 1990s saw fluctuations, while the 2000s showed variability. The early 2010s witnessed a surge, followed by a gradual decline towards the end of the decade. Recent data from the early 2020s indicates ongoing recovery efforts amidst persistent challenges.

Examining the correlation between unemployment and net migration in Egypt reveals a clear link, with a correlation coefficient slightly above 0.61. This suggests that economic conditions strongly influence migration patterns over time. During economic downturns, like the late 2010s, high unemployment rates push people to seek work abroad, increasing net migration out of Egypt. Conversely, during upturns, such as the mid-2000s, lower unemployment rates attract migrants, leading to more people moving into Egypt. This correlation reflects broader economic differences between Egypt and other countries, influencing migration decisions based on job availability and wage levels (p-value $= 4.77 \times 10^{-7}$).

5.1. Modeling Results

Gradient Boosting Regressor:

Parameter	Value
learning_rate	0.2
max_depth	3
min_samples_leaf	2
min_samples_split	2
n_estimators	10
subsample	1
Best Cross-validation R^2 Score	0.5303
Test R^2 Score	0.3919

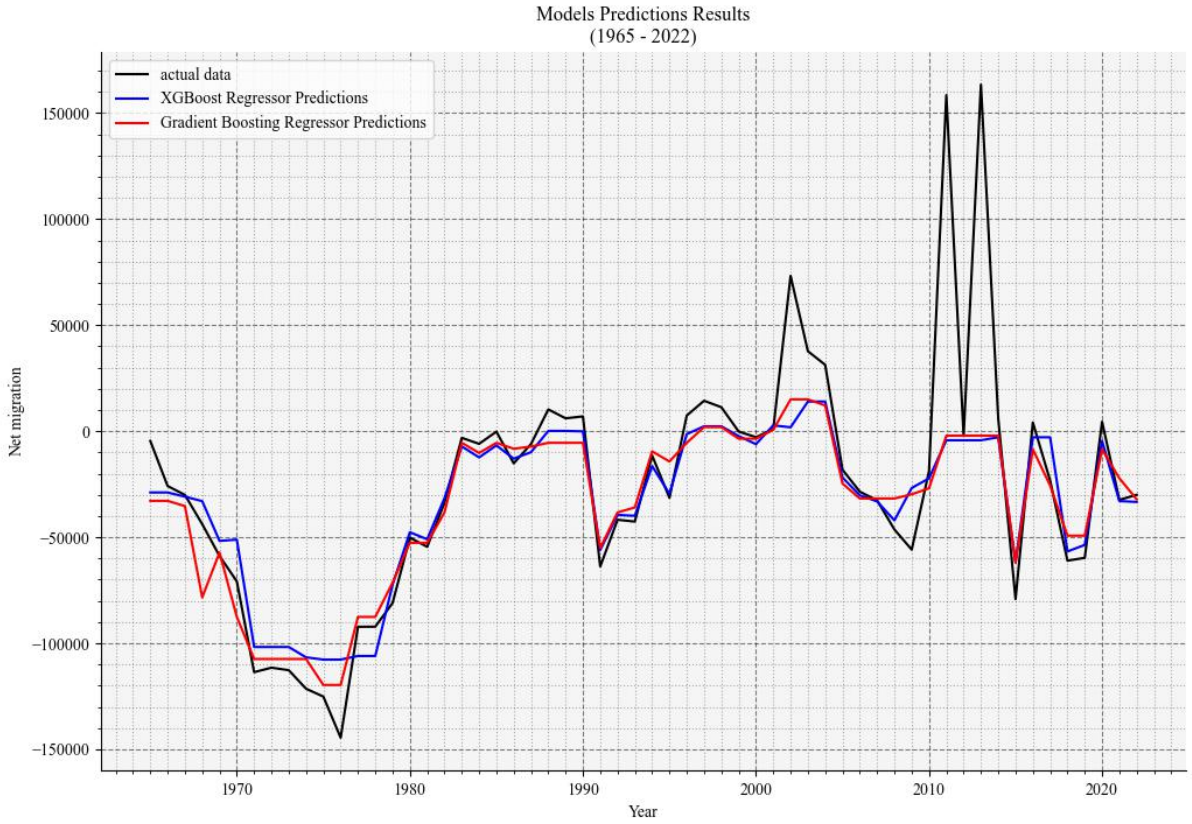
Table 3. *Model parameters and R^2 score after tuning*

XGBoost Regressor:

Parameter	Value
alpha	0.1
colsample_bytree	1.0
gamma	0
lambda	1
learning_rate	0.01
max_depth	5
min_child_weight	1
n_estimators	200
subsample	1.0
Best Cross-validation R^2 Score	0.4944
Test R^2 Score	0.3544

Table 4. *Model parameters and R^2 score after tuning*

Models Predictions:



(a) *Performance of Models in Capturing Net Migration Trends*

Results interpretation and hypothesis testing

The aim of this study was to investigate the predictability of Egypt's net migration using supervised machine learning algorithms, leveraging economic indicators. The null hypothesis (H_0) posited that the coefficient of determination (R^2) would be equal to 0, while the alternative hypothesis (H_α) suggested that R^2 would exceed 0.35.

Two advanced regression algorithms, Gradient Boosting Regressor and XGBoost, were employed for prediction. The best cross-validation R^2 scores achieved were 0.5303 and 0.4944, respectively, indicating promising predictive performance during model training.

Upon testing the models, the Gradient Boosting Regressor yielded a test R^2 score of 0.3919, while XGBoost produced a test R^2 score of 0.3544. Despite the decline in performance from cross-validation to testing, both algorithms demonstrated R^2 values surpassing the threshold set in H_α, indicating a significant degree of predictability in Egypt's net migration based on the selected economic indicators.

Additionally, the model performance graph vividly demonstrates that both Gradient Boosting Regressor and XGBoost are adept at capturing the general trend of net migration. Despite minor deviations, the predicted values closely follow the observed data, indicating that the models effectively capture the underlying patterns and dynamics of net migration. This visual representation further bolsters the confidence in the predictive capabilities of the employed algorithms, corroborating the statistical results obtained from R^2 analysis and feature correlation assessments.

Further analysis revealed that the two engineered features (FE 1 and FE 2) are highly correlated with net migration. FE 1 exhibited a correlation coefficient of 0.5861 (p-value $= 1.338 \times 10^{-6}$), while FE 2 showed a correlation coefficient of 0.4308 (p-value = 0.0007355). These findings underscored the relevance of engineered features in explaining variations in net migration and reinforced the validity of the predictive models.

In conclusion, the results strongly support the rejection of the null hypothesis (H_0), indicating that Egypt's net migration can be predicted with a reasonable degree of accuracy using supervised machine learning algorithms trained on economic indicators, including engineered features.

6. Discussion

- **Overview:** This study aimed to analyse and find if there is a correlation between Egypt's net migration and economic factors such as Population total, GDP, GDP growth, GDP per capital..... We found weak to moderate correlation between Net migration and economic factors in question, with correlation value ranging from x-y, those correlations have proven to be statistically significant and proven to be caused not by random chance.

- **Implications:** We draw connections between the net migration patterns and economic variables, and sociopolitical factors and disputes that happened over the last 60 years (1965-2022). We will discuss each presidency era, as we consider that each president and government can bring different policies and variables that could make a change in the numbers of immigrants and emigrants for Egypt and deal any external events differently.

  - **Gamal Abdel Nasser's Era, *1956-1970*:** At this period, some policies and projections of Abdel Nasser's regime failed to meet it's expectations economically. As Johnson [2] stated in his study, *"The economic accomplishments of the Nasser regime are not spectacular. Cotton production hardly was greater in the mid-sixties than it had been fifty years earlier. Imports of wheat went from 15,000 tons in 1955 to 300,000 tons in 1956, and by 1967 were at 3,000,000 tons. The Five Year Plan (1960-1965) projected that by the end of the period development would be completely financed from within the economy: but in reality outside aid multiplied from about LE 10 million annually in the Fifties to 100 million pounds in 1964. The 7% annual growth forecast was around 4%. Public expenses, which were to have been cut down, rose from 500 million pounds in I960 to 1.2 billion in 1966. The number of state employees more than doubled, and the public debt went from 70 million pounds to 350 million pounds."*

    Another major event that affected the Egypt's GDP Growth significantly was the six-day war in 1967 in which Egypt lost its sovereignty over the lands of Sinai, which made a huge domestic unrest and wave of anger against the government[1]. Such economic and political failures proved to make quite big hurdles to Egyptians. As the GDP Growth graph shows a sudden dip to growth rate of -1.61 which is the lowest to be recorded over the whole graph. Consequently, those economic and national crises have definitely induced many to emigrate outside Egypt in that period to look for better financial opportunities, as the net migration graph shows a steep decline until 1970.

  - **Anwar Sadat's Era, *1970-1981*:** After Abdel Nasser's death, Anwar El-Sadat was chosen as his successor. He changed directions completely from Abdel Nasser as he chose to improve relationships relations with the western powers such as the United States [9]. The difference between immigrants and emigrants kept increasing in favor of emigrants which we can assume is due to the after mass of the six-day war [1]. Egypt. the net migration graph line flattened between 1971-1973 with a significant decrease in unemployment rate to 1.53% from 2.4% in 1970. Despite Egypt's win, Egypt's surprise attack on Israel in 1973 (October War) may have contributed to increasing the number emigrants. El-Sadat also implemented several economic policies starting from 1974. He made the Open-Door Economic Policy (ODEP), also known as *Infitah*, which had a significant impact on the Egyptian economy, allowing more foreign investments and encouraging the private sector participation in the economy. Those economic movements proved quite beneficial recording the highest ever GDP Growth at 1975, just one year after implementing them, with a growth rate of 13.28% all the way from the dip in growth of just below 2% the year before. Even though Net migration reached its lowest in 1976, three years after the war and two years after the start of El-Sadat's new economic policies, it started rising gradually which could indicate the success of El-Sadat's policies in decreasing the emigrations from Egypt up until his assassination in 1981. But Gad [3] said in their study of the Infitah's relation with migration in 1985 the following: *"but in terms of economic and social impact on the total population emigration is much more important. The number of emigrants increased from 100,000 in 1973 to over 3 million in 1984 and the extent of their remittances increased from $184 million in 1973 to nearly $4 billion at present. Serious shortages of skilled and unskilled labor have been created by the departure of 10-15% of the overall labor force and a higher proportion for some skilled professions."*, this can indicate that the number of emigrants over the 70's did in fact increase in total [5] and not the opposite. This mass emigration and the great dip happening up until 1976 was probably also because of the *Infitah*, as the good relations at the time between Egypt and neighboring Arab countries specifically the gulf has increased, which allowed many skilled Egyptian workers to emigrate there to look for jobs and opportunities. Consequently, decreasing net migration and increasing the personal remittance inflows magnificently [3]. As the net migration graph shows, this decline gradually got up again until 1978 which at the time was Camp David political signed. This accord may have disturbed Egypt's relations with some Arab gulf countries. By which we can say that the gradual increase in net migration was because the number of emigrants started to decrease again as it became harder to emigrate to the gulf after Camp David.

    However, it can be said that this movement has made Egypt one of the most economically dependant countries [4] and led to other negative consequences by the early 80's.

  - **Hosni Mubarak's Era, *1981-2011*:**
    Mubarak is the president with the longest presidency period with a full 30 years. Egyptians witnessed so much during his long period and expected huge improvements under his vision as a pragmatic leader [9]. However, over the time of his period, Egypt had the highest levels of perceived corruptions among the all Arab nations, and Unemployment rates kept increasing significantly during his period [7]. The GDP per capita growth also was fluctuating but decreased over all during his period, meaning that the share of each individual in Egypt's economy did not grow much in relative terms. We could not find any specific reason or event leading to the spike in the foreign direct investment graph in 2006, but it is greatly noticeable as it reached an all time high of 9.35% of GDP. We noticed both a great spike of the personal remittances proportion of the GDP with a percentage of 14.58 in 1992 and a great decline too in 2000 with an input of only 2.86% of the GDP. At the beginnings of the 2000's, the 9/11 attacks had significant and far-reaching impacts on the global economy. The immediate effects were devastating, with the

global financial markets experiencing a sharp decline in the days following the attacks. The Dow Jones Industrial Average plummeted by 14.3% on September 17, 2001, and the S&P 500 Index fell by 13.3% on the same day[14], [21], [23]. 9/11, the start of Iraq war in 2003, and other factors were probably the cause of the sudden plummet in Egypt's GDP growth between 2001 and 2004. Mubarak's regime used the emergency laws, which remained in place until the end of his period, in order to suppress any opposition by massive arrests and intimidation tactics [7]. such tactics and policies along with corruption, poverty, and great inflation in prices all lead Mubarak's regime to be overthrown in 2011 by the 25^th of January revolution. It can be said that this process scared many foreign investors, thus explaining the great decrease in it's contribution of the GDP from 2.92 in 2010 to -0.2 in 2011. Consequently making the GDP growth that year under 2% after it was 5.15% the year before. It is noticeable that the net migration was about near zero in most of his period, meaning that the number of both immigrants and emigrants was nearly equal over that time, but a sudden spike in 2011 occurred. a decrease in the number of immigrants at that year is more reasonable to assume due to the state of Egypt during the revolution, along the spark of several conflicts in the region such as Syrian civil war [15] and more.

- **Mohamed Morsi's Era, *2011-2013*:** During Mohamed Morsi's presidency in Egypt, there was a significant increase in Coptic Christian emigration due to rising sectarian violence, perceived discriminatory policies, and inadequate protection from authorities. Attacks on Coptic churches and properties created a climate of fear, while Morsi's government was seen as failing to protect Coptic rights[12]. The lack of adequate security further eroded the community's confidence in the government's ability to ensure their safety, prompting many Copts to seek refuge in countries like the United States, Canada, Australia, and Europe[8].

  The influx of refugees into Egypt in 2012 was significant, driven by regional conflicts. The Syrian civil war forced many to flee, and Egypt, under President Mohamed Morsi, became a key destination. Morsi, a critic of Syrian President Bashar al-Assad, adopted a supportive stance toward Syrian opposition, making Egypt more welcoming compared to other neighboring states[15].

  Simultaneously, the 2011 referendum in South Sudan led to a significant influx of Sudanese refugees in 2012 into Egypt[10]. Egyptian officials anticipated this increase, given the large number of Southern Sudanese in north Sudan.

  The 2013 revolution in Egypt had a significant impact on net migration in the country. Increased emigration, particularly among skilled professionals and youth seeking better opportunities abroad, led to a brain drain. At the same time, immigration to Egypt declined as the country's economic and political situation became less attractive for foreign workers and investors.Certain groups, such as Coptic Christians, experienced disproportionate effects, with many Copts emigrating due to sectarian violence, discriminatory policies, and a lack of protection under Mohamed Morsi's presidency. These changes in migration patterns had economic consequences for Egypt, affecting sectors that relied on foreign labor and investment.
- **Adly Mansour's Era, *2013-2014*:** Adly Mansour's brief presidency in 2013 did not directly impact net migration in Egypt, but the broader political and economic context during this period contributed to changes in migration patterns.
  The post-revolution period saw a shift in migration patterns, with some Egyptians who had previously left the country deciding to return.
- **Abdel Fattah El-Sisi's Era, *2014-present*:** At the beginning of Abdel Fattah el-Sisi's presidential term, the vast majority of migrants cited economic concerns as their top reason for migration. Specifically, 65% stated that insufficient income in Egypt was their primary motivation, while 28% cited a lack of job opportunities or sought better job prospects abroad [18]. Demographic pressures and the lack of opportunities for a well-educated populace have been powerful emigration push factors over the past four decades, as the Egyptian economy has been unable to absorb the large number of educated young people entering the labor market or provide employment commensurate with their skills [19]. This explains the biggest drop in our net migration graph.

  Between 2016 and 2019, the economic state grew steadily, yet we found no clear reason for the net migration fluctuations during that period. However, the COVID-19 pandemic in 2020 caused a contraction in Egypt's economy, with GDP declining by 3.1% in the quarter ending July 2020 and 1.3% in the following quarter due to pandemic-related restrictions, particularly on the tourism sector [24]. The pandemic significantly impacted net migration in Egypt, leading to a decline in the number of migrants leaving the country, particularly in the early stages. This decline was due to various factors such as travel restrictions, lockdowns, and economic uncertainty. Nevertheless, the economy rebounded in the following quarters, hitting 7.2% by July 2021 and 8.3% by July 2022 [24].

- **Limitations:** Although some variables correlations such as unemployment rate with net migration can be explained clearly in a logical manner, some other were not easy to reason their correlation with net migration as we couldn't find real-life connections easily nor were we able to find other works or studies that explained them.

We also faced a huge issue while finding the correlation value between unemployment rate and net migration, as some values for the earlier were missing. We decided to not use another source of data to maintain the integrity of the data we are using. Instead we decided to use Linear Interpolation to calculate the correlation with net migration.

We faced some difficulties identifying the causes of some patterns in the net migration over some periods, as we could find the reasons behind the increase of migration from Egypt but not immigration to it and vice-versa.

7. Conclusion

In conclusion, this study provides a detailed analysis of Egypt's net migration patterns from 1965 to 2022, revealing significant correlations with economic indicators. The findings demonstrate that population growth and GDP per capita have notable positive correlations with net migration, while GDP growth exhibits a negative correlation. The application of advanced regression models, specifically Gradient Boosting and XGBoost, offers promising predictive capabilities, though the models also highlight the inherent complexity in forecasting migration trends. The research underscores the critical impact of sociopolitical and economic factors on migration, suggesting that regional conflicts drive inward migration, whereas domestic issues, including economic hardships and political instability, prompt outward migration.

The study's results reveal important implications for policymakers. Understanding these migration patterns can inform the development of strategies aimed at mitigating the negative effects of mass emigration, such as brain drain, and harnessing the potential benefits of immigration. Furthermore, the research highlights the need for continued investigation into the multifaceted influences on migration to devise effective, evidence-based policies. Future research should consider integrating additional variables and employing more sophisticated models to enhance predictive accuracy and deepen the understanding of migration dynamics in Egypt.

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