Exchange rate volatility and economic indicators: applications of a regime-switching linear regression model in the Kenyan context

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DECLARATION

I declare that this work has not been previously submitted and approved for the award of a degree by this or any other University. To the best of my knowledge and belief, the Research Project contains no material previously published or written by another person except where due reference is made in the Research Project itself.

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This Research Project has been submitted for examination with my approval as the Supervisor.

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Abstract

This study examined the relationship between USD/KES exchange rate volatility and key economic indicators—GDP growth, inflation, trade balance, and the central bank rate—in Kenya from 2010 to 2023 using a regime-switching linear regression model. It explored how these relationships varied across low, medium, and high volatility regimes, providing a more detailed analysis than traditional models.

Results showed that in low-volatility periods, relationships were weak; in medium-volatility periods, only the central bank rate was significant; and in high-volatility periods, inflation had the strongest influence, with the central bank rate stabilizing the economy. The 3-regime model outperformed the single- and two-regime models in terms of AIC, BIC, and R-squared.

Despite limitations such as fewer observations per regime, the study highlighted the importance of regime-specific policies for economic stability and provided valuable insights for policymakers and researchers.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

1) AIC - Akaike Information Criterion
2) BIC - Bayesian Information Criterion
3) BOP - Balance of Payment
4) CBK - Central Bank of Kenya
5) CBR - Central Bank Rate
6) CIP - Covered Interest Rate Parity
7) ER - Exchange Rate
8) FDI - Foreign Direct Investment
9) GDP - Gross Domestic Product
10) GARCH - Generalized Autoregressive Conditional Heteroscedasticity
11) GMM - Generalized Method of Moments
12) GNP - Gross National Product
13) INF - Inflation Rate
14) IRP - Interest Rate Parity
15) KES - Kenyan Shilling
16) LR - Linear Regression
17) PPP - Purchasing Power Parity
18) Q1 - First Quarter of the Year (January-March)
19) Q2 - Second Quarter of the Year (April-June)
20) Q3 - Third Quarter of the Year (July-September)
21) Q4 - Fourth Quarter of the Year (October-December)
22) RER - Real Exchange Rate
23) SD - Standard Deviation
24) SRR - Switching-Regime Regression
25) USD - United States Dollar

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1. Introduction

1.1. Background information

In Kenya, exchange rates have frequently been a hotly debated subject. However, first we must define and clarify a few important terms. The exchange rate is the cost of one currency expressed in terms of another. The degree to which the value of one currency varies in relation to another over a specified period is referred to as exchange rate volatility. It has an impact on trade flows, investment choices, and economic stability, making it a key idea in international finance. Statistical instruments like the standard deviation, which reveal the average deviation of exchange rate fluctuations from their mean value, can be used to quantify volatility.

Key economic indicators for assessing the health of an economy are GDP, inflation, trade balance, and central bank rates. GDP, which measures the total value of goods and services generated over a given duration which is normally shown annually, reflects the state of the economy. GDP growth, which is typically expressed annually, is the percentage increase in the total value of goods and services produced. The rate at which the average level of prices for goods and services increases, decreasing purchasing power, is known as inflation. The difference between a nation's imports and exports is shown by the trade balance, and the Central Bank Interest rates are determined by rates, which also affect monetary policy and have an impact on economic activity.

1.1.1. History of USD/KES exchange rate fluctuations

Kenya's foreign exchange currency was gradually loosened; from a fixed rate till 1982, to a crawling peg from 1983 to 1993, and finally to a floating exchange rate system in 1993 (Jattani, 2013). The exchange rate is more susceptible to swings since it is a floating exchange rate, meaning that its value will be mostly influenced by the supply and demand for the Kenyan Shilling. Our main concern will be the USD/KES exchange rate. The following xe.com figure 1 illustrates the USD/KES exchange rate during the last ten years, from July 2014 to July 2024:

[1]

Figure 1: USD/KES exchange rate from July 2014 to July 2024

The above helps highlight the behaviour of the USD/KES exchange rate, and we can see fluctuations during the decade. The Kenyan shilling was strongest in July 2014 when $1 was KES87.7, while it was weakest in January 2024 when $1 was KES163.5. Taking a closer look at the figure, the exchange rate was quite stable from October 2015 till May 2021, before steady depreciation of the Kenyan Shillings. From February 2023 onwards, the USD/KES exchange rate fluctuated considerably more, as the Kenyan Shilling depreciated at a quicker rate before appreciating from February 2024. As of July 2024, the rate of $1 is KES 130.6. If we reduce the period to annual, fluctuations will be even more apparent. But this demonstrates how volatile the Kenyan shilling was against the dollar.

The reason for the depreciation, as it was approximated that Kenyan shillings dropped around 22% in value against the US dollar from March 2022 till January 2024 was due to the COVID-19 pandemic and its effects, the Ukraine- Russia war which led to sanctions against Russia

[1] https://www.xe.com/currencycharts/?from=USD&to=KES&view=10Y

halting disrupting supply chains, Kenyan debt burden among others (Mbugua, 2024). This shows that the Kenyan shilling is affected, not only due to how the Kenyan economy performs, but external factors beyond its control.

1.1.2. Exchange rate volatility relationship with economic indicators

There have been papers done which investigated how volatility of the exchange rate is linked with Economic growth, inflation, interest rates and trade balance.

Yensu (2022) concluded that exchange rate volatility was found to have a detrimental impact on economic growth when he investigated the impact of exchange rate on Ghana's economic growth. Additionally, he discovered a negative relationship between trade openness and exchange rate volatility.

Musa (2021) studied the effect of exchange rate volatility on inflation in Nigeria. He discovered that inflation is positively correlated with the nominal exchange rate, which shows that inflation is impacted by exchange rate volatility.

Mohammed (2021) investigated the connection between Ghanaian interest rates and exchange rate volatility. Changing the policy rate had an impact on currency movements because it was found that the exchange rate's historical value and the Central Bank's policy rate had a significant influence on the exchange rate volatility in the short run.

Barasa (2013) investigated the connection between Kenya's Balance of Payments and exchange rate volatility. He concluded that the BOP is more impacted by other causes than exchange rate volatility. Although loosening of the exchange rate had increased Kenya's BOP overall, it hasn't assisted in closing the trade deficit

The findings are as we would have expected them to be. The more volatile the exchange rate is, the more uncertainty and less confidence in the economy. This slows down economic growth. The unpredictable export prices will also worsen the trade balance, as less volumes are exported as traders are cautious due the unpredictable prices. We also expect exchange rate volatility to be associated with higher inflation rates due to lack of stability e.g. the volatile USD/KES exchange rate may cause consumers and businesses to predict the shilling to

depreciate, so businesses raise prices to counter rising costs due to depreciating currency. Since interest rates affect currency movements directly, one should expect a positive association between interest rate differentials and volatility i.e. the more interest rate changes, the more volatile the exchange rate is.

All in all, there seems to be a negative relationship between the exchange rate and economic growth, trade balance. A positive association between volatility and inflation. Finally, a strong association between interest rate changes and volatility.

This discussion is vital as it shows the importance of studying exchange rate volatility and how it affects important economic indicators. This is particularly important in Kenya, where the exchange rate has seen periods of high volatility in certain periods.

1.1.3. Regime switching.

The aspect of the research which perhaps differentiates this research paper from others done is the aspect of regime-switch. This applies to time series data. Conventional time series models assume that the behavior of the data over all time can be described by a single set of model parameters. From the facts we come across in the real world, this assumption isn't necessarily true.

Real-world time series data may vary throughout different time periods in terms of their variances and means. Models of regime switching:

1) Give data a characteristic that it belongs to distinct, regimes (or states).
2) Allow for variations in the statistical measures such as mean, variance, and model parameters of time series data between regimes.
3) Assume that there is a chance that the series could be in one of the regimes at any given time and could change to a different regime.

These aspects will allow regime transition models to more accurately represent the actual behavior of empirical data than traditional models (Eric, 2021). When there are variations in the time series data between "states," these models work well.

In the case of this paper, exchange rate volatility does exhibit varying degrees of volatility from

low to high volatility. Looking at figure 1, we can see how fluctuations are more discernible in 2023, while the period of 2017, the exchange rate was more stable. This shows that volatility also exhibits characteristics of regime switching.

1.2. Problem Statement

It is crucial to understand the link between the volatility of the exchange rate and economic indicators because the former can significantly affect the latter. Mahmood (2011) demonstrated how rising volatility can cause economic instability, which has an impact on Pakistan's most important economic indicators. Also, research done by Musyoki (2012) demonstrated that, between 1993 and 2009, exchange rate volatility had a detrimental impact on Kenya's economic growth.

In Kenya, we have seen that USD/KES exchange rate has exhibited significant volatility such as the period of 2023, which impacts various sectors of the economy.

Despite the recognized importance of exchange rate stability, there is a shortage of detailed analysis on the relationship between USD/KES exchange rate volatility and key economic indicators in Kenya. Many papers have put emphasis on modelling volatility e.g. through the GARCH model, but these papers have not studied how analysing different volatility structures can provide a deeper understanding of effects of volatility.

In short, previous research has not adequately addressed the regime-dependent nature of exchange rate volatility and its differential impacts across various economic indicators in Kenya. For example, how high volatility exchange rate affects the indicators in comparison to low volatility. This will also give a more thorough understanding of exchange rate volatility and its relationship with economic indicators. Previous studies have just analysed the relationship between volatility and economic indicators in different countries. This makes it difficult to draw conclusions about the relationship between volatility and economic indicators. Regime switching will also enable us to make easier comparisons.

This study aims to fill this gap by using a regime switching linear regression model to study the relationship between of USD/KES exchange rate volatility, in its various volatility structures such as high and low, and economic indicators particularly GDP growth, inflation

rate, trade balance, and interest rates in Kenya over the past decade. The paper is not interested in the causal relationship between variables, just the relationship in different regimes.

1.3. Research objectives

1.3.1. Main objective

To analyze the relationship between USD/KES exchange rate volatility and key economic indicators in Kenya using regime- switching linear regression.

1.3.2. Particular Objectives

1. To analyze the relationship between USD/KES exchange rate volatility and key economic indicators in Kenya using linear regression on the entire dataset (1-regime model).

2. To analyze the relationship between USD/KES exchange rate volatility and key economic indicators within each identified regime (2 and 3 regimes) using regime-switching linear regression models.

3. To compare the results of the whole dataset model with the regime-specific models to assess the differences in the impact of exchange rate volatility on economic indicators.

1.3.3. Research questions

1. What is the relationship between USD/KES exchange rate volatility and key economic indicators when using the entire dataset?

2. How does the relationship between USD/KES exchange rate volatility and key economic indicators vary across different volatility regimes?

3. How do the results of regime-specific models compare to those of a single model using the entire dataset in terms of explanatory power and economic insights

1.4. Significance of Research

- Policy Makers: This research will help provide valuable insights for policymakers in Kenya regarding how different volatilities in exchange rates will have varying relationships with the economic indicators. Understanding how fluctuations in the KES/USD exchange rate influence economic variables such as GDP, inflation, trade balance, and interest rates will enable policymakers to develop more effective and targeted economic policies depending on the current volatility. This research will emphasize the specific types of exchange rate volatility that have the most significant impact on economic indicators, allowing policymakers to prioritize stabilizing measures in those areas. Furthermore, the regime-switching approach used in this study can offer detailed scenarios under different volatility conditions, enhancing the ability of policymakers to respond proactively to potential economic disruptions.

- Economists and Analysts: For economists and financial analysts, this research offers a fresh perspective of the analysis of the connection between exchange rate volatility and economic performance in Kenya. The findings will be instrumental in economic forecasting and modeling, providing a clearer understanding of how current volatility structures might influence future economic behavior. Researchers can analyze data with increased frequency, such as weekly observations. This study can highlight the importance of having detailed data and the importance of having increased frequency data, in improving the accuracy of economic predictions.

- Academic Contribution: This study makes a significant contribution to the academic literature on exchange rate volatility and economic performance by employing a regime-switching approach. This methodology provides a new perspective and a better comprehension of the ways in which various exchange rate volatility regimes impact economic metrics. While previous studies have explored the relationship between foreign exchange volatility and economic performance, this research adds depth by differentiating the impacts of varying volatility levels. Such differentiation can lead to more refined economic theories and models, fueling further and more comprehensive future research in this field. The analysis presented in this study can be a reference point for researchers aiming to further investigate the dynamics between exchange rate fluctuations and economic indicators.

2. Literature Review

The paper will first conduct a theoretical review, then an empirical review before stating the gaps filled and the contribution of the paper.

2.1. Theoretical Review

2.1.1. Purchasing Power Parity Theory

Gustav Cassel created the idea in 1918. The theory holds, according to Cassel, that "the quotient between the internal purchasing power against goods of the money of each country primarily determines the rate of exchange between two countries." This basically means that in every nation, a unit of currency should be equivalent to a basket of commodities and services in terms of purchasing power. Using KES/USD as an example, the PPP exchange rate would be 1 USD = 100 KES if a basket of items costs $100 in the US and 10,000 KES in Kenya. Megaravalli and Vikram (2016) in their review, say how most economists believe this theory anchors Long-run real exchange rates. In the short term, price fluctuations can help explain volatility in the exchange rate.

According to Dornbusch (1985), the theory is often known as the inflation theory of exchange rates since it identifies changes in price levels as the primary factor influencing exchange rate fluctuations. According to the idea, one important factor influencing exchange rate volatility is inflation.

2.1.2. Interest Rate Parity Theory

This theory explains the connection between two nations' interest rates and the value of their respective currencies. It is assumed that the differences in interest rates between two nations will have an impact on their exchange rates. Stated differently, a nation's interest rate is determined by the value of its currency relative to that of its trading partners. As a result, the exchange rate between the two nations' currencies ought to be explained by the variations in their respective interest rates (Megaravalli & Vikram, 2016). One variation that aids in this explanation is the parity of the covered interest rate.

The idea of covered interest rate parity, or CIP, states that one should not make money by borrowing money in one currency, exchanging it on the spot market for another currency,

lending the foreign currency, and then selling it forward at the original time on the open market (Raja, 2016). This implies that the interest rate differential between two currencies should be equal to the difference between their forward and spot exchange rates. (Raja, 2016) showed that mathematically (tweaked for our context):

$$\frac{F}{S} = \frac{(1 + i_d)}{(1 + i_f)}$$

Where:

F= Forward exchange rate

S= Spot exchange rate

I_d = Domestic interest rate (Kenya rate in our case)

I_f = Overseas interest rate (US interest rate)

An explanation of how interest rate differences between Kenya and the US impact exchange rate volatility and movements may be found in IRP theory.

2.1.3. Regime Switching model

This mini section will discuss not theory, but of the aspect of regime switching modelling and its importance.

Hamilton (1989) paper was based on when processes were subject to discrete shifts in regime, there can be stark changes in behaviour of the process. The starting point is to characterize changes in an autoregressive process's parameters using a Markov switching regression. For instance, the result of a Markov process determines whether the economy is in the fast growth or slow growth phase of the economic cycle. He concentrated on changes in GNP. He pointed out that while his research was based on a nonlinear stationarity process, studies on GNP had been conducted using a linear stationarity method.

The periodic transition from a positive growth rate to a negative growth rate is a recurring feature of the U.S. business cycle, according to an empirical application of this technique to postwar real GNP in the United States. In fact, this technique could be used objectively to define and quantify economic recessions. According to the predicted parameter values, a normal economic recession is linked to a permanent 3% decline in the level of GNP. The actual model and process was beyond my scope of comprehension, but this demonstrates how regime switching can provide more information.

Szulczyk and Zhang (2019) paper discusses a regime in finance and economics that refers to a certain market or economic condition or structural change. Switching behavior, or the parameter of a regression varying according to the size or regime of a variable, has been extensively recognized for financial and economic variables such as exchange rates. This phenomenon is typically not well described by the linear regression (LR) model, which assumes a linear connection between the dependent and explanatory variables. This finding is used to inform a switching-regime regression (SRR) analysis that examines the S&P 500 market return in relation to seven explanatory variables, with the goal of better understanding investor behavior.

It is shown that, in comparison to LR, the new regression produces a much-enhanced adjusted R2, increasing from less than 4% to over 50%. Furthermore, whereas the fitted values from LR do not reflect the 2008 financial crisis, those from the new regression do. Additionally, SRR results in improved out-of-sample forecasting ability. The study found that switching-regime regression improves the data's goodness of fit and other statistical properties significantly and brings the data closer to the theory of investor behavior.

2.2. Empirical Literature Review

Now the empirical review will be conducted. The review of papers will occur in chronological order, not in order of importance or location.

Iqbal Mahmood (2011) paper's aim was to ascertain whether Pakistan's macroeconomic variables are impacted by exchange rate volatility or uncertainty. Only four macroeconomic indicators were examined in the study: trade openness, GDP, FDI, and growth rate. The others were identified as dependent variables, while the real exchange rate volatility was selected as an independent variable. The GARCH model was used in this work to determine the real exchange rate volatility, and the Ordinary Least Squares regression technique was used to look at the relationship between the dependent and independent variables.

The study's findings confirmed the hypothesis that exchange rate volatility affects Pakistan's macroeconomic indicators. Furthermore, it is determined that although fluctuations in exchange rates have a negative effect on foreign direct investment, they have a favorable

influence on GDP, growth rate, and trade openness. The report explains that the country's exporters and international importers will attempt to capitalize as much as possible on the volatility of foreign currencies, which will raise demand for goods thus GDP and growth rate. The higher value of imports in Pakistan's total import and export value has a beneficial impact on trade openness as well. A volatile exchange rate deters international investors from making investments, which has a detrimental effect on foreign direct investment (FDI).

The method used in the paper is like the initial methodology plan of the paper, just that it will bring the aspect of regime switching and that the dependent variable will be foreign exchange volatility. The paper does not specify how the GARCH model was used to calculate volatility. Also, yearly data was taken, where ideally for volatility, monthly, weekly or daily data is more comprehensive but was not available, especially for variables like GDP, a situation which this paper will encounter.

Musyoki (2012) paper was done in Kenya which brings in the local context. The impact of real exchange rate (RER) volatility on Kenya's economic growth was investigated in this article. The study covered the period from January 1993 to December 2009. Throughout the investigation, it was discovered that RER was extremely erratic. Over the duration of the study, Kenya's RER generally shown a growing and variable pattern, indicating a loss in the country's international competitiveness. Kenya's economic growth was negatively impacted by the RER Volatility. This demonstrated the effect of exchange rate fluctuation on economic expansion.

The paper's methodology was quite thorough, explaining why the GARCH model was chosen to represent volatility rather than the standard deviation approach, which ignored volatility clusters and the skewness of the RER data. Additionally, the weighted average exchange rate of all of Kenya's trading partners was calculated first, and inflation was then taken into consideration, before computing the RER. The moments of the Generalized approach were not clearly specified. The main focus of the paper was just economic growth. Additionally, totality (the entire period) variability was modeled in connection to economic growth.

Jattani (2013) was also based in Kenya. Investigating the variables that affect Kenyan exchange rates and their impact on those rates was the aim of the study. This investigation used a quantitative approach to its design. To ascertain the relative significance of each variable in

relation to the exchange rate in Kenya, a multivariate regression model was utilized. Interest rates, the balance of payments, inflation rates, and political factors were the variables. According to the study's findings, Kenya's exchange rate is rising and was previously high. The study goes on to say that the average annual interest rate, inflation rates, balance of payments, and political factors all have a major impact on Kenya's exchange rates. The paper modelled exchange rate in relation to the above variables. This paper will follow a similar model, but will use exchange rate volatility, with regime switching.

BARASA (2013) focused on Balance of Payment. Finding the relationship between Kenya's BOP and exchange rate volatility was the aim of this study. A quantitative comparative design was employed in the study to ascertain the correlation between the two variables. The author used linear regression for the analysis. The study concludes that other factors have a bigger impact on the levels of BOP than the exchange rates that are discussed here. Due to Kenya's status as a net importer, the study suggests that BOP be a significant part of the country's development because Kenya is a net importer. The result was interesting and worth investigating, as this paper believed the exchange rate had an impact on Balance of payment. The thought process is, the exchange rate used was USD/KSH, so maybe a study where a weighted average with all trading partners, currency, is calculated and then finds the relationship with Balance of Payment.

Megaravalli (2016) was an interesting paper based in India. The main aim of the research was to analyze the impact of India's macroeconomic variables—such as GDP, inflation, interest rates, and foreign direct investment (FDI)—on the country's exchange rate in relation to the US dollar spanning the years 1996 to 2014. These variables were regarded as independent, and the volatility of the exchange rate as the dependent variable. To examine the relationship, linear regression method was used.

The findings of the regression analysis indicate that whereas interest rates and exchange rates have a negative and substantial link, the relationship between inflation and GDP rate is negative and negligible. However, there is a small but favorable association between the exchange rate and foreign direct investment. The report gives a comprehensive overview of previous research on each variable's relationship to volatility in foreign exchange. Although the study was intended to model exchange rate volatility, it appeared that the author had only included the

exchange rate as the dependent variable in the analysis i.e. the methodology used to calculate volatility was not explained.

Ehikioya (2019) is a paper done, very similar to Musyoki (2012) paper, but based in Nigeria. The purpose of the study was to investigate how Nigeria's economic growth is impacted by exchange rate volatility. The study period was from January 1980 to December 2017 using the Generalized Method of Moments (GMM) technique and the GARCH model. The estimates' findings demonstrate that exchange rate volatility has a detrimental impact on Nigeria's economic development. According to this result, the Nigerian economy cannot grow if there is too much volatility brought on by a lack of inflows. In the paper, control variables were used in the regression such as inflation, money supply, government expenditure and thus part of the regression used to help account for their effects on economic growth. Additionally, the study provided evidence that exchange rates remain volatile during the course of the investigation, i.e. a shock will be followed by a prolonged period of volatility. It will be interesting to see if this persistence is also demonstrated in this paper's analysis.

Musa (2021) undertook a study to investigate how Nigerian inflation is affected by exchange rate volatility using annual time series data from 1986 to 2019. The money supply (MS), import (IMP), export (EPT), and nominal exchange rate (NER) were the independent variables in the study, while the consumer price index—a proxy for inflation—was used as the dependent variable. The money supply (MS), the nominal exchange rate (NER), and the consumer price index showed a positive and substantial link in the results, suggesting that changes in the exchange rate and an increase in the money supply both contribute to inflation in Nigeria. This serves to emphasize that fluctuations in exchange rates can have a big effect on inflation.

Mohammed (2021) did research that examines the impact of interest rates on the volatility of Ghana's exchange rate. It uses the Quarterly Time Series dataset, which covers the period from 2000 Quarter 1 to 2017 Quarter 2, to examine the short- and long-term associations between the variables. The link was expressed using linear regression. The results showed that the long-run model's forecast of exchange rate volatility was influenced by the money supply, inflation, the central bank's policy rate, and the composite index of the Ghana Stock Exchange. However, it was shown that the historical values of the exchange rate and the policy rate of the Central Bank had a significant influence on the short-run model's exchange rate volatility.

Here, volatility was the dependent variable like it will be in my study, it shows interest rates impacts volatility.

The empirical studies reviewed establishes a broad understanding of how exchange rate volatility impacts various economic indicators such as economic growth, inflation, interest rates and trade balance and how complex this relationship can be. This underscores the need for a deeper understanding of the impact exchange rate volatility has. Thus, there is a need for more models, such as regime-switching models, to capture these dynamics effectively. By comparing the whole dataset model with regime-specific models, this research aims to provide deeper insights into these relationships and improve the accuracy of predictions, addressing the gaps identified in the literature.

2.3. Research/knowledge gap

Although previous research has examined the connection between economic indicators and exchange rate volatility, there are still a number of gaps:

1) Regime-Specific context: A lot of research fails to distinguish between times of high, medium, and low volatility, which could lead to the omission of important differences in these relationships. This is the biggest gap which this research hopes to fill. More research should be done later, that incorporates complex regime models while modelling volatility.

2) Deeper understanding of exchange rate volatility: Linked with the first point, the aspect of using regime-switching models to get a deeper understanding of the relationship between exchange rate volatility and several economic indicators has not received much attention in previous studies.

3) Kenyan context: The paper will put emphasis on Kenya, i.e. the link between exchange rate volatility and economic indicators in Kenya.

2.4. Contribution of the study

Seeing the gaps, the contribution of the study will be:
Using Regime-Switching Model: To gain a deeper understanding of these relationships, separate analyses of periods of high, medium, and low volatility are conducted using regime-switching linear regression models.

Comparative analysis compares the output of models for the entire dataset with models tailored to a particular regime in order to identify differences and produce predictions that are more accurate by studying the volatility currently.

Focus on Kenya: Will add to a more deeper understanding of the impact of exchange rate volatility for the Kenyan economy.

3. Methodology

3.1. Research design

The study employed quantitative research design. Specifically, an explorative and correlational design was used to analyze the relationship between USD/KES exchange rate volatility in Kenya and key economic indicators. The explorative design helped identify patterns and relationships within the data, such as periods of highest volatility, while the correlational design measured the degree and direction of associations between economic indicators (such as GDP growth, inflation rate, trade balance, and interest rates) and exchange rate volatility in different regimes (high, medium, and low volatility). This was achieved by regressing volatility (in its various regimes) against these economic indicators. This combination was justified as it provided a comprehensive understanding of how different regimes of exchange rate volatility correlated with the economic indicators.

3.2. Population and Sampling

The population consisted of all relevant economic data from Kenya over the past decade. The sample included quarterly data points for the exchange rate (USD/KES) and the selected economic indicators. The economic indicators used were GDP growth rate, inflation rate, trade balance, and interest rates. A purposive or deliberate sampling technique was employed, selecting the period from 2010 to 2023. This period was chosen due to the accessibility of detailed data and the occurrence of significant economic events, such as presidential elections and the COVID-19 pandemic. These events captured periods of economic stability and volatility, providing a robust dataset with sufficient data points for analysis.

3.3. Data collection

Secondary sources were used in the data collection process. The Central Bank of Kenya (CBK)[2] provided the data sources. The data collected included the USD/KES monthly exchange rate, monthly foreign trade summaries, monthly Central Bank rate (used as the interest rate), monthly inflation rate, and quarterly GDP at market prices. Since GDP data was available

[2] https://www.centralbank.go.ke/

quarterly, quarterly data was extracted from the rest of the variables to ensure consistency. The CBK, as the data source, was deemed credible for these variables because it is the official public institution responsible for formulating monetary policy in Kenya and maintaining price stability. It provided open-source data available to the public, ensuring transparency, verifiability, and regular updates for key economic statistics.

3.4. Data Analysis

The data analysis was divided into five parts to achieve the research objectives. First, all the variables used in the data analysis were defined. The second part involved obtaining foreign exchange volatility. The third part focused on simple linear regression, modeling the relationship between foreign exchange volatility and the economic indicators. The fourth part addressed the regime-switching aspect, where volatility was split into different regimes, such as high volatility, and modeled with the economic indicators. The final part involved validating the model.

3.4.1. Defining the variables

Table 1: List of variables

Number	Variables	Code	Description
1	USD/KES exchange rate	ER	The price of $1 in terms of KES.
2	USD/KES exchange rate volatility	σ	Deviation of exchange rate from average (this will be measure for foreign exchange volatility)
3	Economic Growth	GDP	Total amount produced in the country.
4	Inflation rate	INF	Annual percentage change in price level
5	Trade Balance	TB	Exports - Imports
6	Central Bank rate	CBR	Interest rate the Central Bank charges to Commercial Banks. Used as a measure of interest rate.

NB: σ which denotes standard deviation in its true definition, here it is just used to denote volatility which is measured as deviation shown in 3.4.2. part iv). Volatility is a measure of variation, and the paper used σ to denote it, not the true definition.

3.4.2. USD/KSH Exchange Rate Volatility.

Since the aim of the research was not to model volatility through methods like GARCH, but to obtain a measure of volatility, I used the following process to obtain it:

i) Calculate the Mean exchange Rate per Quarter

Assuming daily exchange rate data, E_d, where d represented each day within a quarter, the mean exchange rate for each quarter was calculated by averaging the daily exchange rates within that quarter.

$$E_{Q_k} = \frac{1}{n_k} \sum_{d=1}^{n_k} E_d$$

E_{Q_k} represent the mean exchange rate for quarter k.

n_k is the number of days in quarter k.

ii) Calculate the Percentage Change in Exchange Rate

Let E_t represent the exchange rate at time t. The absolute percentage change in exchange rate for a given quarter can be expressed as:

$$\Delta E_t = ABS(\frac{E_t - E_{t-1}}{E_{t-1}} \times 100)$$

I use Absolute value to ensure all percentage changes are positive as study is more interested in deviation from mean.

iii) Calculate the Average Percentage Change Over the Period

Let $\underline{\Delta E}$ represent the average percentage change over the entire period of interest:

$$\underline{\Delta E} = \frac{1}{n} \sum_{t=1}^{n} \Delta E_t$$

Where n is the total number of quarters

iv) Calculate the Deviation of Each Quarter's Percentage Change from the Average

The absolute value of the deviation for each quarter from the average percentage change is given by:

$$\sigma = ABS(\Delta E_t - \underline{\Delta E})$$

σ is the deviation of the percentage change in exchange rate for quarter t from the average percentage change.

3.4.3. linear regression model

The economic model that was used was:

$$\sigma = f(GDP, INF, TB, CBR)$$

The dependent variable was the volatility of the USD/KES exchange rate, while the independent variables were GDP, inflation rate, trade balance, and the Central Bank rate. This framework encapsulated the relationship between exchange rate volatility and the economic indicators.

The initial base Linear regression looked like:

$$\sigma_t = \alpha + \beta_1 GDP_t + \beta_2 INF_t + \beta_3 TB_t + \beta_4 CBR_t + \epsilon_t$$

Where:

σ_t *is the exchange rate volatility at time t*

α *is the intercept*

β_1 *is the co − efficient of GDP*

β_2 *is the co − efficient of Inflation*

β_3 *is* co-efficient of Trade balance

β_4 *is the co − efficient of the Central Bank rate*

ϵ_t *is the error term*

In the previous section, the deviation was calculated in terms of percentage change. To ensure all variables were expressed in the same terms (i.e., as percentages), the GDP growth rate,

inflation rate, trade balance as a percentage of GDP, and Central Bank rate were used. This approach ensured data consistency.

$$\sigma_t = \alpha + \beta_1 \Delta GDP_t + \beta_2 INF_t + \beta_3 TB_t/GDP_t + \beta_4 CBR_t + \epsilon_t$$

If β_1= 0.5, a 1% increase in GDP is associated with a 0.5% increase in the exchange rate volatility measure.

The significance of the beta coefficient was tested using the T-test, which determined whether β_i was significantly different from zero by evaluating the p-value associated with the T-test. A small p-value (typically less than 0.05) indicated that the coefficient was significantly different from zero. (Beers, 2024):

$$t = \frac{\widehat{\beta_\iota}}{SE(\widehat{\beta_\iota})}$$

where $\widehat{\beta_\iota}$ is the estimated coefficient and $SE(\widehat{\beta_\iota})$ is its standard error.

3.4.4. Regime switching aspect

In part b), after obtaining the USD/KES foreign exchange volatility, percentiles were used for the regime switching. The 33rd percentile of the volatility data was computed and denoted as Q1, the median (50th percentile) as Q2, and the 66th percentile as Q3. This approach ensured that the data was split equally among regimes.

To analyze the effect of regimes, three regime scenarios were defined.

- One regime model: this scenario included a single regime that modeled the full data set using the equation outlined in Section 3.4.3.

- Two regime model (High/Low Volatility):
    - Low Volatility Regime: Included observations with volatility less than the median (Q2), denoted by L.

- High Volatility Regime: Included observations with volatility greater than or equal to the median (Q2), denoted by H.

- Three regime model (High/Medium/Low Volatility):
  - Low Volatility Regime: Included observations with volatility less than Q1, denoted by L.
  - Medium Volatility Regime: Included observations with volatility between Q1 and Q3, denoted by M.
  - High Volatility Regime: Included observations with volatility greater than Q3, denoted by H

After defining the regimes, linear regression was applied again, this time with the specific regimes. The two-regime model was first analyzed, followed by the three-regime model.

For the two-regime model (high/low volatility)

$$\sigma_t = \alpha_L + \beta_{1L}\Delta GDP_t + \beta_{2L}INF_t + \beta_{3L}TB_t/GDP_t + \beta_{4L}IR_t + \epsilon_{tL}$$

$$\sigma_t = \alpha_H + \beta_{1H}\Delta GDP_t + \beta_{2H}INF_t + \beta_{3H}\Delta TB_t/GDP_t + \beta_{4H}IR_t + \epsilon_{tH}$$

For the three-regime model (high/medium/low volatility)

$$\sigma_t = \alpha_L + \beta_{1L}\Delta GDP_t + \beta_{2L}INF_t + \beta_{3L}TB_t/GDP_t + \beta_{4L}IR_t + \epsilon_{tL}$$

$$\sigma_t = \alpha_M + \beta_{1M}\Delta GDP_t + \beta_{2M}INF_t + \beta_{3M}TB_t/GDP_t + \beta_{4M}IR_t + \epsilon_{tM}$$

$$\sigma_t = \alpha_H + \beta_{1H}\Delta GDP_t + \beta_{2H}INF_t + \beta_{3H}TB_t/GDP_t + \beta_{4H}IR_t + \epsilon_{tH}$$

We used t-stat again to test the significance of the Beta co-efficient for each regime.

3.5. Model Validation

3.5.1. R^2 for each model

R^2 (coefficient of determination) was used to measure how well the independent variables explained the variability of the dependent variable on scale from 0%-100%. The higher the percentage, the better the model was in terms of explaining the variation (Fernando, 2024). It was calculated as:

$$R^2 = 1 - \frac{SS_{res}}{SS_{tot}}$$

Where SS_{res} is the residual sum of squares and SS_{tot} is the total sum of squares.

We compared the R^2 values of the whole dataset model and the regime-specific models to see which model explained the variability of the dependent variable better.

3.5.2. AIC (Akaike Information Criterion) and BIC (Bayesian Information Criterion)

Hirotugu Akaike developed the AIC (Akaike Information Criterion) model selection criterion, which penalized models for complexity while estimating the relative quality of multiple models. (Kumar, 2023)

AIC was calculated as:

$$AIC = 2k - 2\ ln\ ln\ (L)$$

Where *k* is the number of parameters in the model and *L* is the maximum likelihood of the model.

In many instances, it was difficult to calculate the Likelihood, so we used an alternate method to calculate, where we used the sum of squared of errors or residuals (SSE):

$$AIC = 2k + n\ ln\ ln\ \left(\frac{SSE}{n}\right)$$

Where *k* is the number of parameters in the model, n is the number of observations, SSE is the sum of squared of errors.

Another model selection criterion that considered both model fit, and complexity was the Bayesian Information Criterion (BIC), which was comparable to AIC. Compared to AIC, BIC, which was founded on Bayesian principles, offered a more robust penalty for model complexity. (Kumar, 2023)

BIC was calculated as:

$$BIC = k\ ln\ ln\ (n)\ - 2\ ln\ ln\ (L)$$

Where *k* is the number of parameters in the model, *L* is the maximum likelihood of the model and n is the number of observations.

Again, due to the difficulty in calculating the likelihood, we used an alternate method involving sum of squared of errors:

$$BIC = k\ ln\ ln\ (n)\ + n\ ln\ ln\ \left(\frac{SSE}{n}\right)$$

Where *k* is the number of parameters in the model, n is the number of observations, SSE is the sum of squared of errors.

Lower AIC and BIC values indicate better models.

4. Data Analysis and Results

4.1. Data Description

Data analysis for this study was conducted using Microsoft Excel. Following the methodology outlined earlier, the quarterly data for the following variables was compiled: exchange rate, exchange rate deviations, GDP growth rate (calculated as the percentage change in GDP between corresponding quarters of consecutive years, e.g., comparing Q1 of 2009 to Q1 of 2010), inflation rate, trade balance as a percentage of GDP, and the Central Bank rate.

Before proceeding with the modeling and analysis, it is essential to provide an overview of the compiled data. This description will offer a clearer understanding of how the variables evolved during the study period, spanning from the beginning of 2010 to the end of 2023.

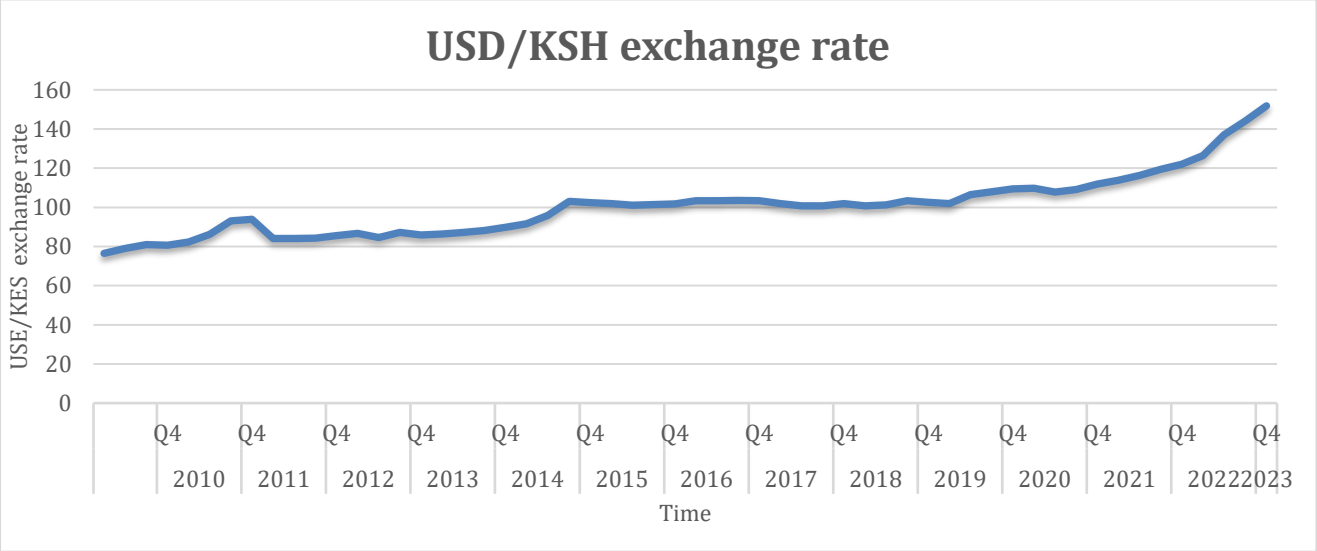

Figure 2: Quarterly USD/KSH exchange rate from 2010 Q1 till 2023 Q4

Figure 2 above illustrates the value of the Kenyan shilling (KES) relative to 1 USD. It shows a general depreciation of the Kenyan shilling against the US dollar. Notably, from the beginning of 2022 onwards, the rate of depreciation accelerated. Additionally, increased volatility in the exchange rate is evident in 2011, as indicated by the noticeable spike in the graph.

When we looked at the summary statistics of exchange rate from 2010 to 2023, the average USD/KES exchange rate was 100.49, with a median of 101.54, suggesting a slight skew above the mean. The exchange rate exhibited moderate volatility, reflected in a standard deviation of 15.62. Over this period, the rate ranged significantly, fluctuating between a minimum of 76.49 and a maximum of 151.84 KES, resulting in a total range of 75.35 KES.

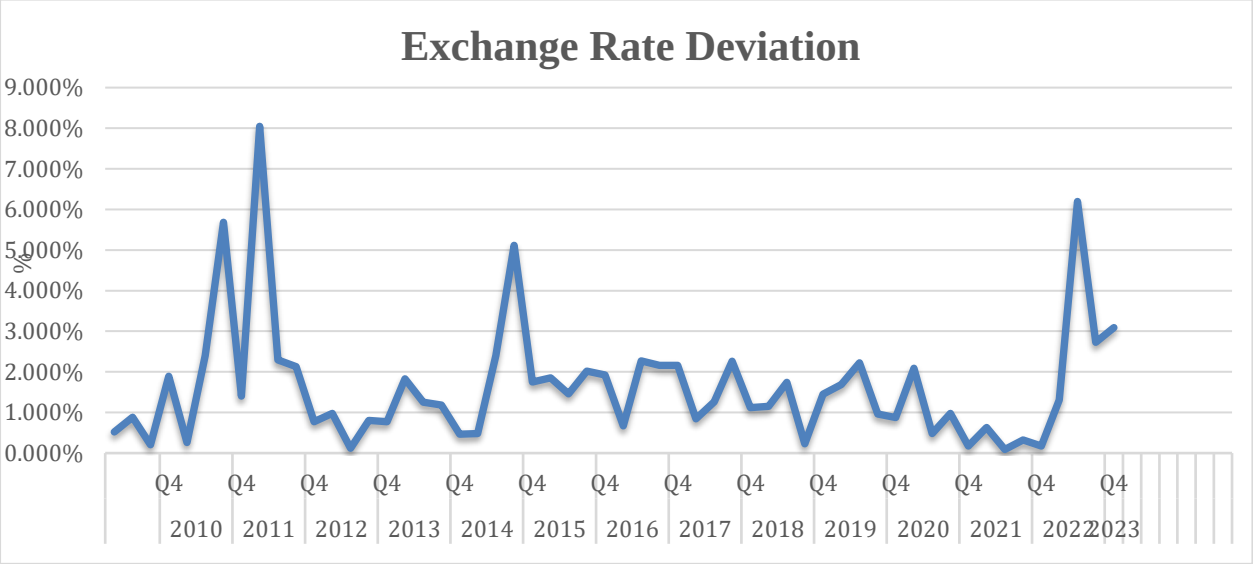

Figure 3: USD/KSH deviation for period of 2010 Q1-2023 Q4

Figure 3 shows exchange rate deviation, which is a measure of exchange rate volatility, represented as a percentage. The greater the percentage, the greater the exchange rate volatility is. In terms of trend, the volatility was low but fluctuated in 2010, before volatility increased, and fluctuated in 2011 and early 2012 where it became 8%, the highest in the study period. The Volatility declined in late 2012 and stabilized after, until early 2015 when there was a brief spike. From 2016 onwards, the volatility stabilized and fluctuated between 0.5%-2% until early 2022, where volatility % increased again to 6% in 2023.

When we looked at the summary statistics of exchange rate deviation, the average exchange rate deviation during the period was 1.65%, indicating a modest level of fluctuation around the baseline exchange rate and reflecting the general variability in the USD/KES rate over time. The median deviation, slightly lower at 1.28%, suggested that most deviations were concentrated below the average, with a few higher values skewing the mean upward. This trend

is evident in Figure 3, where the majority of deviations ranged between 0.5% and 2%, interspersed with periods of elevated volatility that increased the overall mean deviation percentage. The deviation ranged from a low of 0.09% to a high of 8.05%, highlighting periods of relative stability alongside instances of significant volatility. Notably, the mean and median deviations were much closer to the minimum than to the maximum deviation, emphasizing the asymmetry in the data.

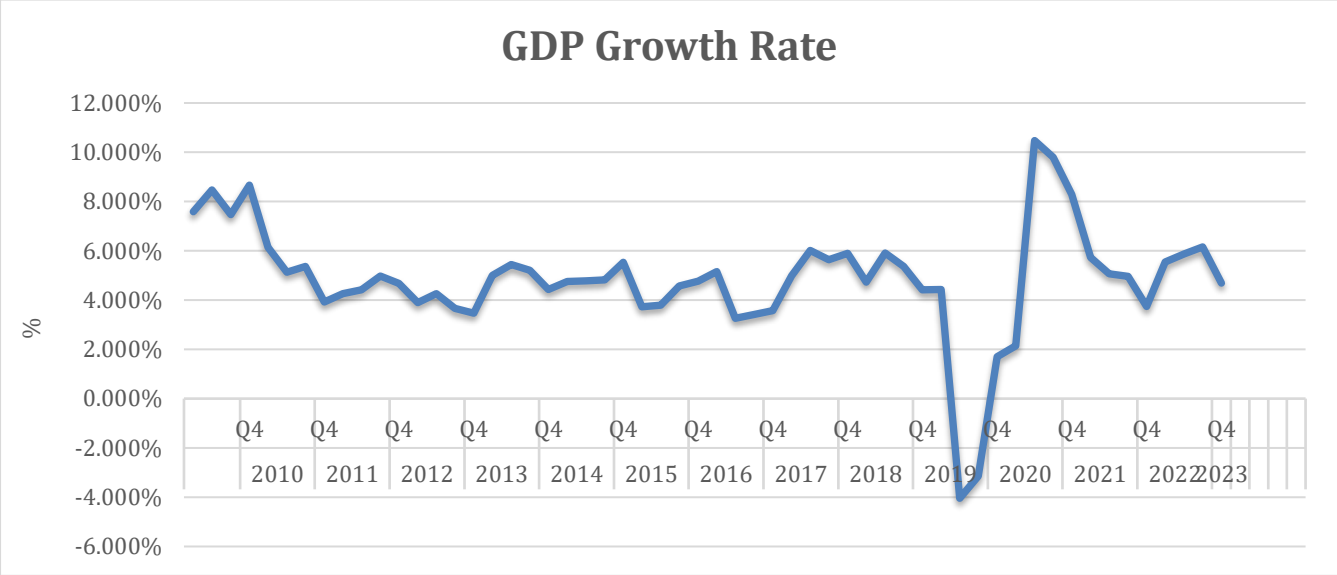

Figure 4: GDP Growth rate for the period of 2010 Q1-2023 Q4

When we looked at figure 4, GDP Growth rate was around 8% in 2010, before the growth rate fell to almost 3% in 2013 before growth rate stabilized and fluctuated between 4%-6% from 2014-2019. Then the Growth rate fell dramatically to -4% in 2020 Q2, before it rose dramatically to 10.5% in 2021 Q2. The rate fell again and oscillated around 4%-6% from 2021 Q4 till 2023 Q4.

When we looked at the summary statistics of GDP growth rate, the average GDP growth rate over the period was 4.87%, indicating moderate economic growth. The median growth rate, at 4.89%, was closely aligned with the mean, suggesting that growth rates were centered around this level with minimal skewness. Variability in annual GDP growth was moderate, as indicated by a standard deviation of 2.33%, reflecting fluctuations in economic performance over the years. GDP growth exhibited a broad range, spanning from a low of -4.04% to a high of 10.48%. The minimum rate of -4.04% occurred during a recessionary period, such as the

COVID-19 pandemic, while the maximum rate of 10.48% reflected robust economic recovery following the pandemic.

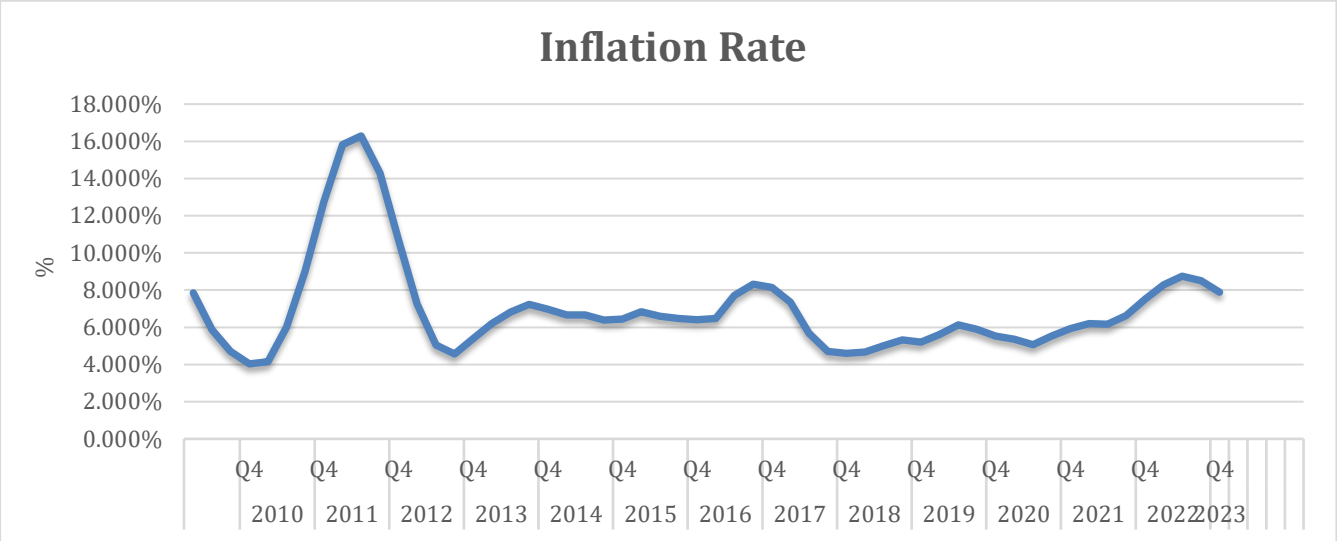

Figure 5: Inflation rate for the period of 2010 Q1-2023 Q4

When we looked at figure 5, Inflation rate initially fell in 2010 from 8% to 4% before inflation rate spiked and reached 16% in Q2 2012. It is interesting to note that this was a similar period when exchange rate deviation % was at its highest i.e. volatility was high. The inflation rate fell again to almost 4% by the end of 2013. Since then, the inflation rate has oscillated between 4%-8.5% from 2014 till end of 2023.

When we looked at the summary statistics for inflation rate, the average inflation rate over the period was 6.99%, reflecting a moderately high inflation environment. The median inflation rate, at 6.42%, was slightly below the mean, indicating that most values were clustered around this level, with some higher rates pulling the mean upward. Inflation demonstrated moderate variability, with a standard deviation of 2.58%, reflecting the changing economic conditions throughout the years. The inflation rate fluctuated significantly, ranging from a minimum of 4.03% to a maximum of 16.29%. The peak of 16.29% likely signaled a period of economic pressure which may have occurred due to the 2012 elections.

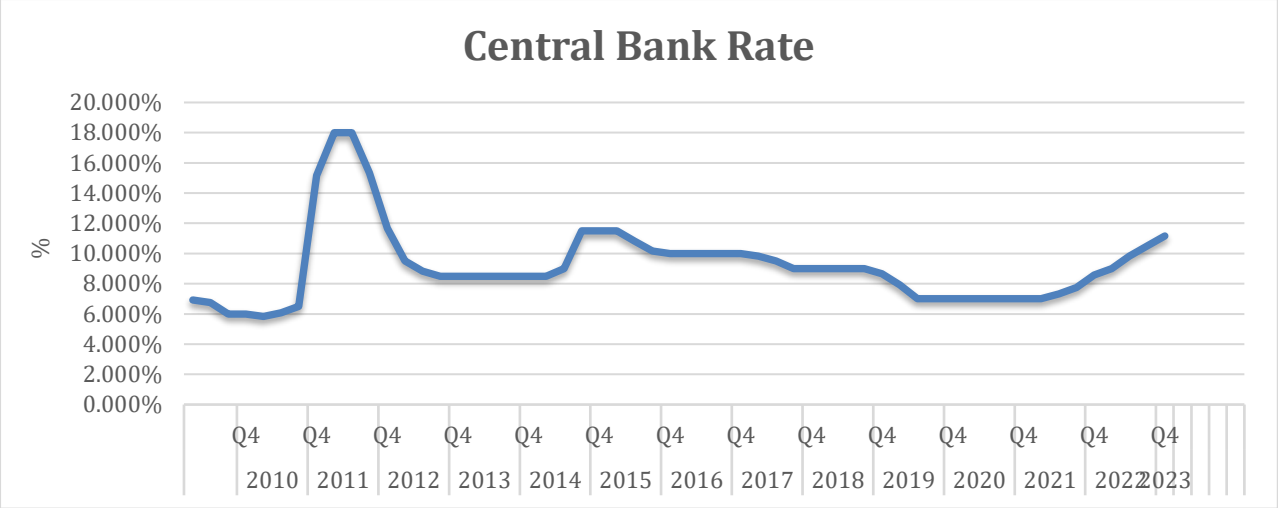

Figure 6: Central Bank rate for the period of 2010 Q1-2023 Q4

When we looked at the Central Bank rate trend follows a similar pattern to the inflation rate trend, which makes sense because if the inflation rate increases, the Central Bank rate will need to increase as part of a contractionary monetary policy to help reduce and control the rate of inflation. This is why Central Bank rate was highest at 18% at Q2 2012. It was initially around 6% around early 2011. Post 2012, the central bank rate fell to around 8.5% and remained so from late 2013 till late 2015, before the rate increased to 11.5% in 2016. The Central Bank rate then steadily declined to 7% in mid-2022 before increasing to 11% by 2023 end.

When we looked at the summary statistics of the CBR, the average CBR over the period was 9.21%, reflecting a moderate interest rate policy. The median CBR, at 8.92%, was close to the mean, indicating that the rates were balanced with minimal skewness. CBR exhibited moderate variability, with a standard deviation of 2.61%, suggesting that policy adjustments were made in response to changing economic conditions. CBR fluctuated between a low of 5.83% and a high of 18.00%, with the maximum occurring during periods of heightened inflation, such as in 2012.

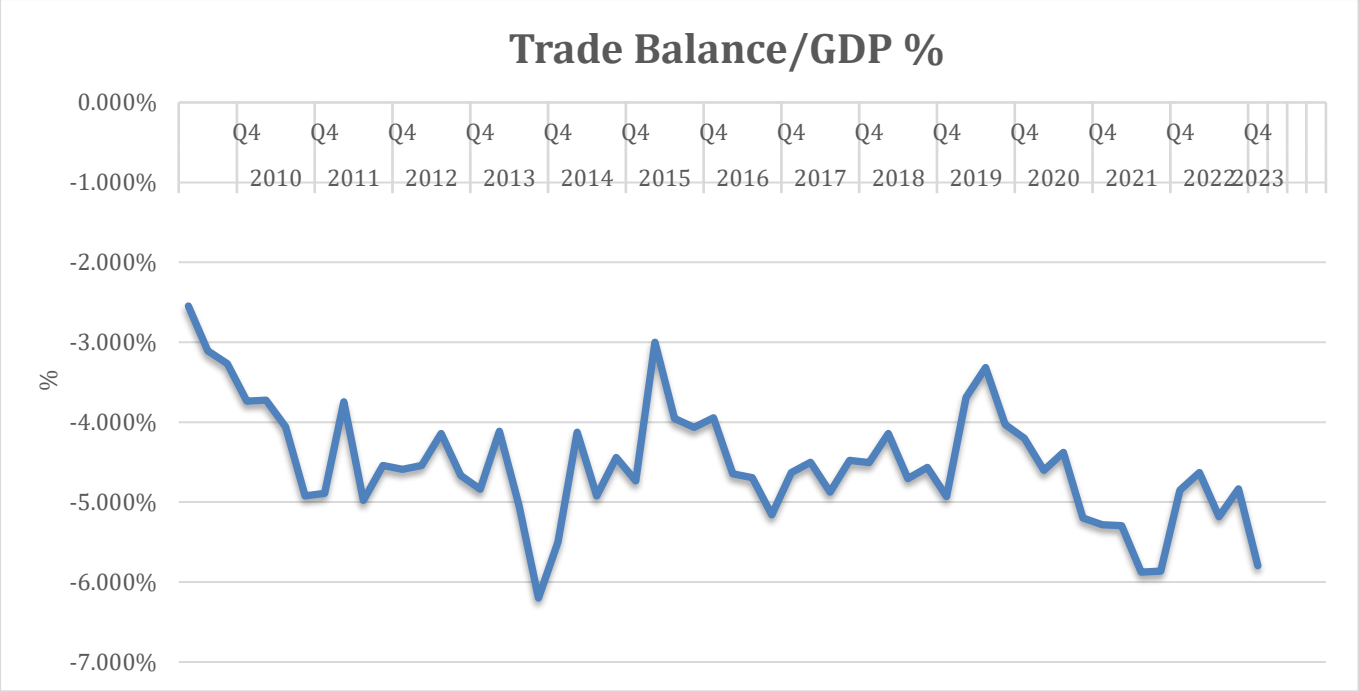

Figure 7: Trade Balance as a percentage of GDP for the period of 2010 Q1-2023 Q4

The percentages are always negative indicating Kenya operated with a trade deficit for the entire period i.e., imports were always greater than exports. The trade balance % was highest at start of period at around -2.5% before it declined steadily to -5% at end of 2011. It then fluctuated for 2 years before it declined steeply to -6.2% by 2014. It then rose again to -3% in 2016. Trade balance % fell again before it fluctuated between -4% to -5% from 2017-2019. It then rose again to -3.3% in 2020 before a general decline in trade balance %.

When we looked at the summary statistics for trade balance, the average trade balance over the period was -4.52% of GDP, indicating a consistent trade deficit. The median trade balance, at -4.60%, closely aligned with the mean, suggesting that the deficit remained stable throughout the period. With a standard deviation of 0.73%, the trade balance exhibited low variability, reflecting a stable trade deficit relative to GDP. The trade balance ranged from -6.20% to -2.55%, showing a narrow spread, with the maximum deficit of -6.20% associated with higher imports or weaker exports.

4.2. Determination of Regimes

The study has three regimes' scenarios as discussed in 3.4.4. The 1-regime model involves the entire data set which was fifty-six observations.

The 2-regime model split the data into two regimes, which is why the median was used, as it ensured equal data points in each regime. The median exchange rate deviation was 1.284%. 28 observations had a deviation which was less than 1.284% which was the 2-regime low volatility model, while 28 observations had deviation greater than 1.284% which was the 2-regime high volatility model.

The 3-regime model split the data into 3 regimes, which is why the 33rd and 67th percentile was used. This ensured each regime had almost an identical number of observations. The 33rd percentile exchange rate deviation was 0.8795% while the 67th percentile exchange rate deviation was 1.885%. 19 observations had a deviation of less than 0.8795% which was the 3-regime low volatility model. 18 observations had a deviation between 0.8795% and 1.885%, which was the 3-regime medium volatility model. 19 observations had a deviation greater than 1.885% which was the 3-regime high volatility model.

4.2.1. 1-regime model volatility regression analysis

The R Square of 0.2395 indicated that the independent variables (GDP growth rate, inflation, trade balance, and central bank rate) accounted for 23.9% of the variance in exchange rate volatility. This was comparatively low, indicating that volatility may be influenced by other factors.

The F-statistic tests of the overall regression model was significant. Since the p-value (0.0066) was below 0.05, the model was statistically significant, which meant that, collectively, the independent variables explain a significant amount of the variation in exchange rate volatility.

Table 2: Co-efficient of independent variables

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.001483456	0.013586807	0.109183543	0.913485387
GDP growth rate	-0.025266689	0.080954105	-0.31211127	0.756228477
inflation	0.206359319	0.131091871	1.574158016	0.121634696
Central Bank Rate	0.091295531	0.129655603	0.704138727	0.484549264
Trade balance as % of GDP	0.146446464	0.259293109	0.564791192	0.574691783

The regression analysis revealed varying relationships between exchange rate volatility and the economic indicators, though none were statistically significant. GDP growth rate had a coefficient of -0.0253, indicating a slight negative relationship, where higher GDP growth marginally reduced exchange rate volatility. However, the high p-value of 0.756 suggested this relationship was not statistically significant. Inflation showed a positive coefficient of 0.2065, implying that higher inflation rates were associated with increased volatility, but the p-value of 0.121 exceeded the 0.05 threshold, indicating a lack of statistical significance. Similarly, the Central Bank Rate had a coefficient of 0.0913, suggesting a minor positive impact on volatility, though the p-value of 0.485 confirmed this effect was not significant. Lastly, the trade balance as a percentage of GDP had a coefficient of 0.1464, indicating a positive but statistically insignificant relationship with exchange rate volatility, as evidenced by the p-value of 0.575.

To conclude, for the 1-regime model, although none of the individual predictors are significant at the 5% level, the model as a whole is statistically significant. This implied that although some exchange rate volatility can be explained by the model, no single independent variable stood out as having a significant impact by itself.

4.2.2.1. 2-regime model low volatility regression analysis

The R-squared value of 0.1275 suggested that about 12.75% of the variability in exchange rate volatility was explained by the model. This low R-squared indicated that the independent variables only slightly explained changes in exchange rate volatility within the low-volatility regime.

The F-statistic for the model was 0.840 with a p-value of 0.514, indicating that the overall model was not statistically significant. This suggested that the combination of the four variables does not significantly predict exchange rate volatility in the 2-regime low-volatility regime.

Table 3: Co-efficient of independent variables

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.001423328	0.006145276	0.231613294	0.818886604
GDP growth rate	-0.012179256	0.029452281	-0.413525064	0.68305235
inflation	-0.037385069	0.063526693	-0.588493853	0.561936107
Central Bank Rate	0.107921213	0.066807701	1.615400784	0.119859917
Trade balance as % of GDP	0.013630693	0.091225273	0.149417951	0.882526317

The analysis of this regime revealed weak and statistically insignificant relationships between exchange rate volatility and the economic indicators. The GDP growth rate had a coefficient of -0.0122 and a p-value of 0.683, indicating a very weak negative relationship with exchange rate volatility that lacked statistical significance. Similarly, inflation showed a coefficient of -0.0374 with a p-value of 0.562, suggesting a weak negative association that was not significant. The Central Bank Rate, with a coefficient of 0.1079 and a p-value of 0.120, displayed a potential positive relationship with volatility, though it did not reach statistical significance. Lastly, the trade balance as a percentage of GDP had a coefficient of 0.0136 and a p-value of 0.883, indicating a negligible and insignificant positive relationship with exchange rate volatility in this regime.

To conclude, this model for the low-volatility regime does not provide a statistically strong explanation for exchange rate volatility. The low R-squared and high p-values across variables suggested that other factors may be more relevant in predicting exchange rate volatility within this regime.

4.2.2.2. 2-regime model high volatility regression analysis

The R square was 0.1914, which meant that this model explained about 19.14% of the variability in exchange rate volatility within the high-volatility regime. While higher than in the low-volatility regime, it still suggested that the independent variables provide a limited explanation for changes in exchange rate volatility.

The F-statistic was 1.361, with a high p-value of 0.2782 (greater than common significance levels like 0.05). This high p-value suggested that the independent variables, taken together, do not provide a statistically significant prediction of exchange rate volatility in the high-volatility regime.

Table 4: Co-efficient of independent variables

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.017046461	0.023936471	0.712154333	0.483531293
GDP growth rate	0.098533324	0.155940458	0.631865039	0.533705895
inflation	0.350851195	0.192617344	1.821493267	0.081564924
Central Bank Rate	-0.173946821	0.193393852	-0.899443386	0.377737393
Trade balance as % of GDP	0.109345366	0.526341689	0.207745972	0.837255835

In high-volatility periods, the relationship between exchange rate volatility and the economic indicators varied in strength and significance. The GDP growth rate had a coefficient of 0.0985 with a p-value of 0.534, indicating a positive but weak and statistically insignificant relationship. Inflation exhibited a coefficient of 0.3509 and a p-value of 0.082, suggesting a relatively stronger positive association with exchange rate volatility. While this relationship approached significance, it fell slightly short of the conventional threshold of 0.05. The Central Bank Rate showed a weak negative relationship, with a coefficient of -0.174 and a p-value of 0.378, though this was not statistically significant. Lastly, the trade balance as a percentage of GDP had a coefficient of 0.1093 and a p-value of 0.837, reflecting an insignificant positive relationship with exchange rate volatility during these periods.

To conclude, in this high-volatility regime, inflation showed the strongest (although still statistically insignificant) association with exchange rate volatility, suggesting it may play a

more prominent role in periods of high currency fluctuation. However, the overall model had limited explanatory power, and most variables do not significantly predict exchange rate volatility.

4.2.3.1. 3-regime model low volatility regression analysis

The R-Square was 0.2493 which meant that this model explained approximately 24.93% of the variation in exchange rate volatility in the low-volatility regime. This was relatively low, which indicated that the chosen independent variables only account for a small part of the changes in volatility.

The F-statistic was 1.163 with a high p-value (0.369), which implied that, collectively, the variables in this model are not statistically significant predictors of exchange rate volatility. This result suggested that these variables, in this low-volatility context, may have limited predictive power.

Table 5- Co-efficient of independent variables.

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.005054169	0.005931049	0.852154353	0.408469881
GDP growth rate	-0.039027527	0.035579918	-1.096897598	0.291195519
inflation	0.013910235	0.054954816	0.253121307	0.803853463
Central Bank Rate	0.051633477	0.062070366	0.831853915	0.419454588
Trade balance as % of GDP	0.072640675	0.078232586	0.928521981	0.368869892

The analysis revealed weak and statistically insignificant relationships between exchange rate volatility and the economic indicators in this regime. GDP growth rate had a coefficient of -0.0390 and a p-value of 0.291, suggesting a weak negative association that lacked statistical significance. Inflation exhibited a coefficient of 0.0139 and a high p-value of 0.804, indicating a very weak and statistically insignificant positive relationship with volatility. Similarly, the Central Bank Rate showed a coefficient of 0.0516 and a p-value of 0.419, pointing to a weak positive but insignificant association. The trade balance, with a coefficient of 0.0726 and a p-

value of 0.369, also demonstrated a small, statistically insignificant positive relationship with exchange rate volatility.

None of the variables, either separately or in combination, significantly predicted exchange rate volatility in this low-volatility regime. The low R-squared and limited significance imply that additional data may strengthen the model's robustness or that other factors may provide a more compelling explanation for exchange rate volatility in low-volatility settings.

4.2.3.2. 3-regime model medium volatility regression analysis

The R-squared was 0.3326, which indicated that about 33.26% of the variation in exchange rate volatility in the medium-volatility regime was explained by this model. This is a moderate fit, which suggested that independent variables contribute meaningfully to explaining exchange rate volatility, especially compared to the low volatility scenario.

The F-statistics were 1.620 with a p-value of 0.228, which indicated that, collectively, the independent variables are not statistically significant predictors of exchange rate volatility at conventional levels. However, this regime had more explanatory power than the low-volatility regime.

Table 6: Co-efficient of independent variables

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.00993928	0.005460228	1.820305019	0.091803883
GDP growth rate	0.000823722	0.029197546	0.028212015	0.977921554
inflation	-0.081924574	0.057974301	-1.413118799	0.181114824
Central Bank Rate	0.123557924	0.052325902	2.361314739	0.034490571
Trade balance as % of GDP	0.059618131	0.099275885	0.600529837	0.558477882

In the medium-volatility regime, the relationships between exchange rate volatility and the economic indicators varied in significance and direction. GDP growth rate had a coefficient of 0.0008 and a high p-value of 0.978, indicating no significant relationship with exchange rate volatility. Inflation showed a negative association, with a coefficient of -0.0819 and a p-value of 0.181, but this relationship was not statistically significant. The Central Bank Rate, with a

coefficient of 0.1236 and a p-value of 0.034, exhibited a statistically significant positive relationship at the 5% level, suggesting that increases in the rate were associated with higher exchange rate volatility. Lastly, the trade balance as a percentage of GDP showed a weak and statistically insignificant positive relationship, with a coefficient of 0.0596 and a p-value of 0.558.

In the medium-volatile regime, the central bank rate was the only statistically significant predictor of exchange rate volatility, which suggested a link between policy rate adjustments and volatility. Other variables, while moderately correlated with volatility, were not statistically significant in this regime.

4.2.3.3. 3-regime model high volatility regression analysis

The R-squared was 0.1933, which indicated that approximately 19.33% of the variation in exchange rate volatility in this high-volatility regime was explained by the model. This suggested a weak explanatory power for the selected variables.

The model as a whole was not statistically significant in explaining exchange rate volatility, as indicated by the F-statistic of 0.839 and the p-value of 0.523. This low significance indicated that the independent variables' combined impact in this highly volatile scenario is minimal.

Table 7: Co-efficient of independent variables

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	0.021303106	0.033541029	0.635135711	0.535583295
GDP growth rate	0.118317179	0.183896264	0.643390883	0.530368939
inflation	0.308554112	0.266800793	1.156496231	0.266832033
Central Bank Rate	-0.113206094	0.264740276	-0.427611907	0.675437941
Trade balance as % of GDP	0.203065166	0.745435756	0.272411357	0.789282324

In the high-volatility regime, the relationships between exchange rate volatility and the economic indicators were generally weak and statistically insignificant. GDP growth rate had a coefficient of 0.1183 with a high p-value of 0.530, indicating no meaningful association with

volatility. Inflation exhibited a positive relationship, with a coefficient of 0.3086 and a p-value of 0.267, suggesting that higher inflation might slightly increase the volatility of the exchange rate, though this effect was not statistically significant. The Central Bank Rate, with a coefficient of -0.1132 and a p-value of 0.675, showed a weak negative relationship that lacked significance. Similarly, the trade balance as a percentage of GDP had a positive coefficient of 0.2031 but a high p-value of 0.789, highlighting an insignificant influence on exchange rate volatility in this regime.

In the high-volatility regime, none of the independent variables were statistically significant predictors of exchange rate volatility. The model's explanatory power was low, suggesting that other factors outside GDP growth rate, inflation, central bank rate, and trade balance might better capture exchange rate volatility in this regime.

4.3. Comparison of Regimes and discussion

To gain deeper insights from the regression results, it was necessary to compare the performance of each regime model collectively and evaluate the benefits of segmenting the data into distinct regimes.

A key metric for comparison was the weighted R-squared, which measures the explained variance across combined regimes, weighted by the number of observations. The analysis revealed that the 1-regime model achieved a weighted R-squared of 0.239, while the 2-regime model slightly underperformed with a weighted R-squared of 0.159. However, the 3-regime model demonstrated improvement, achieving a weighted R-squared of 0.257, indicating a better fit when the data was split into three regimes.

Additionally, model comparisons were carried out using AIC and BIC which provided further evaluation of the models' performance. These results offered valuable insights into the trade-offs between model complexity and explanatory power across the different regime structures:

Table 8: AIC and BIC results

1 regime AIC	**1 regime BIC**
-474.7482933	-464.6215349
2 regime AIC	**2 regime BIC**
-535.6780581	-522.356013
3 regime AIC	**3 regime BIC**
-574.8790922	-560.9828437

The analysis of AIC and BIC values revealed consistent improvements as the number of regimes increased. Since lower AIC and BIC values indicate better model fit, the results suggest that the 3-regime model provided a superior fit compared to the 1-regime and 2-regime models.

This finding implies that introducing additional regimes enhances the model's ability to capture variations in exchange rate volatility. The increased number of regimes allows the model to account more distinctly for the different behaviors observed in exchange rate volatility across varying conditions.

Considering both AIC/BIC values and the weighted R-squared, the 3-regime model emerged as the most effective, offering a better balance between complexity and explanatory power than the 1-regime and 2-regime models.

4.3.1. Impact of Increased Regimes

With reference to the 3-regime model, each regime represented a unique state of exchange rate volatility (low, medium, and high). These regimes allowed the regression to better capture the varying relationships between exchange rate volatility and the independent variables (GDP growth rate, inflation, central bank rate, and trade balance as a percentage of GDP).

The results in Section 4.2.3 (3-regime linear regression results) showed that in low volatility periods, macroeconomic indicators had weaker and less significant relationships with exchange rate volatility, primarily reflecting times of stability. In medium volatility periods, this regime represented an intermediate state where changes in the central bank rate became the most important factor in explaining exchange rate volatility, as it was the only statistically significant

variable, while other variables had limited influence. In high volatility periods, inflation played a stronger role in driving exchange rate movements, whereas monetary policy appeared to mitigate volatility, as indicated by the negative relationship between the central bank rate and exchange rate volatility. GDP growth's positive association suggested that high growth periods may exacerbate volatility during times of elevated exchange rate fluctuations.

The distinction in coefficients across different regimes explained why introducing multiple regimes improved model fit. Having low, medium, and high volatility regimes aligned with real-world scenarios where the economic drivers of exchange rate volatility varied depending on the prevailing economic environment. By allowing these relationships to differ across regimes, the 3-regime model captured nuances missed by the single-regime model, resulting in:

- Lower AIC and BIC values.
- A higher weighted R-squared compared to the 1-regime and 2-regime models.

Introducing additional regimes also provided more insights into how each variable influenced exchange rate volatility under different conditions. For instance, the central bank rate became significant in the medium volatility regime, highlighting the effectiveness of monetary policy during transitional periods. However, its stabilizing role diminished in the high volatility regime, where it was no longer statistically significant, likely due to market forces overwhelming policy impacts. Furthermore, the coefficient for the central bank rate was positive in the medium volatility regime but negative in the high volatility regime, suggesting that its effects depended on the prevailing volatility regime.

In contrast, the 1-regime model provided a more generalized view of the relationships between macroeconomic variables and exchange rate volatility. For example, the central bank rate coefficient in the 1-regime model was positive, suggesting that higher rates might be associated with greater exchange rate volatility. However, this model did not offer insights into the differential impacts of the central bank rate across different volatility regimes.

It is important to note that splitting the data into more regimes resulted in fewer observations per regime, which sometimes reduced the statistical significance of individual coefficients. This was evident in the higher standard errors and lower t-statistics observed in the 3-regime model compared to the 1-regime model.

5. Conclusion and Recommendations

The objective of this study was to analyze the relationship between USD/KES exchange rate volatility and key economic indicators (GDP growth rate, inflation, trade balance, and central bank rate) in Kenya over the past decade. The research employed a regime-switching linear regression model to capture the varying impacts of these indicators across different volatility regimes: low, medium, and high. By utilizing quarterly data from 2010 to 2023, the study aimed to provide a nuanced understanding of the relationships between exchange rate volatility and macroeconomic factors under different volatility conditions.

The key findings demonstrated that the relationships between exchange rate volatility and economic indicators varied across regimes. In low-volatility periods, the macroeconomic indicators showed weak and statistically insignificant relationships with volatility, reflecting periods of economic stability. In medium-volatility periods, the central bank rate emerged as the only statistically significant variable, indicating its critical role in transitional economic states. In high-volatility periods, inflation played a more prominent role in driving exchange rate movements, while the central bank rate exhibited a stabilizing, albeit insignificant, influence. The comparison of models revealed that the 3-regime model provided the best fit, as evidenced by the lowest AIC and BIC values and the highest weighted R-squared. This highlighted the advantage of regime-specific analysis in capturing the complexities of exchange rate volatility.

From these findings, several conclusions were drawn. First, exchange rate volatility is not uniformly influenced by macroeconomic indicators; rather, the impact varies depending on the volatility regime. Second, inflation and the central bank rate consistently showed stronger impacts on exchange rate volatility compared to GDP growth and trade balance as they highlighted by their lower p-values. Inflation and central bank rate changes are therefore more critical, especially in periods of high and medium volatility underscoring the importance of monetary policy in managing volatility. Lastly, regime-specific models offer a more detailed and accurate representation of the dynamics between exchange rate volatility and economic indicators, compared to traditional single-regime models as evidenced by the lower AIC/BIC scores and higher weighted average R-squared value.

The analysis faced several limitations. One key limitation was the smaller number of observations within each regime due to the partitioning of data, which reduced the statistical

power of the models. Additionally, the study relied on quarterly data, which, while sufficient for broader trends, may not fully capture shorter-term fluctuations.

Based on the research, the following recommendations are suggested:

For Policymakers: Emphasize targeted monetary policies to address volatility-specific conditions. For instance, inflation control measures should be prioritized in high-volatility regimes, while interest rate policies should focus on transitional periods. Understanding the regime-specific impacts can enable more effective and timely interventions.

For Economists and Analysts: Incorporate regime-switching models into economic forecasting and analysis to better account for the differential impacts of exchange rate volatility across conditions. This approach provides a deeper understanding of the underlying relationships and improves predictive accuracy.

For Further Research: Future studies should consider higher-frequency data, such as monthly or weekly observations, to capture short-term volatility dynamics. Additionally, exploring the inclusion of external factors like political events and global economic shocks could enhance the robustness of the analysis.

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Appendices

Appendix 1: Summary statistics for exchange rate, dependent variable and independent variables

Table 9. Summary Statistics of USD/KSH exchange rate

Exchange rate	
Mean	100.4864881
Median	101.535
Standard Deviation	15.6240598
Range	75.35
Minimum	76.49
Maximum	151.84

Table 10: Summary statistics for Exchange rate deviation

Exchange rate deviation	
Mean	1.6471%
Median	1.2835%
Standard Deviation	1.5264%
Range	7.9578%
Minimum	0.0891%
Maximum	8.0469%

Table 11: Summary statistics for GDP Growth Rate

GDP growth rate	
Mean	4.874257%
Median	4.890405%
Standard Deviation	2.329198%
Range	14.518869%
Minimum	-4.043191%
Maximum	10.475679%

Table 12: Summary statistics for Inflation Rate

Inflation	
Mean	6.99408%
Median	6.42000%
Standard Deviation	2.58014%
Range	12.25667%
Minimum	4.03333%
Maximum	16.29000%

Table 13: Summary statistics for Central Bank Rate

Central Bank Rate	
Mean	9.208%
Median	8.917%
Standard Deviation	2.607%
Range	12.167%
Minimum	5.833%
Maximum	18.000%

Table 14: Summary statistics of Trade Balance as a percentage of GDP

Trade balance as % of GDP	
Mean	-4.52071%
Median	-4.59586%
Standard Deviation	0.72720%
Range	3.65329%
Minimum	-6.19967%
Maximum	-2.54638%

Appendix 2: 1-regime volatility model statistics

Table 15: 1- regime model regression statistics

Regression Statistics	
Multiple R	0.489359338
R Square	0.239472561
Adjusted R Square	0.179823351
Standard Error	0.013824032
Observations	56

Table 16: ANOVA (Analysis of Variance)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	0.003068884	0.000767221	4.014681131	0.00660828
Residual	51	0.009746297	0.000191104		
Total	55	0.012815182			

Appendix 3: 2-regime low volatility model statistics

Table 17: 2-regime low volatility summary statistics

Regression Statistics	
Multiple R	0.357041035
R Square	0.127478301
Adjusted R Square	-0.024264603
Standard Error	0.003791593
Observations	28

Table 18: ANOVA (Analysis of Variance)

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	4.83093E-05	1.20773E-05	0.840093985	0.513948818
Residual	23	0.000330652	1.43762E-05		
Total	27	0.000378961			

Appendix 4: 2-regime high volatility model statistics

Table 19: 2-regime high volatility summary statistics

Regression Statistics	
Multiple R	0.437470662
R Square	0.19138058
Adjusted R Square	0.050751116
Standard Error	0.015746408
Observations	28

Table 20: ANOVA (Analysis of Variance)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	0.001349723	0.000337431	1.360885367	0.278180615
Residual	23	0.005702835	0.000247949		
Total	27	0.007052558			

Appendix 5: 3-regime low volatility model statistics

Table 21: 3-regime low volatility model summary statistics

Regression Statistics	
Multiple R	0.499347485
R Square	0.249347911
Adjusted R Square	0.034875885
Standard Error	0.002653454
Observations	19

Table 22: ANOVA (Analysis of Variance)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	3.2743E-05	8.18575E-06	1.162612747	0.368707617
Residual	14	9.85715E-05	7.04082E-06		
Total	18	0.000131314			

Appendix 6: 3-regime medium volatility model statistics

Table 23: 3-regime medium volatility model summary statistics

Regression Statistics	
Multiple R	0.576705885
R Square	0.332589678
Adjusted R Square	0.127232656
Standard Error	0.002976553
Observations	18

Table 24: ANOVA (Analysis of Variance)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	5.73966E-05	1.43492E-05	1.619568079	0.228293155
Residual	13	0.000115178	8.85987E-06		
Total	17	0.000172575			

Appendix 7: 3-regime high volatility model statistics

Table 25: 3-regime high volatility model summary statistics

Regression Statistics	
Multiple R	0.439672724
R Square	0.193312104
Adjusted R Square	-0.037170152
Standard Error	0.018031833
Observations	19

Table 26: ANOVA (Analysis of Variance)

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	0.001090841	0.00027271	0.838728793	0.523112147
Residual	14	0.004552058	0.000325147		
Total	18	0.005642898			