

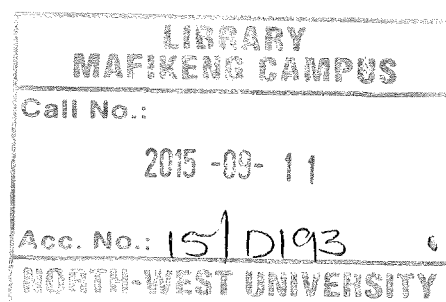
**Exchange rate volatility in South Africa: A comparative analysis of  
the ARCH and GARCH models**

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**Full dissertation submitted in fulfilment of the requirements  
for the degree Master of Commerce in Statistics at the  
Mafikeng Campus of the North-West University**

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**November 2014**



## DECLARATION

I declare that the study titled “*Exchange rate volatility in South Africa: A comparative analysis of the ARCH and GARCH models*” towards the award of the M.Com degree is my own work, that it has not been submitted for any degree or examination in any other university, and that all the sources I have used or quoted have been indicated and acknowledged by complete references.

Full names..... Date.....

Signed.....

Signature..... Date.....

Supervisor

## **ACKNOWLEDGEMENTS**

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I am particularly grateful for the post graduate bursary given to me by the North West University Mafikeng Campus (NWU). Finally, I wish to thank my family for their support and encouragement throughout my studies.

## **DEDICATION**

“Other things may change us, but we start and end with family”. Anthony Brandt.

Here goes this dissertation to my loving mother Reginah, my brother Tsie and wonderful sister Pinky, my two nephews and niece – Keaobaka, Aobakwe and Omphemetse and lastly my late brothers, Andrew and Thapelo.

## ABSTRACT

*In SA, the Rand has been particularly volatile over the course of the 1990s. For a country that depends largely on foreign trade like SA, during periods of excessive volatility in exchange rate, foreign trade and investments are affected negatively. The main purpose of this study was to assess exchange rate volatility in SA. It was important to investigate this subject since volatility in the exchange rate causes lot of uncertainties in terms of foreign investment and therefore macroeconomic factors such as GDP, INTR and INF are affected negatively.*

*The study applied ARCH (1), GARCH (1, 1) and GARCH (1, 2) models to assess exchange rate volatility in SA. These models were constructed using four variables; namely, exchange rate (ER), gross domestic product (GDP), inflation rate (INF) and interest rate (INTR). Quarterly time series data from the year 1990:Q1 until 2014:Q2 was sourced from SARB and OECD databases. The period was considered mainly because it captures the 2007 and 2008 financial crisis and also gives a clear picture of what happened after the apartheid era.*

*E-Views 8 version was used to obtain results. A detailed analysis for ARCH (1), GARCH (1, 1) and GARCH (1, 2) model estimation was given. Prior to estimating the models, preliminary data analysis was conducted to check variable description. All the variables passed the diagnostics such as independence, unit root and normality. This stage was followed up with primary data analysis applying ARCH (1), GARCH (1, 1) and GARCH (1, 2) frameworks. Three models were constructed and subjected to model diagnostics testing. GARCH (1, 1) model was found to be fit and stable for the data. This model was recommended for further analysis and was later used for producing forecasts of exchange rate volatility in SA for the period 2014:Q3 and 2020:Q4.*

*The ER volatility forecasts showed consistency when compared to the past values proving that GARCH (1, 1) was suitable and valid for forecasting. The model further produced a high volatility constant compared to other models. GARCH (1, 1) – BEKK and GARCH (1, 1) – CCC models were also applied to check volatility spill over effects and conditional volatilities among variables. All variables for both models were statistically significant at 5% level of significance except for ER. The GARCH (1, 1) – BEKK model indicated a high volatility spill over effect for all variables while the GARCH (1, 1) – CCC indicated an independent relationship between the conditional volatilities for all variables except for ER.*

*Based on these findings, the study recommended the use of this model to do further forecasting. These forecasts may be used when embarking on new policies concerning exchange rate in the country. A follow-up study was recommended where other GARCH family models will be estimated and the results compared with those obtained in this study.*

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## LIST OF ACRONYMS

ADF	: Augmented Dickey Fuller
ARDL	: Autoregressive Distributed Lag
AIC	: Akaike Information Criterion
AR	: Autoregressive
ARCH	: Autoregressive Conditional Heteroscedasticity
ARMA	: Auto Regressive Moving Average
BDS	: Brock, Dechert and Scheinkmans
BEKK	: Baba, Engle, Kroner and Kraft
CCC	: Constant Correlation Coefficient
CPI	: Consumer Price Index
ECM	: Error Correction Model
EGARCH	: Exponential Generalized Autoregressive Conditional Heteroscedasticity
CUSUM	: Cumulative Sum Control Chart
ER	: Exchange Rate
FDI	: Foreign Direct Investment
FII	: Foreign Indirect Investment
GDP	: Gross Domestic Product
GARCH	: Generalized Autoregressive Conditional Heteroscedasticity
INF	: Inflation
INTR	: Interest Rate
MA	: Moving average
MAPE	: Mean Absolute Percentage Error
MGARCH	: Multivariate Generalized Autoregressive Conditional Heteroscedasticity
MSE	: Mean squared error
OECD	: Organisation for Economic Cooperative and Development
OLS	: Ordinary Least Squares
OGARCH	: Orthogonal Generalized Autoregressive Conditional Heteroscedasticity
PPP	: Purchasing Power Parity
PP	: Phillips Perron
R	: South African Rand
RESET	: Regression Error Specification Test
SA	: South Africa
SIC	: Schwarz's Information Criterion
SARB	: South African Reserve Bank
TARCH	: Threshold Generalized Autoregressive Conditional Heteroscedasticity
US	: United States
VAR	: Vector Autoregressive

## **CHAPTER ONE**

### **ORIENTATION OF THE STUDY**

#### **1.1 INTRODUCTION**

In the era of globalization, there is a need for foreign currency in order to manage economic activities such as exports, imports and investments. There are other components that benefit from the exchange of foreign currency such as industrialization and advancement, government departments, industries and organisations (Rishipal and Jain, 2012). The availability of various economic resources and means of production in the government depends on the value of the currency (Rishipal and Jain, *ibid*). Therefore, the resources responsible for evaluation of currency are not stable and fixed. Subsequently, the value of currency keeps on changing with respect to its purchasing power in the government and foreign currencies.

As Van Der Merwe and Mollentze (2010) highlighted, if all the countries in the world were to use one currency to purchase and sell goods and services, the whole subject matter of monetary economics would have been completely different. However, each country is represented by its own national currency. For instance, South Africa (SA) has the South African rand, Britain has the British pound, Europe has the European euro, India has the Indian rupee, and the United States (US) has the American dollar, to name but a few (Rishipal and Jain, 2012).

Van Der Merwe and Mollentze (2010) make an example that, when SA exports goods to the US, SA receives American dollars which cannot be used to do in house transaction. Similarly, when goods are being imported from European markets, SA uses its currency to make purchases of goods in Europe, however the South African currency is not acceptable for domestic use in that country.

Van Der Merwe and Mollentze (2010) highlight that these transactions form a market where national currencies are exchanged at a particular rate are called the exchange rate. The authors define exchange rate as the price of one currency in terms of another currency. Mohr, Fourie and Associates (2008); Azid, Jamil and Kousar (2005) and Chaudhary and Goel (2013) proposed similar definition of exchange rate in support of Van Der Merwe and Mollentze (2010).

Exchange rate volatility in SA has remained one of the key research topics for both academics and policy makers (Otuori, 2013). According to Chaudhary and Goel (2013), exchange rate volatility may be caused by a number of factors like interest rates, inflation rates, terms of trade, speculations, foreign direct investment (FDI), imports and exports, foreign indirect investment (FII), GDP, current account deficit, and public debt amongst others.

Exchange rate volatility has been found to have a significant impact on the overall economy of a country as reported by Rishipal and Jain (2012). The adverse consequences of exchange rate volatility on various parts of the domestic economy have now been well documented in numerous research works (Rahmatsyah, Rajaguru, and Siregar, 2002) and Siregar and Rajan 2004). In particular, an appreciation in the exchange rate has been found to have negative consequences on the trade sector (i.e. exports and imports) of the local economy (McKenzie, 1999 and Chou, 2000).

The Economist Intelligence Unit in 2007 asserted that the impact of exchange rate on the economy has become an important question for economic policy makers. The former President Thabo Mbeki created the Myburgh Commission to investigate the causes of the acute depreciation of the rand in 2001. The unit reported that the South African rand remains one of the most volatile of emerging market currencies, and is prone to sharp movements.

Movements in the exchange rate affects the country in such a way that, an appreciation in the exchange rate may create current account problems because it leads to overvaluation, which in turn makes imports artificially cheaper for foreign buyers while the volume of exports becomes relatively expensive for foreign buyers, thus reducing the international competitiveness of a country (Takaendesa, 2006). Furthermore, movements in exchange rate hurt producers and investors alike given that exchange rate affects their projected (planned) revenue and costs, including profits margin (Ben, Obida, Wafure, Nurudeen and Abu, 2010).

The main question posed by this study is: Which factors contributes to exchange rate volatility in SA? To achieve this objective, the study uses related theories as a basis for identifying the determinants. The autoregressive conditional heteroscedasticity (ARCH (q)) and generalized autoregressive conditional heteroscedasticity (GARCH (p, q)) frameworks are used in this study as main models. Models assists in measuring volatility between exchange rate and its determinant factors as it allows the conditional variances to be dependent upon previous own lags and it is simple and possible to interpret the current fitted variances.

The remainder of this study is structured as follows: Section 1.2 study background, Section 1.3 problem statement, followed by research aim and objectives in Section 1.4. Section 1.5 research methodology employed in the study. Section 1.6 highlights the novelty and discusses the significance of the study, contribution of the study follow in Section 1.7. Study scope limitations and delimitations of the study are given in Section 1.8. Ethical considerations in this study are given in Section 1.9. In Section 1.10 lists of terms are defined and the preliminary structure of the entire study is explained in Section 1.11.

## **1.2 BACKGROUND TO THE STUDY**

Exchange rates across the world have fluctuated widely particularly after collapse of the Bretton woods system of fixed exchange rate (Srinivasan and Kalaivani 2012). Excessive fluctuations have been observed in the currency prices of different countries causing lot of uncertainties all around (Chaudhary, Shah and Bagram, 2012). SA was one of the countries that experienced this volatility according to Nyahokwe (2013). The author further states that, this gave rise to lots of debates amongst parties like the South African government and the Congress of South African Trade Union.

After the collapse of the Bretton Woods system, majority of the affected countries initiated the flexible/floating exchange rate system (Chaudhary et al, 2012). The change in the exchange rate regime from fixed to floating exchange rate system in 1983 caused a spike in exchange rate volatility and this had marked effects on economic growth, capital movements and international trade (Insah and Chiaraah, 2013).

Fixed and floating exchange rate systems are two types of exchange rate according to Mohr, et al (2008). Some countries use the fixed exchange rate system, while other countries use the floating exchange rate system. According to their explanation, Rishipal and Jain (2012) are of the view that fixed exchange rate system does not fluctuate overtime, while floating exchange rate system keeps on changing continuously.

Immediately after the move to a floating exchange rate system, exchange rate became highly volatile in Africa which had negative repercussions for trade, investment and growth (Benson, Omojimite and Akpokodje, 2010). SA currently uses the floating exchange rate system, which means that the South African government intervenes only if the exchange rate seems to go out of hand (Noel and Noel, 2012). Government intervenes by increasing or reducing the money supply as the situation demands (Noel and Noel, *ibid*).

In the history of SA, exchange rate has been represented by rising and declining trends over the last few years. Reference can be made to recent information provided by Officer (2014). The figures prove that this construct has been volatile in the 2000s. The following table provides detailed rates of the South African Rand against the US dollar.

**Table 1: South African Rand against the US dollar**

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
R / \$	10.5	7.55	6.44	6.36	6.77	7.05	8.24	8.411	7.31	7.25	8.34

Data provided in table 1 highlight volatility of exchange rate between the years 2002 and 2013. Samson, Ampofo, Mac Quene, Ndlebe, and Van Niekerk (2003), highlighted that this volatility has the potential to unsettle investors and undermine the role of exports in SA's growth strategy.



### 1.3 PROBLEM STATEMENT

In SA, the Rand has been particularly volatile over the course of the 1990s. Exchange rate volatility occurs as a result of a number of elements such as the sharp depreciation of the currency, a large decline in foreign reserves, increase in interest rates or a combination of these elements. Managing exchange rate volatility has been a major challenge facing developing countries, including SA. For a country that depends largely on foreign trade like SA, during periods of excessive volatility in exchange rate, foreign trade and investments are affected negatively. Therefore this impacts on the overall macro-economy and variables such as the real GDP growth, inflation rate and interest rates, to name the few in the country.

Volatility in the exchange rate affects a country in such a way that an appreciation in the exchange rate creates current account problems since it leads to overvaluation. This in turn makes imports artificially cheaper for foreign buyers while the volume of exports become relatively expensive for foreign buyers, thus reducing the international competitiveness of a country. Furthermore, the implication of the volatility in the exchange rate is that it hurts producers and investors alike because it affects their projected (planned) revenue and costs, including profits margin. Therefore, this subject requires a large amount of research attention.

In light of the above mentioned information, this study seeks to build on previous studies by quantitatively measuring the determinants of exchange rate volatility and their casual effects in SA covering the period 1990:Q1 until 2014:Q2. In this regard, an innovative statistical method such as ARCH (q) and GARCH (p, q) are proposed in executing the analysis. These models are suited for this study as it has the ability to handle data with heteroscedastic problems which is a problem encountered in exchange rates.

## **1.4 RESEARCH OBJECTIVES**

The objectives of the study are:

- To identify the factors that contributes to volatility in the exchange rate.
- To construct a multivariate ARCH (q) and GARCH (p, q) models of exchange rate in SA.
- To provide forecasts of the exchange rate in order to help plan for the future.
- To use the findings of the study to provide recommendations to policy makers on how to deal with the problem of exchange rate volatility.

## **1.5 RESEARCH METHODOLOGY**

This Section discusses the manner in which data is collected, data sources, research approach, statistical tests, and the methods that are used for data analyses.

### **1.5.1 RESEARCH APPROACH**

For the purpose of this study, quantitative research method is used. The purpose behind the use of quantitative research approach is based on the nature of this study and the methods that are used for data analysis. This also helps in achieving the objectives of the study.

### **1.5.2 RESEARCH METHODS AND TESTS**

By employing ARCH (q) and GARCH (p, q) model, the study empirically analyses exchange rate volatility in SA. In testing stationarity, the study uses both the formal and informal methods. Informal methods include graphical presentation whereas formal methods include all the statistical tests.

A general multivariate model GARCH (p, q) known as Baba, Engle, Kroner and Kraft (BEKK) representation proposed by Engle and Kroner (1995) is reviewed. Also reviewed is the related model with time-varying conditional variance and covariance called the constant conditional correlations (CCC). Depending on the model selected, GARCH (p, q) and ARCH (q) models are also employed to forecast exchange rate volatility in SA.

Matei (2009) indicate that, when forecasting the volatility with large observations, the appropriate model to use is the GARCH (p, q) model. Statistical methods amongst others include ADF and PP stationarity tests, the Brock, Dechert and Scheinkmans (BDS) test for statistical independence, and model selection criteria.

### **1.5.3 DATA**

The empirical study uses quarterly time series data obtained from the electronic data delivery system of the South African Reserve Bank (SARB) and Organisation for Economic Co-operative and Development (OECD) covering the period 1990:Q1 until 2014:Q2. The sample period is selected because it covers the 2007 and 2008 financial crisis and the period gives a clear trend of what happened after the apartheid era. E-VIEWS version 8 is used for the analysis.

### **1.6 SIGNIFICANCE OF THE STUDY**

The study empirically analyses exchange rate volatility in SA using quarterly time series data during the period between 1990:Q1 and 2014:Q2. Due to the current rising and declining trends in the South African exchange rate, the study is worth undertaking. This study is expected to be beneficial to policy makers as it may help them better exchange rate volatility and its effects on country's economic performance. This study serves as a guide to policy makers in the economic sector especially the SARB and the Department of Treasury in coming up with relevant policies.

This study is also expected to guide policy makers in the country to embark on policies that may help with reducing if not stabilising the problem of exchange rate volatility. SA, as a developing country and a country that other countries are using as a benchmark, it is important to conduct this study given that the findings are to be informative not only to the South African government but also in the African countries that wish to attract investors. Researchers and academicians in the field of finance and economics are to find this study as a useful guide when dealing with issues of exchange rate.

## **1.7 STUDY CONTRIBUTION**

This study is expected to contribute to the growing body of research about volatility in the exchange rate in SA. The results of the study would assist policy makers towards policy planning and formulation. Through the findings of the study, better strategies on how to best manage the volatility of the exchange rate at the same time maintaining a good relationship with foreign countries may be formulated. The contribution of this study lies in investigating not only the volatility itself but also its determinants and their casual effects.

This research is important as similar research has not been conducted with the focus area being factors affecting exchange rate volatility in SA using ARCH (q) and GARCH (p, q) models. Also, this is the first study in SA to analyse quarterly data accommodating the 2006 and 2007 financial crisis. The absence of literature in factors affecting exchange rate volatility in SA is a gap the study seeks to fill. The study could also lead to a conclusion that the subject needs further exploration. Therefore, examining factors that determine exchange rate volatility becomes very important.

## **1.8 LIMITATIONS AND DELIMITATIONS OF THE STUDY**

### **1.8.1 LIMITATIONS**

No matter how well a study can be conducted or constructed, researchers still encounter potential challenges either with data or literature which are out of the researcher's control and sometimes can affect the end results or conclusion that can be drawn. Firstly, the researcher is not familiar with the data collection processes carried out by the sources and how well it was done. Data collection processes and data capturing errors or any omissions regarding data cannot be traced. Secondly, the researcher has no control over what is contained in the data set. This may have influence on the results and the conclusion thereof.

In terms of literature survey, the researcher uses both national and international. Literature highlights several factors such as inflation, current account deficits, GDP economic growth, public debt, terms of trade, economic and political factors, foreign direct investment (FDI), and foreign indirect investment (FII) amongst others which affect exchange rate volatility. From these factors, the researcher uses the purchasing power parity and inflation rates as a basis for choosing the factors.

### **1.8.2 DELIMITATIONS**

The study does not anticipate delimitations.

## **1.9 ETHICAL CONSIDERATION**

There are no ethical considerations since this research does not involve collection of primary data. The study uses quarterly time series data from the year 1990:Q1 until 2014:Q2 and was sourced from SARB and OECD databases.

### **1.10 DEFINITION OF TERMS**

The following terms are defined in order to share a common understanding of the basic and primary concepts included to form part of the study.

- I. Autocorrelation: may be defined as correlation between members of series of observations ordered in time or space (Gujarati and Porter, 2009).
- II. Currency appreciation: An increase in the value of the currency against another currency (Van Der Merwe and Mollentze, 2010).
- III. Currency depreciation: A decrease in the value of the currency against another currency (Van Der Merwe and Mollentze, 2010).
- IV. Exchange rate: The exchange rate is the price of one unit of foreign currency in terms of domestic currency (Gartner, 2006).
- V. Exchange rate volatility: may be defined as the swings or fluctuations in the exchange rate over a period of time or the deviations from a benchmark or equilibrium exchange rate (Mordi, 2006).
- VI. Export: goods that are produced within the country but sold to the rest of the world (Mohr et al., 2008).
- VII. Forecasting: the act of making future predictions (Bowerman, O'Connell, and Koehler, 2005).
- VIII. Globalization: the increasing integration of economies around the world particularly through trade and financial flows, but also through the movement of ideas and people, facilitated by the revolution in telecommunication and transportation (Salvatore, 2011).
- IX. Heteroskedasticity: when the variance of the error terms appears to be non-constant over a range of predictor variables (Hair, Black, Babin and Anderson, 2010).
- X. Import: goods that are produced in the rest of the world but purchased for use in the domestic economy (Mohr et al., 2008).
- XI. International trade: The exchange of goods and services between countries (Mohr, et al., 2008).
- XII. Time series: a chronological sequence of observations on a particular variable (Bowerman et al., 2005).

## 1.11 PRELIMINARY STRUCTURE

The study is divided into four chapters.

- **Chapter two:** This chapter discusses theory and literature on the subject.
- **Chapter three:** discusses the methodological procedure to be used in achieving the set objectives and the data to be used in the analysis.
- **Chapter four:** This chapter provides and discusses the results obtained from performing different tests. The results are obtained with reference to the objectives of the study and the methods discussed.
- **Chapter five:** To be presented in this chapter is the summary study of findings, conclusions and recommendations for further study and policy.

## 1.12 CHAPTER SUMMARY

This chapter presented the introduction and background to the study. The research problem is clearly stated with the objectives of the study. The importance of conducting this study is also outlined and how the study can contribute to the economy of SA or other countries that use SA as a benchmark on issues such as trade. The methods of research to be applied in this study are provided including statistical methods.

Limitations and delimitations of the study are provided. Ethics are not applied in this study as the study does not involve collection of primary data. The researcher provided terms that are used throughout this study with the aim of sharing a common understanding of the basic and primary concepts used. A road map of how the study is structured, in the next chapter, the literature review on the factors affecting exchange rate volatility in SA are explored in detail.

## **CHAPTER TWO**

### **LITERATURE REVIEW**

#### **2.1 INTRODUCTION**

This chapter is about an overview of relevant literature and information associated with exchange rate volatility in SA. The aim of this chapter is to provide the theoretical framework and empirical literature done by others and various methods of research applied in order to identify any existing gaps in literature. This chapter is divided in two Sections. The first Section deals with the theoretical background on exchange rate volatility while the second Section deals with the empirical literature.

#### **2.2 THEORETICAL LITERATURE**

This Section examines the review of studies on exchange rate volatility with the aim of identifying statistical methods used and the variables adopted. Advantages and disadvantages as well as the classification of factors affecting exchange rate levels are also reviewed. In literature, there are a variety of macroeconomic and financial variables that are identified by previous researchers as contributors to the exchange rate volatility.

##### **2.2.1 REVIEW OF STUDIES ON EXCHANGE RATE VOLATILITY**

Uddin, Quaasar and Nandi (2013) indicate that, before exploring a new phenomenon, it is necessary for a researcher to look into various aspects already studied. As research is a continuous process, it must have some continuity with earlier facts. The knowledge gathered in the past should be consolidated to keep it on record for future use. It is like consulting attempts to present a review of some of the important research findings relevant to the objective of the present study (Uddin, Quaasar and Nandi, *ibid*).



Various studies around the world have investigated the factors affecting exchange rate volatility. For instance, in Pakistan, Zada (2010) studied the factors affecting exchange rate volatility for the period 1979 through 2008. The author employed multiple regression technique whereby exchange rate was taken as dependent variable while inflation, interest rate, foreign exchange reserves, trade balance, money supply and gross domestic product were the independent variables. The findings of the study indicated that inflation rate; interest rate and foreign exchange reserves strongly influence the exchange rate volatility and remained significant at 1% level while other variables such as gross domestic product (GDP), money supply, and trade deficit remained insignificant.

In Nigeria, Mayowa and Olushola (2013) used time series data to investigate the determinants of exchange rate volatility for the period 1981 through 2008. Variables used in the study include exchange rate, productivity, trade openness, government expenditure, real interest rate and money supply. The GARCH (1, 1) technique, Augmented Dickey Fuller (ADF) and the error correction model (ECM) was applied to examine the various determinants of exchange rate volatility. The findings of the study indicated that openness of the economy, government expenditure, interest rate movement as well as the lagged exchange rate are among the major significant variables that influence exchange rate volatility. The findings further indicated that exchange rate, money supply and productivity are stationary at levels under both methods while trade openness and interest rate are non-stationary at levels under both methods.

In India, an analysis of the macroeconomic determinants of exchange rate volatility and their extent of correlation were investigated by Mirchandani (2013). The author used time series data for the period of 1991 to 2010 employing various macroeconomic variables such as the exchange rate, inflation, consumer price index (CPI), interest Rate, (lending rate), external debt, GDP and foreign direct investment (FDI) in India. Pearson's correlation analysis was utilized to carry out the analysis. The findings of the study highlighted that there is correlation between exchange rate volatility and macroeconomic variables such as interest rate, inflation rate, and GDP either direct or indirect. The findings further indicate that, strong indirect correlation between interest rate and exchange rate volatility exists.

In Ghana, Insah and Chiaraah (2013) investigated the sources of exchange rate volatility using annual time series data covering the period 1980 to 2012. Variables employed for this study were government expenditure and exchange rate. The methodology employed is a dynamic econometric technique based on the Autoregressive Distributed Lag (ARDL) Model to account for psychological inertia among others. Consistent with the empirical literature, the findings of the study reported that government expenditure was a major determinant of exchange rate volatility. There existed a positive relationship between government expenditure and exchange rate volatility. Further, both domestic and external debts were negatively related to exchange rate volatility.

In Nigeria, Danmola (2013) studied the relationship between exchange rate volatility and macroeconomic variables. The study covered the period 1980 to 2010. For the purpose of analysis, the author employed the unit root tests using both Augmented Dickey Fuller (ADF) and Phillip Perron (PP), the correlation matrix, ordinary least square (OLS) and Granger causality test to test the short run dynamics. The findings of the study indicated that GDP, FDI and Trade Openness have a positive influence on exchange rate volatility. The findings further indicated that all variables are stationary at different levels of significance and order of integrations.

Mahmood, Ehsanullah and Ahmed (2011) studied the relationship between Pakistan exchange rate volatility and FDI, GDP and trade openness. The investigation was mainly to check whether fluctuations in exchange rate volatility affect FDI, GDP and trade openness in Pakistan. The study use annual data from 1975 to 2005. Variables adopted for their study include FDI, GDP, and trade openness which were used as independent variables. Exchange rate was used as a dependent variable for the study. GARCH (1, 1) model was applied in order to calculate exchange rate volatility. The findings of the study indicated the impact of exchange rate volatility on macroeconomic variables in Pakistan. The results further indicated that exchange rate volatility positively affects GDP and trade openness and negatively affects the FDI.

Umaru, Sa'idu and Musa (2013) analysed the behavior of the exchange rate volatility on export trade in Nigeria. The author's used ARCH (q) and GARCH (p, q) models to test volatility of the data. The study covered the period from 1970 to 2009. Exchange rate was used as a dependent variable while export was the independent variable. The findings of the ARCH (q) and GARCH (p, q) models indicated that exchange rate is volatile while export is found to be non-volatile. The study recommended that, Nigerian government implement a fixed and sustainable exchange rate policy that will promote greater exchange rate stability and improve terms of trade.

Adeleke and Ogunleye (2013) provided an analysis of the impact of exchange rate volatility on export of Ghana and Nigeria. The study explored the impact of exchange rate volatility on the export of Ghana and Nigeria between 1980 and 2006. The study used exchange rate as a dependent variable while terms of trade and interest rate were independent variables. The ARCH (q) model was employed to generate and test for volatility. The findings of the study indicated that exchange rate for two countries are volatile. In addition, the study indicated that exchange rate volatility has a negative impact on the exports of both countries, while, exchange rate was identified to have a positive and significant impact on both countries' export. The study recommended that a proper analysis of terms of trade be thoroughly done to establish if devaluation will actually induce export to the benefit of the growth of a country's economy.

From the literature gathered above, it is evident that exchange rate volatility is investigated in several countries including Pakistan, Nigeria, Ghana, and India to mention a few. The researcher thoroughly analysed these studies with the aim of identifying statistical methods, time frames and variables used. In terms of the methods used, the results indicated that the subject is investigated using different statistical methods (for instance, multiple regression analysis, Pearson's correlation, ECM, et cetera) for analysing data. However, few studies used ARCH (q) and GARCH (p, q) models as opposed to multiple regression analysis, Pearson's correlation and ECM. This is an indication that the application of this model has not been exhausted in the field of econometrics.

Many variables are employed including GDP, FDI, government expenditure, exports and money supply amongst others. The commonly used variables are the inflation rate, FDI, GDP and interest rate. Each study employed different statistical methods to analyse exchange rate volatility but using almost the same variables. Each study provided different results whereby a negative relationship between exchange rate and abovementioned variables was revealed while other studies revealed a positive relationship. This may be due to the fact that other studies might have used time frames to investigate exchange rate volatility. All studies were investigated covering the period between 1980 and 2013.

It is highly important to attain further understanding of the effects that exchange rate volatility pose. Only then countries become more proactive to explore possible benefits, and prevent potential economical threats (Ekanayake and Chatrna, 2011). Therefore, the current study is conducted in order to analyse exchange rate volatility in SA. In the current study, the researcher employs ARCH (q) and GARCH (p, q) models for estimating volatility. Both models have been applied for analysing data and good results are obtained. The selected time series variables used in the study are similar to those previously investigated exchange rate volatility such as GDP, interest rate, and inflation rate.

Previous studies investigated exchange rate volatility in different parts of the world using annual data. Therefore the current study is different from previous studies as it uses quarterly data though similar variables are adopted (GDP, interest rates and inflation rate). There is no evidence that a similar study on the subject is undertaken in SA using ARCH (q) and GARCH (p, q) models. Therefore, this is a gap which the current study seeks to fill. The contribution of this study lies in investigating not only the exchange rate volatility itself but also its determinants. The time frame for above studies is almost the same as of the current study because the period for undertaking studies above included the subprime crisis which took hold in 2007 and the financial crisis in 2008. The period also captures the trend of what happened before the apartheid era.

## **2.2.2 ADVANTAGES AND DISADVANTAGES**

Over the past year, exchange rates have fluctuated enormously leading to instability and a lack of confidence. Traditionally, volatility of exchange rate has influenced the majority of all market participants either in a positive or negative way. Therefore, with the increasing instability of international economies, it is highly important to know and understand the effects of exchange rate volatility (Ekanayake and Chatrna, 2010).

### **2.2.2.1 ADVANTAGES**

Rishipal and Jain (2012) assert that when the domestic currency exchange rate is high, it is cheaper to import raw materials, component parts and capital inputs such as plant and equipment. This may in turn be beneficial for businesses that rely on imported components. Those who are wishing to increase their investment of new technology from overseas countries may also benefit. Domestic producers will benefit as they will have a cost advantage over imported goods. Therefore, output will rise and improve employment in the country.

### **2.2.2.2 DISADVANTAGES**

Exchange rate volatility affects firms within a given country differently. Firms face a number of risks when engaging in international trade. In particular, economic and commercial risks that are determined by macroeconomic conditions over which they have little control, such as exchange rate and their volatility (Huchet-Bourdon and Korine, 2011). A volatile and constantly depreciating exchange rate can adversely affect a number of key macroeconomic variables such as private investment, GDP, foreign trade and the demand for money (Valadkhani, 2010).

A depreciating currency makes exports cheaper and imports expensive. Therefore, this becomes music in the ears to sectors such as information technology (IT), textiles, hotel and tourism *et cetera*, which generate revenue mainly from exporting products or services. Currency depreciation makes goods and services cheaper for the foreign buyers, thus leading to increase in demand and higher revenue generation (Rishipal and Jain, 2012). Furthermore, movements in exchange rate hurt producers and investors alike because it affects their projected (planned) revenue and costs, including profits margin (Ben, Obida, Wafure, Nurudeen, and Abu, 2010).

### **2.2.3 EXCHANGE RATE POLICY AND REGIMES IN SOUTH AFRICA 1994 - 2010**

In the economy of a country, the exchange rate is among the most important prices. Exchange rate movements have a significant impact on economic growth, employment, inflation, imports and exports and the balance of payments as well as on the wellbeing of individuals. Among others, people who have invested abroad or in rand hedge equities and people who wish to travel abroad have a good experience of exchange rate movement (Mohr et al., 2008).

Management of exchange rate in SA is characterised by numerous exchange rate regime changes, that is, since the year 2000, exchange rate regimes have evolved from being fixed, to managed floating, and finally the free floating. These regime changes are indicative of the importance attached to the exchange rate, possibly as one of the stable instruments for the monetary authority in its desire to achieve macroeconomic stability. The following paragraphs are dedicated to the exchange rate regimes that were adopted in SA from 1994 to 2010 (Mohr et al., 2008).

After the democratic elections in 1994, SA was faced with economic and political crises. The country devoted significant attention to stabilisation measures in the domestic-foreign exchange market (Van der Merwe, 1996). This was done through numerous changes to the exchange rate regime. Since the year 1994, the SA adopted three main regimes namely dual exchange rate regime under a managed float commercial and free float financial rand and unitary exchange rate (managed float rand). Table 3 summarises these regimes according to the year of adoption.

**Table 2.1: Exchange rate regime changes in South Africa**

Episode	Date	Exchange rate regime
I	September 1985- February 1995	Dual exchange rate regime: managed float commercial and free float financial rand
II	March 1995 – January 2000	Unitary exchange rate : Managed float rand
III	February 2000 – present	Unitary exchange rate: free floating rand, with Inflation targeting framework of monetary policy.

Source: adapted from Mtonga (2011)

The choice of an exchange rate regime was mainly influenced by socio-political events that hindered the development of the foreign exchange market in SA from the late 1984 to 1994 (Aron, Elbadawi, and Kahn, 2000). These problems forced the authorities to opt for more direct control measures to manage exchange rate.

Van der Merwe (1996) explains that as a result of the financial sanctions imposed on the country, the South African Reserve Bank (SARB) was forced to re-enter the foreign exchange market as an active participant under conditions of direct control measures. This was aimed at regulating the influence of capital flows on monetary reserves. Van der Merwe (*ibid*) further states that during the first two years of the new Government of National Unity (1994-1995) South Africa's international financial relations was normalised and steps were taken in the development of a forward market without the bank's involvement and progressive relaxation of exchange control.

The period from March 1995 to January 2000 saw the country adopting a unitary exchange rate under the managed float rand. Under this regime the spot exchange rate was determined by market forces under conditions where exchange rate control is exercised only over residents in respect of capital movements. According to Aron et al. (2000), changing to this regime was a great step towards the gradual liberalisation of the financial markets and repositioning South Africa into the global economy. Mtonga (2011) explains that financial liberalisation resulted in the gradual removal of exchange control regulations. On eliminating the financial rand the exchange control was abolished on transactions of non-residents.

Van der Merwe (1996) asserts that under the managed floating regime, the SARB did not prescribe fixed buying and selling rate for dollars to be quoted by the banks in their transactions with the public, neither did it quote its own predetermined buying or selling rate for spot dollars. The managed float allowed the currency to fluctuate under market conditions and also allowed the bank to intervene in the market to minimise short run variability by adjusting the stock level of gold and foreign exchange reserves (Nattrass, Wakeford, and Muradzikwa, 2000).

The year 2000 witnessed another shift in South Africa's monetary policy framework. The country adopted inflation targeting as a framework for monetary policy. This change was followed by the adoption of the free floating exchange rate which complemented the fundamentals of inflation targeting regime. For instance, Masson *et al.* (1998) believe that for inflation targeting to be effective, there has to be no pre-commitment to an exchange rate target. This implies that the rand exchange rate is basically determined by the forces of demand and supply in the foreign exchange market.

Mtonga (2011) argue that the year 2000 demarcates the previous years of controls from the present regime in which market conditions are allowed to influence the domestic foreign exchange market. The move to a free floating exchange rate regime was mainly due to the fact that for inflation targeting to work well, there was need for an independent monetary policy. The independence of monetary policy is limited if the exchange rate is targeted because the primary goal of the monetary policy will be that of defending the exchange rate.

The current policy of the central bank is generally to stay out of the market and to allow market forces to determine the exchange rate. In recent years, however, according to the SARB 2012 reports, the bank has been building up foreign exchange reserves and this involves the purchase of foreign exchange from the market. Thus, the central bank influences the equilibrium exchange rate since it interferes with the demand for foreign exchange.

Though SARB ceased the direct control on the foreign exchange, still influences the exchange rate by participating in the market by buying or selling other currencies. SARB also contends that the exchange rate, however, is not the objective or the target of the bank. The decisions by the bank regarding reserve accumulation should rather be seen as management of international liquidity, not exchange rate policy.



Mohr et al., (2008) suggest that with a free floating currency, there are basically only three policy options. These policy options are mentioned below:

- **Do nothing**, that is, allow market forces, including the actions of currency speculators, to determine exchange rate.
- **Intervene in the foreign exchange market** by buying or selling foreign exchange that is practice **managed floating**.
- **Use interest rate** to influence exchange rate. For instance, if the SARB wishes to avoid a depreciation of the Rand against the major currencies, it can raise interest rate relative to the rate in the rest of the world. This will encourage an inflow of foreign capital and will also raise the costs of speculators who want to speculate against the Rand. The results will be an increase in the demand for Rand relative to what it would have been otherwise, and therefore a stronger Rand (than in the absence of intervention).

#### **2.2.4 EXCHANGE RATE MANAGEMENT**

Rodrick (2007) assert that a poorly managed exchange rate is disastrous for economic growth. The author further highlights that exchange rate managements has taken on an added importance especially with the increasing global integration of developing countries into the global trading system and participation in international production networks. Lastly, the author states that a number of macro-economic factors such as the GDP, aggregate demand, inflation, economic growth, employment creation and income distribution amongst others can be affected by the exchange rate policy.

Flassbeck (2004) asserts that the overall competitiveness of the country is influenced directly by exchange rate movements and exchange rate has the potential to directly improve the overall trade performance in a country. Flassbeck (*ibid*) SA as an open economy is involved in the exportation and importation of goods and services therefore these requires the need to properly manage the exchange rate.

Engel (2009) highlights that a debate was held by policy makers on the desirable degree of foreign exchange rate flexibility whereby one party decided that exchange rate should be freely determined by market forces independently of any foreign exchange intervention or targeting by central bank monetary policy. Engel (*ibid*) further highlighted that other policy makers holds that the central bank should have control over the exchange rate market. The former view is based on the notion that markets work better than the government to determine the appropriate level of the exchange rate while the latter holds that the central bank can be handy in dealing with undesirable aspects such as currency volatility and exchange rate misalignment (Engel, 2009).

### **2.2.5 EXCHANGE CONTROL IN SOUTH AFRICA**

SA used the financial rand system until the system was decided to be ended in March 1995 which resulted to exchange control being effectively abolished from non-residents (Van Der Merwe, 1996). Currently, in SA a non-resident may at any time sell foreign currency to a bank in SA in order to acquire rand for any kind of investment or current expenditure in SA. Again, a non-resident may at any time sell their investments in or outside SA and convert the rand proceeds from transactions into freely transferable foreign currency with a bank in SA. The income earned on such investments is also freely transferable from SA (Van Der Merwe, 1996).

An entity in SA which a non-resident owns 25% or more is, however, restricted with regard to the extent of its borrowing in the common monetary area (Van Der Merwe, 1996). The acceptance of loans from abroad also requires exchange control approval, which is easily forthcoming subject to considerations of maturity profile and interest charges. Exchange control on residents and emigrants however remains in force. There are no restrictions on payments for imports. Majority of huge goods are not subject to import control. No period within which payment for imports has to be made is stipulated and the granting of credit by overseas exporters is welcomed (Van Der Merwe, 1996).

In respect of exports, the exchange control regulations stipulate that payment of the foreign currency proceeds to be received within six months of date of shipment. Furthermore, authorised dealers may allow a further six months credit if this will lead to an expansion of exports (Van Der Merwe, 1996). From the date of account of the foreign currency, such funds must be transferred to SA within seven days. Any investment outside the common monetary area by a South African resident requires exchange control. New portfolio or non-direct foreign investments by SA residents are generally prohibited. For, July 1995 investors were allowed to invest a portion of their assets abroad through asset swap arrangements. The same basic approach or criteria in respect of investments in sub-Saharan Africa countries but a slightly easier policy approach has been adopted (Van Der Merwe, 1996).

#### **2.2.6 CLASSIFICATION OF FACTORS AFFECTING EXCHANGE RATE**

There is no consensus in the literature on the factors affecting exchange rate and their volatility. These factors are usually divided into two groups: economic and non-economic factors. The focus is only on the economic factors mainly because of the current investigation which analyses economic phenomenon. In the first group, Twarowska and Kakol (2014) distinguish between the long-term and short-term factors. Analysing the impact of various factors on exchange rate, the relative values (in relation to situation abroad – especially in main trading partners' countries) should be taken into account. Table 2.2 provides a detailed classification of the factors affecting exchange rate volatility in short and long term.

**Table 2.2: Factors affecting exchange rate fluctuations**

<b>Economic factors</b>	
<b>Short-term</b>	<ul style="list-style-type: none"><li>• rate of economic growth</li><li>• inflation rate</li><li>• interest rate in the country and abroad</li><li>• current account balance</li><li>• capital account balance</li><li>• currency speculation</li></ul>
<b>Long-term</b>	<ul style="list-style-type: none"><li>• level of economic development of the country</li><li>• competitiveness of the economy</li><li>• technical and technological development</li><li>• size of the foreign debt</li><li>• budget deficit</li><li>• relative domestic and foreign prices</li><li>• capital flows</li></ul>
<b>Non-economic factors</b>	
<ul style="list-style-type: none"><li>• political risk (e.g. risk of armed conflict)</li><li>• natural disasters</li><li>• policy approaches</li><li>• psychological factors</li></ul>	

Source: Twarowska and Kakol (2014)

## **2.3 EMPIRICAL FRAMEWORK**

This Section provides a detailed description of the framework employed when modelling exchange rate volatility in SA. It is important to describe this framework as a guide to achieve the objectives set for this study. Last but not least, the theoretical background on the theories which explain movements or governing exchange rate in SA is also given.

### 2.3.1 MODELS FOR MEASURING VOLATILITY

Over the past decade, modelling volatility has been the subject for both empirical and theoretical enquiry (Brooks, 2008). In addition to that, the author highlights that, both academics and practitioners support this enquiry as volatility is regarded as one of the most important subjects in both economics and finance.

There are several models which can be used to model volatility. These models include the autoregressive conditional heteroskedasticity (ARCH), generalized autoregressive conditional heteroskedasticity (GARCH), threshold autoregressive conditional heteroscedasticity (TARCH), exponential generalized autoregressive conditional heteroscedasticity (EGARCH), multivariate generalized autoregressive conditional heteroscedasticity (MGARCH) and orthogonal generalized conditional heteroscedasticity (OGARCH), among others (Brooks, 2008). For the purpose of this study, the ARCH and GARCH models are adopted to model exchange rate volatility.

The decision to adopt the ARCH and GARCH models were influenced mainly by its advantages and previous studies adopted them. The advantage of these models is that, they allow conditional variance to change over time as a function of past errors leaving the unconditional variance constant (Bollerslev, 1986). In addition to that, the author highlights that, the ARCH and GARCH models are most appropriate models to use when evaluating volatility with large amounts of observations (Matei, 2009).

Engle (2001), supported by Brooks (2008), argues that the ARCH and GARCH models are useful when the goal of the study is to analyse and forecast volatility. Therefore these models are also important for our study since forecasting exchange rate volatility is considered. Brooks (*ibid*) also highlighted that producing forecast from the ARCH and GARCH class is relatively simple. A GARCH model was derived from the ARCH model and therefore a detailed description of these models is provided below.

### 2.3.1.1 FROM ARMA (p, q) TO ARCH (q) MODEL, WHAT IS NEW IN ARCH (q)?

This Section provides a detailed explanation of where the ARCH (q) model was derived from the beginning and the qualities of the model. The ARCH (q) model was derived from the autoregressive moving average (ARMA) (p, q) process. The ARMA model is made up of the autoregressive known as the (AR) and moving average abbreviated (MA) (Matei, 2009). The author further highlights that, the model aims at keeping the number of parameters small. The importance of AR and MA models in finance is given mainly to be used in explaining ARCH (q) or GARCH (p, q) models. However, the GARCH (p, q) model is seen as a non-standard ARMA (p, q) model for an  $a_t^2$ .

The ARMA model which in its simplest form use the statistical properties of the past of a variable  $y_t$  to predict the autoregressive (AR). In other words, to predict  $y_{t+1}$  the sum of the weighted values that  $y_t$  took in the previous period plus the error term  $\varepsilon_t$  needs to be taken into account (Matei, 2009). The ARMA (p, q) model was introduced by Box, Jenkins and Reinsel (1994). The simplest form of an ARMA (p, q) model can be given by (1, 1) which is in univariate form.

$r_t$  follows an ARMA (1,1) process if it verifies the following equation:

$$r_t - \phi_1 r_{t-1} = \varphi_0 + a_t - \theta_1 a_{t-1} \quad [2.1]$$

Where  $a_t$  is a white noise series and  $\varphi_0$  is a constant,  $r_{t-1}$  is the AR component of the model, while  $\varphi_0 + a_t - \theta_1 a_{t-1}$  is the MA component.

The following is the general ARMA model:

$$r_t = \varphi_0 + \sum_{i=1}^p \phi_i r_{t-i} + a_t - \sum_{l=1}^q \theta_l a_{t-l} \quad [2.2]$$

With  $a_t$  as white noise series and  $p$  and  $q$  as non-negative integers. The ARCH (q) model assumes that  $r_t$  follows a simple time series model such as ARMA (p, q) model with some explanatory variables.

The ARCH (q) model has the following form:

$$r_t = \mu_t + a_t, \mu_t = \varphi_0 + \sum_{i=1}^k \beta_i x_{it} + \sum_{i=1}^p \varphi_i r_{t-i} - \sum_{i=1}^q \theta_i a_{t-i} \quad [2.3]$$

With  $x_{it}$  explanatory variables, while  $k$ ,  $p$  and  $q$  are non-negative integers,  $\mu_t$  is the mean equation of  $r_t$ . Matei (2009) asserts that ARCH (q) models are simple and easy to use and take care of clustered errors. The author further highlights that one characteristic of ARCH (q) model is the random coefficient problem: the power of forecast changes from one period to another.

The ARCH (q) model is simple and easy to handle, but has weaknesses or limitations as well. One of the weaknesses of the ARCH (q) model is that, it assumes that positive and negative shocks have similar effects on volatility as they depend on the square of the previous shocks. Another weakness is that the ARCH (q) model is rather restrictive. The last but not the least, the ARCH (q) model is likely to over - predict the volatility given that the model respond slowly to large isolated shock to the return series (Matei, 2009). Bollerslev (1986) extended the ARCH (q) model to a more general one, the GARCH model, which allows for the conditional variance to be dependent upon previous own lags (Xu and Sun, 2010).

### **2.3.1.2 FROM ARCH (q) TO GARCH (p, q) MODEL, WHAT IS NEW IN GARCH (p, q)?**

This Section provides a detailed explanation of where the GARCH (p, q) model was derived from the beginning and the qualities of the model. The GARCH model was derived from the ARCH (q) model. The GARCH (p, q) model is an extension of the ARCH (q) model similar to the extension of the ARMA (p, q) process. The basic form of the ARCH (q) model was discussed in Section 2.3.1.1 above.

One of the characteristics of the ARCH (q) model is that it requires many parameters to describe the volatility process of an asset return (Matei, 2009). Matei (2009) further highlights that, Bollerslev (1986) proposed an alternative model known as the generalized ARCH (q) model. The GARCH (p, q) compared to the ARCH (q) model has three parameters that allow for an infinite number of squared roots to influence the current conditional variance.

The feature allows the GARCH (p, q) model to be simpler than the ARCH (q) model which explains a wide preference for use in practice as against ARCH (q). While ARCH (q) model incorporates the feature of autocorrelation, GARCH (p, q) improves ARCH (q) by adding a more general feature of conditional heteroscedasticity. Like other models, the GARCH (p, q) model is not a perfect model and therefore could be improved.

The improvements are observed in the form of the alphabet soup that uses GARCH (p, q) as its prime ingredient: the threshold autoregressive conditional heteroscedasticity (TARCH), exponential generalized autoregressive conditional heteroscedasticity (EGARCH), and multivariate generalized autoregressive conditional heteroscedasticity (M-GARCH) amongst others *et cetera* (Matei, 2009). Last but not least, the conditional variance determined through GARCH is a weighted average of the past residuals which is similar to the ARCH model.

The GARCH model is given as follows:

$$a_t = \sigma_t \varepsilon_t, \sigma_t^2 = \alpha_0 + \sum_{i=1}^p \alpha_i a_{t-i}^2 + \sum_{j=1}^q \beta_j \sigma_{t-j}^2 \quad [2.4]$$

where  $\varepsilon_t$  is a sequence of *iid* random variables with mean 0 and variance 1,

$$\alpha_0 > 0, \alpha_i \geq 0, \beta_j \geq 0 \text{ and } \sum_{i=1}^{\max(p,q)} (\alpha_i + \beta_i) < 1$$

Here it is understood that  $\alpha_i = 0$  for  $i > m$  and  $\beta_j \geq 0$  for  $j > s$ . The constraint on  $\alpha_i + \beta_i$  implies that the conditional variance of  $a_t$  is finite, whereas its conditional variance  $\sigma_t^2$  evolves over time.



## 2.4 CHAPTER SUMMARY

In this chapter a review on studies of exchange rate is given with the aim of identifying the related factors and methodologies used followed by the advantages and disadvantages of exchange rate volatility. The findings of the chapter showed that different statistical methods such as VAR, GARCH (p, q), ECM, Regression analysis, *et cetera*, were employed for the variety of data. However, few studies used ARCH (q) and GARCH (p, q) models as opposed to the VAR, ECM and regression analysis. This is an indication that the application of this framework has not been exhausted in the field of econometrics.

This study follows the said methodological model and uses the identified variables to analyse exchange rate volatility in SA. Classification of factors affecting exchange rate volatility is also given. The theoretical background gave a detailed review of volatility models which are ARCH (q) and GARCH (p, q) models. The next chapter gives a review of the methodology and defines the data used for the study.

## **CHAPTER THREE**

### **RESEARCH METHODOLOGY**

#### **3.1 INTRODUCTION**

This chapter focuses on the research methodology employed to help achieve the objectives of the study. The chapter further provides a detailed empirical framework of time series methods that assists the researcher in achieving the objectives. The study adopts and discusses ARCH (q) and GARCH (p, q) frameworks to model and estimate the South African exchange rate volatility. This is so due to an extensive use of ARCH (q) and GARCH (p, q) models in related studies. Additionally, these models have been reported to provide a good approach to conditional variance modelling.

Three determinants of exchange rate namely GDP, INF and INTR are factored in the building of the model. This may help in determining the determinant responsible for exchange rate volatility in the South African context. The choice of these determinants is informed by the associated literature discussed in Chapter 2. General multivariate GARCH (P, q) model known as Baba, Engle, Kroner and Kraft (BEKK) representation proposed by Engle and Kroner (1995) were reviewed.

Also reviewed is the related GARCH (p, q) model with time-varying conditional variance and covariance called the constant conditional correlations (CCC). This model was proposed by Bollerslev (1990). Prior to review of the models, the study provides a highlight of the data and the variables used in Section 3.2. Methods used for the preliminary data analyses are discussed in Section 3.3.

#### **3.2 DATA USED**

Quarterly time series data was obtained from SARB and OECD database. The data covers the period 1990:Q1 and 2014:Q2. The sample period was selected mainly because it covers the 2007 and 2008 financial crisis and the period gives a clear trend of what happened after the apartheid era. With a considerable number of observations, the assumption of normality may also not be violated.

It should be noted that not all the data used in this study is measured in similar scales, for instance, percentages, millions, *et cetera*. This therefore serves as a limitation for this study. Four variables namely: exchange rate, GDP, inflation rate and interest rate are identified through the help of literature and relevant theory discussed in Chapter 2. A detailed description of these variables is given below. The last part of this Section discusses the data analysis methods used in this study.

**Exchange rate (ER):** *Todaro and Smith (2011) define the ER as the rate at which the domestic currency is converted into (sold for) foreign currency, for instance, the exchange of the Rand for the US dollar. This variable is used in this study as a dependent variable  $ER(Y_t)$  and is measured in percentages.*

**Gross Domestic Product (GDP):** *Mohr et al., (2008) define GDP as the total value of all goods and services produced within the boundaries of a country in a particular period (usually on year). According to Rishipal and Jain (2012), a volatile ER, especially when it depreciates constantly, affects the GDP growth which will lead to exports becoming cheaper and imports expensive.  $GDP(x_1)$  is an independent variable and is measured in millions.*

**Inflation rate (INFR):** *Mohr et al. (2008) define INFR as a continuous and considerable rise in prices in general. According to Chaudhary and Goel (2013), INFR is a determinant of ER whereby a higher INFR in the country will be followed by a depreciation of the currency while a lower INFR in the country will be followed by an appreciation of the currency. Inflation rate  $INFR(x_2)$  as an independent variable in the model is measured in percentages.*

**Interest rate (INTR):** *According to Mohr et al. (2008), INTR is the percentage charged by the lender to the borrower for the use of money / assets. Chaudhary and Goel (2013) further suggest INTR as another determinant of ER. A higher INTR in the domestic country attracts foreign investors which in turn increases the value of the domestic currency.  $INTR(x_3)$  as another independent variable in this study is measured in millions.*

The econometric views (E-Views) version 8 software package is utilised to analyse data. Starz (2013) highlights that with E-Views, the researcher is able to manage data, perform econometric and statistical analysis, generate forecasts and model simulations, and produce high quality graphs and tables.

### 3.3 ARCH (q) AND GARCH (p, q) MODEL SPECIFICATION

For this study, ARCH (q) and GARCH (p, q) models are adopted to measure exchange rate volatility in SA. The basic models consist of four variables with time series data collected from the SARB and OECD for period of 1990:Q1 to 2014:Q4. The study modifies the ARCH (q) followed by GARCH (p, q) model adopted from Kirchgassner and Wolters (2007). In both models, ER is expressed as a dependent variable of other series namely GDP, INF and INTR.

The general form of the ARCH (q) model is:

$$h_t^2 = \alpha_0 + \sum_p^q \alpha_i \varepsilon_{t-i}^2 + \sum_p^q \alpha_i \varepsilon_{t-i}^2 + \sum_p^q \alpha_0 \varepsilon_{t-1}^2 \quad [3.1]$$

The applicable ARCH (q) model for this study is written as:

$$ER_t^2 = \alpha_0 + \sum_p^q GDP \varepsilon_{t-i}^2 + \sum_p^q INF \varepsilon_{t-i}^2 + \sum_p^q INTR \varepsilon_{t-1}^2 \quad [3.2]$$

Presented next is the general form of the GARCH (p, q) model.

The general form of the GARCH (p, q) model is:

$$h_t^2 = \alpha_0 + \alpha(L) \varepsilon_t^2 + \beta(L) h_t^2 \quad [3.3]$$

For the sake of this study, the appropriate model becomes:

$$ER_t^2 = \alpha_0 + GDP(L) \varepsilon_t^2 + INF(L) \varepsilon_t^2 + INTR(L) h_t^2 \quad [3.4]$$

where a detailed description of the terms are given fully in Section 3.2 and 3.7 respectively.

### 3.4 PRELIMINARY DATA ANALYSIS

Preliminary data analysis is performed before the actual statistical data analysis. Firstly, it is important to quantify the behaviour of a random variable. Therefore basic descriptive statistics are employed for this reason. Statistics provided include the skewness and Jarque – Bera.

### 3.5 TESTING FOR STATIONARITY

Challis and Kitney (1991) define stationarity as a process whereby the statistical parameters, for instance, the mean and standard deviation of the process do not change with time. On the other hand, Aas and Dimakos (2004) clarify that a sequence of random variables  $X_t$  is stationary if there is no trend and if the covariance does not change over time, that is:

$$E[X_t] = \mu \text{ for all } t \quad [3.5]$$

and

$$\text{Cov}(X_t, X_{t-k}) = E[(X_t - \mu)(X_{t-k} - \mu)] = \gamma_k \text{ for all } t \text{ and any } k \quad [3.6]$$

Sibanda (2012) asserts that the dependent and independent variables of a classical regression model be stationary and the errors have a zero mean and finite variance. Hill, Griffiths, and Lim, 2008; Bowerman and O’Connell (1979) provide reasons why stationarity needs to be assessed. The first basic reason is to avoid spurious results. Secondly, if a regression model has variables which are non-stationary then  $t$ -ratios do not follow a  $t$ -distribution whereby it becomes impossible to undertake hypothesis test about the regression parameters.

The sequence for stationarity check is to firstly show time series plots which determine the behaviour of random variables. This further assesses whether or not the properties of time series are violated. The formal tests conducted are the Augmented Dickey – Fuller (ADF) and Phillips Perron (PP) formal tests. These tests are important as they give insight into the structural breaks, trends and stationarity of the data set (Brooks, 2008). Discussed is the ADF and PP tests for stationarity in Sections 3.5.1 and 3.5.2.

### 3.5.1 AUGMENTED DICKEY FULLER (ADF) TEST FOR STATIONARITY

The ADF model was developed by Dickey and Fuller (1979). Chun Leng (2006) emphasised this test as a good measure in assessing the stationarity of the series. Balke (1991) in Chun Leng (2006) also suggested this test based on the assumption that, time series is unchanging. The following is the ADF model for studying unit root in the data:

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \sum_{i=1}^m \alpha_i \Delta Y_{t-i} + \varepsilon_t \quad [3.7]$$

where  $\varepsilon_t$  is a pure white noise error term and where  $\Delta Y_{t-1} = (Y_{t-1} - Y_{t-2})$ ,  $\Delta Y_{t-2} = (Y_{t-2} - Y_{t-3})$  *et cetera*. The number of lagged difference terms to include is often determined empirically. The idea being to include enough terms so that the error is serially uncorrelated, so that an unbiased estimate of  $\delta$  which is the coefficient of lagged  $Y_{t-1}$  can be obtained. The ADF model is used to test the following hypothesis:

$$H_0 = 0 \text{ (Time series is non-stationary)}$$

$$H_1 < 0 \text{ (Time series is stationary)}$$

The calculated value of ADF is then compared with the critical value at a conventional level of significance. If the calculated value is greater than the critical value, reject the null hypothesis that the series have a unit root, therefore confirming that the series are stationary.

### 3.5.2 PHILLIPS PERRON (PP) STATIONARITY TEST

The PP stationarity test was developed by Phillips (1987) and Phillips and Perron (1988). The test is similar to the ADF test but it incorporates an automatic correction to the DF procedure to allow for auto correlated residuals (Brooks, 2008).

The test regression for the PP test is given as:

$$y_t = \rho y_{t-1} + u_t \quad [3.8]$$

where  $u_t$  is  $I(0)$  and may be heteroscedastic,  $y_t$  represents time series to be tested. The PP model is used to test the following hypothesis:

$$H_0 : y_t \sim I(1)$$

$$H_1 : y_t \sim I(0)$$

The calculated value of PP is then compared with the critical value at a certain significance level. If the calculated value is greater than the critical value, reject the null hypothesis that the series have a unit root, therefore confirming that the series are stationary.

### 3.6 BROCK, DECHERT AND SCHEINKMANS (BDS) TEST FOR INDEPENDENCE

The series is assessed for statistical independence using the BDS test statistic. The test was first devised by Brock, Dechert and Scheinkmans in 1987. The intention is to test whether time series are independently and identically distributed (*iid*). The importance behind performing this test is to check whether or not there is a hidden non linearity, hidden stationarity or other type of structure missed by model fitting.

Panagiotidis (2002), supported by Bisaglia and Gerilimetto (2014), recommends this test as a powerful test of independence. He further suggests the use of this test under certain circumstances for linear dependencies. Panagiotidis (*ibid*) states that for a time series which is *iid*, the distribution of the statistic should be:

$$W_m(\varepsilon) = \frac{\sqrt{n} \{C_m(\varepsilon) - C_1(\varepsilon)^m\}}{\sigma_m(\varepsilon)} \quad [3.9]$$

The test is asymptotically and normally distributed with  $N(0,1)$ .  $W_n(\varepsilon)$  is known as the BDS statistic.  $C_m(\varepsilon)$  is the fraction of  $m$ -tuples in the series.  $\sigma_m(\varepsilon)$  is an estimate of the standard deviation. The BDS tests the null hypothesis that the elements of a time series are *iid*.

The null hypothesis is rejected if the test statistic is absolutely large, (greater than 1.96). If the null hypothesis of *iid* cannot be accepted, this implies that the residuals contain some kind of hidden structure which might be nonlinear (Panagiotidis, 2002).

### 3.7 MODEL ESTIMATION ANALYSIS

ARCH (1), GARCH (1, 1) and GARCH (1, 2) models are adequate for modelling volatilities even over long sample periods (Bollerslev, Chou, and Kroner, 1992) in Ngailo (2011). In the current investigation, the researcher followed a recommendation by Bollerslev et al., (1992) as a reference. A detailed review for the GARCH (1, 1) model is provided to estimate exchange rate volatility in SA. The ARCH (1) and GARCH (1, 2) models are adopted for this reason but the idea is to compare the three in order to make concrete decisions on whether or not exchange rate in SA is volatile. This also helps in determining the model that best measures exchange rate volatility in SA.

In their studies, Ngailo (2011); Dickson (2012); Adeleke and Ogunleye (2013); Mayowa and Olushola (2013); Umaru et al., (2013) did not log transform variables in order to obtain simple and easy to interpret results. In this regard, the researcher followed the same approach when estimating ARCH (q) and GARCH (p, q) models. Variance equation coefficients exhibit low volatility when they are less than 1 and high volatility when they are greater than 1.

Ngailo (2011) and Umaru et al., (2013) followed the same benchmark. A general multivariate GARCH (p, q) - BEKK model is reviewed to capture volatility transmission among different series. Also the GARCH (p, q) – CCC model is reviewed to test for an independent relationship between the conditional volatilities. The researcher starts by reviewing the ARCH (q) model and redesign it to suit multivariate analyses.



### 3.7.1 ARCH (q) MODEL

The ARCH (q) model was first introduced by Robert Engle in 1982. The model is mostly used in finance (Brooks, 2008). The advantage of using this model is because it is simple and easy to handle and it takes care of clustered errors as well as non linearities (Matei, 2009). Kirchgassner and Wolters (2007) assert that the variable  $y$  can be explained in a linear model with the predetermined variables  $X$  and the parameter vector  $\beta$  as:

$$y_t = X_t' \beta + \varepsilon_t \quad [3.10]$$

Along with truly exogenous deterministic and stochastic variables, the vector  $X$  might also contain lagged endogenous variables. The error term  $\varepsilon_t$  has zero mean,  $E[\varepsilon_t] = 0$  and a constant unconditional variance  $E[\varepsilon_t^2] = \sigma^2$ . It also holds that  $\varepsilon_t$  is not autocorrelated whereas  $\varepsilon_t^2$  is allowed to be auto-correlated. It is assumed that this autocorrelation can be captured by the following AR (1) process:

$$\varepsilon_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 \varepsilon_{t-2}^2 + \alpha_3 \varepsilon_{t-3}^2 + \dots + \alpha_q \varepsilon_{t-q}^2 + \varepsilon_t \quad [3.11]$$

Equation [3.11] is modified to suit this study and the resulting equation becomes:

$$ER_t^2 = \alpha_0 + GDP_1 \varepsilon_{t-1}^2 + INFR_2 \varepsilon_{t-2}^2 + INTR_3 \varepsilon_{t-3}^2 + \dots + \alpha_q \varepsilon_{t-q}^2 + \varepsilon_t, \quad [3.11a]$$

where  $ER$  is the South African exchange rate,  $GDP$  is the gross domestic product,  $INFR$  is the inflation rate,  $INTR$  is the interest rate, and  $\varepsilon_t$  is the white noise. The information set  $I_t$  contains all information which is available at time  $t$ , therefore  $I_{t-1} = \{y_{t-1}, y_{t-2}, \dots, X_{t-1}, X_{t-2}\}$ . If the parameter vector  $\beta$  is known, this information set also contains all residuals up to time  $t-1$  because of  $\varepsilon_{t-1} = y_{t-1} - X_{t-1}' \beta$ ,  $i=1, 2, \dots$

The conditional variance of  $\varepsilon_t$ ,  $h_t^2$  can be written as:

$$h_t^2 = V[\varepsilon_t | I_{t-1}] = E[\varepsilon_t^2 | I_{t-1}] \quad [3.12]$$

The resulting equation after modifying Equation [3.12] to suit this study becomes:

$$ER_t^2 = V[\varepsilon_t | I_{t-1}] = E[\varepsilon_t^2 | I_{t-1}] \quad [3.12a]$$

Because of equation [3.12], the following ARCH (q) model is developed

$$h_t^2 = \alpha_0 + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2 + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2 \quad [3.13]$$

The applicable ARCH (q) model for this study is written as:

$$ER_t^2 = \alpha_0 + \sum_{i=1}^q GDP_i \varepsilon_{t-i}^2 + \sum_{i=1}^q INF_i \varepsilon_{t-i}^2 + \sum_{i=1}^q INTR_i \varepsilon_{t-i}^2 \quad [3.13a]$$

With  $\alpha_0 > 0$  and  $\alpha_i \geq 0$  for  $i = 0 \dots q-1$  as well as  $\alpha_q \geq 0$ . These conditions ensure that the conditional variance is always positive. If a large shock occurs in equation [3.10], for instance, if there is a large positive or negative value of  $\varepsilon_t$ , this leads, according to equation [3.13], to a series of large values for the conditional variance, as the latter is a monotonically increasing function of lagged realised values of  $\varepsilon_t$ . If the occurring shock is only small, further small shocks are assumed to occur in the near future. The higher the value of  $q$ , the more extended are the volatility clusters.

Due to limitations of the ARCH (q) model mentioned in the theoretical review. The ARCH model assumes that positive and negative shocks have similar effects on volatility as they depend on the square of the previous shocks. Bollerslev (1986) introduced the GARCH (p, q) model which allows for conditional variance to be dependent upon previous own lags. Discussed below is the GARCH (p, q) model built from the ARCH (q) model.

### 3.7.2 GARCH (p, q) MODEL

The GARCH (p, q) model was derived from the ARCH (q) model. The basic form of the ARCH (q) model was discussed in the previous Section. The GARCH (p, q) model was developed independently by Bollerslev (1986). According to Brooks (2008), the advantage of using the model is that, it allows for conditional variance to be dependent upon previous own lags. Brooks (*ibid*) further highlights on the possibility to interpret the current fitted variance  $h_t$  as the weighted function of a long term average value (dependent on  $\alpha_0$ ).

If the maximum lag in ARCH (q) model becomes too large, problems with the non-negativity constraints might occur if the estimates are not restricted appropriately. Bollerslev (1986) developed a more flexible generalization of the ARCH (q) approach, the GARCH (p, q) model which is more flexible. Bollerslev (*ibid*) additionally included  $p$  lagged values of the conditional variance into equation [3.11]. The  $p$  lagged values of the conditional variance into equation [3.11] leads to a GARCH (p, q) process given by:

$$h_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \dots + \alpha_q \varepsilon_{t-q}^2 + \beta_1 h_{t-1}^2 + \dots + \beta_p h_{t-p}^2 \quad [3.14]$$

For the sake of this study, the appropriate GARCH (p, q) model becomes:

$$\begin{aligned} ER_t^2 = & \alpha_0 + GDP_1 \varepsilon_{t-1}^2 + INF_2 \varepsilon_{t-1}^2 + INTR_3 \varepsilon_{t-3}^2 + \dots \\ & + \alpha_q \varepsilon_{t-q}^2 + GDP_1 h_{t-1}^2 + INF_2 h_{t-2}^2 + INTR_3 h_{t-3}^2 + \dots \beta_p h_{t-p}^2 \end{aligned} \quad [3.14a]$$

Sufficient conditions for the non-negativity of the conditional variance of the process above are:  $\alpha_0 > 0$ ,  $\alpha_i \geq 0$ ,  $i = 0 \dots q-1$ ,  $\alpha_q > 0$ ,  $\beta_i \geq 0$ ,  $i = 0 \dots p-1$ ,  $\beta_p > 0$ .

Using the lag polynomials,

$$\alpha(L) = \alpha_1 L + \dots + \alpha_q L^q, \beta(L) = \beta_1 L + \dots + \beta_p L^p,$$

The GARCH (p, q) process in equation [3.14] can be written as:

$$h_t^2 = \alpha_0 + \alpha(L) \varepsilon_t^2 + \beta(L) h_t^2 \quad [3.15]$$

The applicable GARCH (p, q) model for this study is written as:

$$ER_t^2 = \alpha_0 + GDP(L)\varepsilon_t^2 + INF(L)\varepsilon_t^2 + INTR(L)h_t^2 \quad [3.15a]$$

Or, if all roots of  $1 - \beta(L)$  are outside the unit circle, as

$$h_t^2 = \frac{\alpha_0}{1 - \beta(1)} + \frac{\alpha(L)}{1 - \beta(L)} \varepsilon_t^2$$

If the rational function of the lag operator is expanded into a series, then  $ARCH(\infty)$  is developed as follows:

$$h_t^2 = \alpha_0^* + \sum_{i=1}^{\infty} \delta_i \varepsilon_{t-i}^2 \quad [3.16]$$

The resulting equation after modifying Equation [3.16] to suit this study becomes:

$$ER_t^2 = \alpha_0^* + \sum_{i=1}^{\infty} \delta_i \varepsilon_{t-i}^2 \quad [3.16a]$$

with  $\varepsilon_0^* > 0$  and  $\delta_i \geq 0$ ,  $i=1,2,\dots$ , thus, GARCH (p, q) model allow the parsimonious parameterisation for conditional variance in the same way as ARMA (1, 1) model for conditional means.

### 3.7.3 GARCH (p, q) – BEKK MODEL

The GARCH (p, q) - BEKK model was developed by Engle and Kroner (1995). This is an extension of the bivariate GARCH (p, q) model which can capture volatility transmission among different series. The model also captures the persistence of volatility within each series (Padhi and Lagesh, 2012). Xu and Sun (2010) recommend the application of the GARCH (p, q) - BEKK model in examining the volatility spill over effects. The advantage of using the GARCH (p, q) – BEKK model is that, positive definiteness is automatically ensured according to Su and Huang (2010).

The study prefers to use the GARCH (p, q) - BEKK model mainly because of the superiority and flexibility of modelling spill over effects for low dimensions (Alexander, 2008). In the present study to examine the volatility transmission for instance, spill over effects, the GARCH (p, q) - BEKK model is applied. The GARCH (p, q) - BEKK model is represented by:

$$H_t = W'W + A' H_{t-1} A + \Xi_{t-1} B \quad [3.17]$$

where A, and B are (2x2) matrices of parameters and  $W$  is an upper triangular matrix of parameters. The positive definiteness of the covariance matrix is ensured owing to the quadratic nature of the terms on the RHS of equation [3.17]. The GARCH (p, q) - BEKK volatility spill over effects is present in the series when standard errors of the variables are high (Brooks, 2008). Note: the standard error should be greater than 0.10 in order to conclude that high volatility spill over effects are present (Xu and Sun, 2010).

#### 3.7.4 GARCH (p, q) – CCC MODEL

The CCC multivariate GARCH (p, q) model was proposed by Bollerslev (1990) whereby the correlation matrix remains unchanged even when transformations in the model take place. Therefore the model became known as a constant conditional correlation multivariate GARCH model. The GARCH (p, q) model does not test for an independent relationship between the conditional volatilities; hence the GARCH (p, q) – CCC model is employed (Chan and McAleer, 2003).

The advantage of the GARCH (p, q) - CCC model is its simplicity to estimate and therefore it uses less number of parameters (Bollerslev, *ibid*). In the present study the GARCH (p, q) - CCC model is applied to examine the independent relationship between the conditional volatilities. Consider the constant conditional correlation multivariate GARCH (p, q) model of Bollerslev (1990):

$$Y_t = E(Y_t | F_{t-1}) + \varepsilon_{0t} \quad [3.18]$$

$$\varepsilon_{0t} = D_{0t} \eta_{0t}$$

$$Var(\varepsilon_{0t} | F_{t-1}) = D_{0t} \Gamma_0 D_{0t}$$

Where  $F_t$  is the past information available up to time  $t$   $D_{0t} = diagonal(h_0^{1/2})$ ,  $i=1,...,m$ , for which  $m$  is the total number of assets on markets, and

$$\Gamma_0 = \begin{pmatrix} 1 & \rho_{012} & \dots & \rho_{01m} \\ \rho_{021} & 1 & \rho_{023} & \dots \\ & & \dots & \\ \rho_{0m1} & \dots & \rho_{0m,m-1} & 1 \end{pmatrix}$$

In which  $\rho_{0ij} = \rho_{0ji}$  for  $i,j=1,...,m$ , and  $\eta_{0t} = (\eta_{01t}, \dots, \eta_{0mt})$

GARCH (p, q) – CCC model uses nonlinear combinations of univariate GARCH (p, q) model to represent the conditional covariance (Stata.com, 2014). In each of the conditional correlation models, the conditional covariance matrix is positive definite by construction and has a simple structure, which facilitates parameter estimation. There is independent relationship between the conditional volatilities when the probability values are less than 0.05 or 5%.

### 3.8 MODEL SELECTION CRITERIA

Model selection criteria provide a basis for model selection (Acquah, 2010). The study uses the Akaike information criterion (AIC) and Schwarz information criterion (SIC) in order to select the best model. AIC and SIC are most commonly used model selection criterion beyond classical hypothesis tests (Fox, 2008). Discussed below is the procedure for using the AIC and SIC criteria.

### 3.8.1 AIC AND SIC

AIC was developed by Akaike (1973) while SIC was developed by Schwarz (1978). The AIC test is aimed at finding the best approximating model to the unknown data generating process (Acquah, 2010). Gujarati and Porter (2009) emphasise that the advantage of forecasting performance of a regression model using the AIC is useful for not only in-sample but also out-of-sample.

The advantage of using the SIC is to identify the true model (Fox, 2008). Gujarati and Porter (2009) emphasises that the SIC can be used to compare in-sample or out-of-sample forecasting performance of a model. Both models are given in equations 3.19 and 3.20 respectively:

$$AIC = 2 \log_e L(\hat{\theta}) + 2s \quad [3.19]$$

$$SIC = -2 \log_e L(\hat{\theta}) + s \log_e n \quad [3.20]$$

where  $\log_e L(\hat{\theta})$  is the maximised log likelihood under the model and  $\theta$  is the parameter vector for the model. Gujarati and Porter (*ibid*) points out that, for both the AIC and SIC, the model with the smallest value is the better model and therefore the one most supported by the data.

### 3.9 MODEL DIAGNOSTICS TESTS

Moroke (2005) postulates that, after model estimation, diagnostics checks must be performed to determine model adequacy. Tandrayen-Ragoobur and Emandy (2011) emphasise that model diagnostics testing is important as it helps the researcher to identify if there is misspecification of a functional form and the stability of regression coefficients. In light of the above information, the cumulative sum control chart (CUSUM) stability test and Ramsey's (regression error specification test) RESET tests are adopted to test for stability of regression coefficients and misspecification of a functional form.

### 3.9.1 CUSUM STABILITY TEST

Checking model stability is necessary for prediction and econometric inference (Hansen, 1992). The author further cautions that model instability generally makes it difficult to interpret regression results. In the present study, the CUSUM stability test is used to assess stability of the long run dynamics (Tandrayen-Ragoobur and Emandy, 2011). The test is essentially designed to detect instability in the model (Hansen, *ibid*).

This test was developed by Page (1954). It is based on a normalized version of the cumulative sums of the residuals (Brooks, 2008). Tandrayen-Ragoobur and Emandy (*ibid*) point out that, if a plot of the CUSUM statistics stays within the critical bounds of 5% significance level, it means that all coefficients in the model are stable. Stability of the model implies that the explanatory variables are fit for the selected model.

### 3.9.2 RAMSEY'S RESET TEST

The RESET test was developed by Ramsey (1969). This test is a general misspecification test designed to check the inappropriate functional form of the model (Brooks, 2008). It is also used to test whether a regression model is correctly specified in terms of the regressors that have been included (DeBenedictis and Giles, 1998).

Among the reasons for employing this test is the fact that it is easily implemented (DeBenedictis and Giles, *ibid*). Brooks (*ibid*) view the test as Keenan's statistic as it allows for a functional of the fitted values of a higher order than two. In the present study, the Ramsey's RESET test is employed to check the inappropriate functional form of the model. The Ramsey's statistic can be achieved via the following steps:

- The researcher must first run the multivariate regression with a constant, then save the residual,  $u_t$ , and the fitted values.
- The second step is to run a regression which constitutes the alternative model of the form:

$$y_t = \tilde{x}_t' \alpha + \beta_2 \hat{x}_t^2 + \dots + \beta_k \hat{x}_t^k + v_t \quad [3.21]$$

for  $k \geq 2$ ,



where  $\tilde{x}_t$  is a vector containing the original regressors, and  $k$  is the highest order of the fitted values from the regression model. The regression model can also be expressed as equation [3.21a] to suit this study:

$$ER = \tilde{x}_t' \alpha + \beta_1 GDP + \beta_2 INTR + \beta_3 INF + \dots + \beta_k \hat{x}_t^k + v_t \quad [3.21a]$$

The RESET test statistic is given by:

$$RESET = \frac{(\hat{u}'\hat{u} - \hat{e}'\hat{e})/p^*}{\hat{e}'\hat{e}/(\hat{t} - k)} \quad [3.22]$$

This test is an  $F$  statistic for testing the following hypothesis:

$$H_0 : \phi_j = 0 \text{ (For instance, the model is correctly specified)}$$

$$H_1 : \phi_j \neq 0 \text{ (For instance, the model is not correctly specified)}$$

If the probability value of the Ramsey's RESET test is greater than 0.05 or 5% reject the null hypothesis and if the probability value is less than 0.05 or 5% accept the null hypothesis.

According to Hill, Griffiths and Lim (2008), rejection of  $H_0$  implies that the specification of the equation can be improved.

### 3.10 FORECASTING EXCHANGE RATE VOLATILITY

Forecasting is very crucial as predictions of future events are used for decision making processes in many organisations (Bowerman et al., 2005). In the present investigation, the selected model is employed to forecast exchange rate volatility. Producing forecasts from the model of ARCH (q) or GARCH (p, q) class is relatively simple and the algebra involved is very similar to that required to obtain forecasts from ARIMA models according to Brooks (2008).

Matei (2009) points out that, ARCH (q) or GARCH (p, q) are appropriate models to measures when forecasting volatility with large observations. The appropriateness of the ARCH (q) and GARCH (p, q) models is seen through a unidirectional perspective of the quality of volatility forecast provided by ARCH (q) and GARCH (p, q) models when compared to any other model (Matei, *ibid*). Discussed below is the GARCH (p, q) model adopted from Aas and Dimakos (2004). Presented in Sections 3.10.1 and 3.10.2 are ARCH and GARCH models for forecasting exchange rate volatility.

### 3.10.1 FORECASTING WITH GARCH (p, q) MODEL

$$\sigma_t^2 = a_0 + a \epsilon_{t-1}^2 + b \sigma_{t-1}^2 \quad [3.23]$$

Rewriting GARCH (p, q) using variable labels

$$ER_t^2 = a_0 + GDP \epsilon_{t-1}^2 + INFR \sigma_{t-1}^2 + INTR \sigma_{t-2}^2 \quad [3.23a]$$

The parameters satisfy  $0 \leq a \leq 1$ ,  $0 \leq b \leq 1$  and  $a + b \leq 1$ . The variance process is stationary if  $a + b < 1$  and the stationary variance is given by  $a_0 / (1 - a - b)$ . Aas and Dimakos (2004) further state that the model is fitted to a data set for the time period  $t = 1, \dots, T$ . The 1-step forecast of the variance, given the information at time  $T$  is given by:

$$E[\sigma_{T+1}^2 | \sigma_T^2] = a_0 + a \epsilon_T^2 + b \sigma_T^2 \quad [3.24]$$

Where  $\epsilon_T^2$  and  $\sigma_T^2$  are the fitted values from the estimation process. The above derivation can be iterated to get the k-step forecast ( $k \geq 2$ ).

$$E[\sigma_{T+k}^2 | \sigma_T^2] = a_0 \sum_{i=1}^{k-2} (a+b)^i + (a+b)^{k-1} (a_0 + a \epsilon_T^2 + b \sigma_T^2) \quad [3.25]$$

As  $k \rightarrow \infty$ , the variance forecast approaches the stationary variance  $a_0/(1-a-b)$  (if the GARCH (p, q) process is stationary). The forecasted volatility can be used to generate confidence intervals of the forecasted series values. Discussed below is the ARCH (q) model adopted from Ngailo (2011) and Tsay (2002).

### 3.10.2 FORECASTING WITH ARCH (q) MODEL

A theory of forecasting with the ARCH (q) model is given in detail:

Let  $r_1, r_2, r_3, \dots, r_t$  to be an observed time series, then the  $l$ -step ahead of forecast, for  $l=1, 2, \dots$ , at the origin  $t$ , denoted as  $r_t(l)$  is taken to be the minimum mean squared error predictor, that is,  $r_t(l)$  minimises:

$$E(r_{t+l} - f(r))^2 \quad [3.26]$$

where  $f(r)$  is a function of the observations, then

$$r_t(l) = E[r_{t+l} \mid r_1, \dots, r_t] \quad [3.27]$$

however for the ARCH (q) model

$$r_t(l) = E[r_{t+l} \mid r_1, \dots, r_t] = 0 \quad [3.28]$$

The forecast for the  $r_t$  series provide no much helpful information. It is therefore important to consider the squared returns  $r_t^2$  given as (Shephard, 1996):

$$r_t^2 = E[r_{t+l}^2 \mid r_1^2, \dots, r_t^2] \quad [3.29]$$

Hence the  $l$ -step ahead forecast for  $r_t^2$  is given by:

$$r_t^2(1) = \hat{\alpha}_0 + \alpha_1 r_t^2 \quad [3.30]$$

which is equivalent to:

$$\begin{aligned} \sigma_t^2 &= E[\sigma_{t+1}^2 | r_t] \\ &= \hat{\alpha}_0 + \hat{\alpha}_1 r_t^2 \end{aligned} \quad [3.31]$$

where  $\hat{\alpha}_0$  and  $\hat{\alpha}_1$  are the conditional maximum likelihood estimates of  $\alpha_0$  and  $\alpha_1$ .

### 3.11 FORECAST EVALUATION AND ACCURACY CRITERIA

After forecasting volatility using ARCH (q) and GARCH (p, q) models above, the researcher intends to forecast performance using the mean squared error (MSE) and mean absolute percentage error (MAPE). Bowerman et al., (2005), assert that, MSE and MAPE are able to assist the researcher to monitor a forecasting system in order to detect when something has “gone wrong” with the model. Discussed below are the (MSE) and the (MAPE).

#### 3.11.1 MSE

MSE is obtained when the sum of squared errors is divided by its degrees of freedom and the result is the error variance or mean square error (Yaffee and McGee, 1999). According to SAS Institute Inc. (2012), MSE is useful to rely on the concepts of bias, precision and accuracy in statistical estimation. In the present study, MSE is employed to check precision and accuracy in statistical estimation. Given in equation 3.32 is the MSE:

$$MSE = \frac{\sum_{t=1}^n (y_t - \hat{y}_t)^2}{n} \quad [3.32]$$

where n is the number of observations, forecast error  $e_t$  is equal to  $y_t - \hat{y}_t$ ,  $y_t$  is the actual value,  $\hat{y}_t$  is the predicted value,  $t$  is the time period and ER is the exchange rate (Bowerman et al., 2005). When making decisions, the smaller the error, the better forecasting ability of the model.

### 3.11.2 MAPE

MAPE is the average of the sum of the absolute values of the percentage errors (Yaffee and McGee, 1999). MAPE is also useful to rely on the concepts of bias, precision and accuracy in statistical estimation (SAS Institute Inc., 2012). For the purpose of this study, MAPE is also employed to check precision and accuracy in statistical estimation. Discussed below in 3.34 is the MAPE:

$$APE_t = \frac{|e_t|}{y_t} (100) \quad [3.33]$$

From the equation [3.33], MAPE can be derived as follows:

$$MAPE = \frac{\sum_{t=1}^n APE_t}{n} \quad [3.34]$$

where  $n$  is the number of observations, forecast error  $e_t$  is equal to  $y_t - \hat{y}_t$ ,  $y_t$  is the actual value,  $\hat{y}_t$  is the predicted value and  $t$  is the time period, MAPE is the absolute percentage error and ER is the exchange rate (Bowerman, et al. 2005). When making decisions, the smaller the error the better the forecasting ability of the model.

### 3.12 CHAPTER SUMMARY

This chapter covered the methodology process used in the study. The chapter discussed the data used including data sources, variables, and the methods used to analyse the data. The study employed three independent variables which are identified through the help of literature and relevant theory discussed in Chapter 2 and one dependent variable. Preliminary data analysis procedures are looked at. This procedure highlights the basic statistics. A detailed review of the ADF and PP stationary test is given. The purpose of these two statistics is to assess the series for stationarity in order to avoid spurious results.

The BDS test for statistical independence is reviewed in order to test whether time series are *iid*. A detailed review for GARCH ( $p, q$ ), ARCH ( $q$ ), GARCH ( $p, q$ ) – BEKK model and GARCH ( $p, q$ ) - CCC model estimation are also given. Model diagnostics is reviewed in order to check for misspecification of functional form, the stability of regression coefficients and normality of model residuals. On the other hand, model selection reviewed the method which helps to identify the best model for forecasting. The next chapter provides an analysis and results of the data used for the study.



## **CHAPTER FOUR**

### **DATA ANALYSIS AND RESULTS**

#### **4.1 INTRODUCTION**

This chapter presents and analyses data obtained from SARB and OECD. The chapter aims to provide the results on the exchange rate volatility in the South African context. The objective of the chapter is to determine the effect of the three selected variables on exchange rate volatility in the South African context. The analysis takes into consideration the objectives as outlined in Chapter 1 and the methodology discussed in Chapter 3. Data is analysed through the econometric views (E-Views) version 8.

The variables factored in the analysis are exchange rate (ER) as a dependent variable, gross domestic product (GDP), interest rate (INTR) and inflation rate (INF) as independent variables. The results are presented in the form of figures and tables. The rest of the chapter is structured as follows: Section 4.2 discusses the preliminary results. Section 4.3 discusses the stationarity test results.

The BDS test for statistical independence given in Section 4.4. This is followed by ARCH and GARCH modelling results in Section 4.5. The chapter further provides model selection criteria in Section 4.6. Given in Section 4.7 is the GARCH (1, 1) – BEKK and GARCH (1, 1) – CCC volatility spill over models. Section 4.8 provides model diagnostic check for the chosen model. Lastly, accuracy criteria and forecasting are given in Section 4.9 and 4.10 respectively.

#### **4.2 PRELIMINARY RESULTS**

The study uses time series data, therefore it is important to quantify the behaviour of each random variable. For this reason, basic statistics are employed. Statistics used include the skewness, and Jarque – Bera test for normality. Variables used in the study include ER, GDP, INF and INTR. It should be noted that all the variables are measured in percentages except for GDP which is measured in millions.

#### 4.2.1 Descriptive statistics results

**Table 4.1: Basic descriptive statistics**

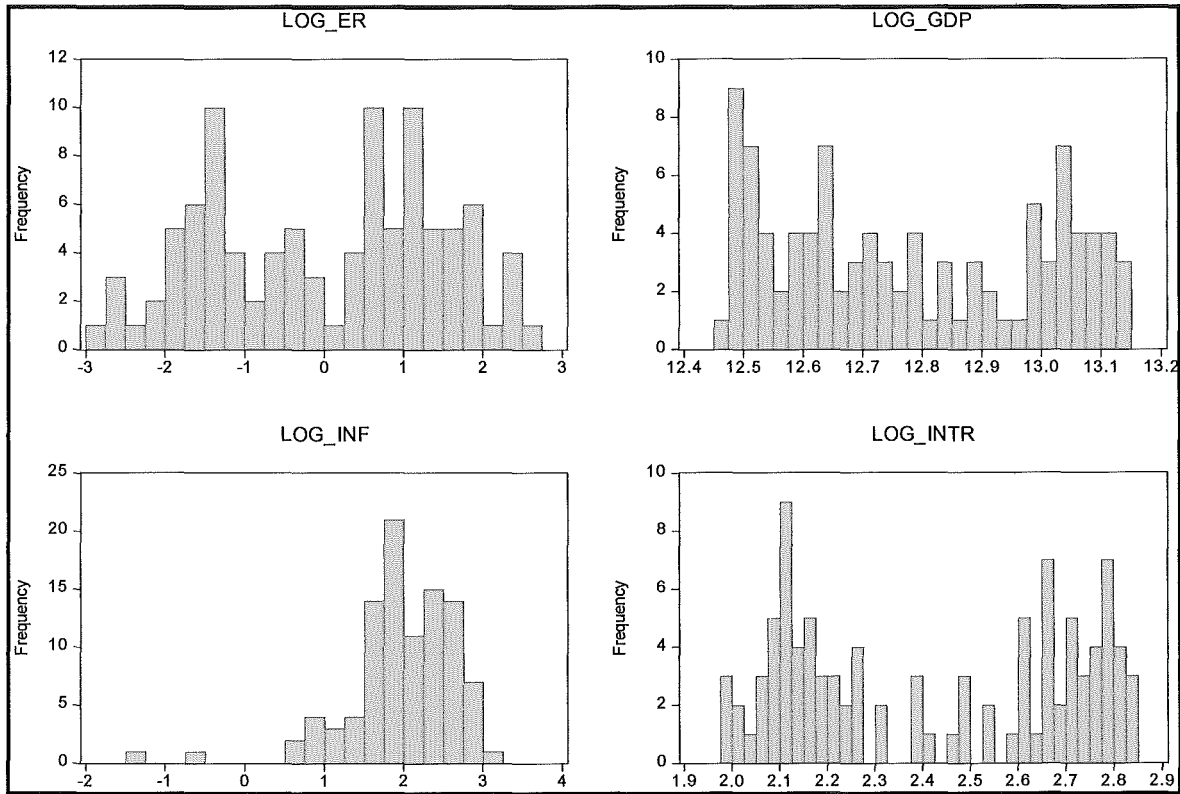
	LOG_ER	LOG_GDP	LOG_INF	LOG_INTR
Skewness	-0.163254	0.169258	-1.639801	0.018633
Jarque-Bera	6.000574	8.664917	149.4681	10.83688
Probability	0.049773	0.013135	0.000000	0.004434
Observations	98	98	98	98

Note: Wegner (2012), indicates that a slight marginal skewness is present if the skewness coefficient lies between - 0.5 and + 0.5. The sign of the coefficient is evidence of the direction of skewness. If the value of the skewness coefficient is negative, the distribution is marginally skewed to the left and vice versa.

LOG\_ER and LOG\_INF have negative skewness of -0.163 and -0.1639 presented in Table 4.1. These values suggest that the series is moderately skewed to the left which suggest that there is a few low valued outliers. On the other hand, LOG\_GDP and LOG\_INTR have positive skewness value of 0.169 and 0.018 respectively, suggesting that the series is moderately skewed to the right. This may be an indication that the data contain few outliers.

The Jarque – Bera test was applied to check whether or not the data comes from a normal distribution. The probability values for all variables are less than 0.05 or 5%. Therefore, the Jarque – Bera test accepts the null hypotheses at 5% level of significance that the distribution is normal for all variables. Figure 4.1 presents the distribution for all variables and the direction of the skewness. In Section 4.3 the analyses of stationarity among variables is presented.



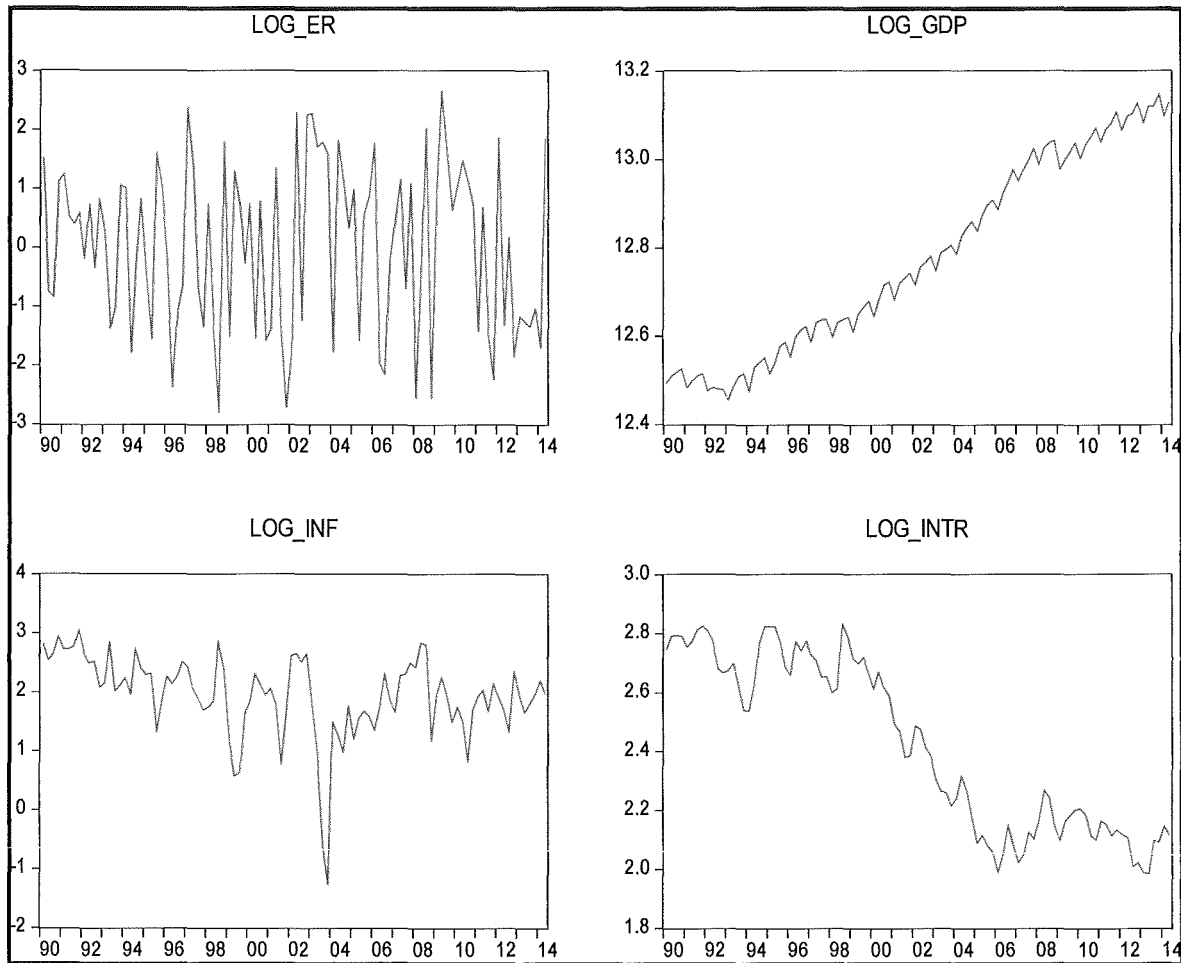


**Figure 4.1: Distribution of variables**

In Figure 4.1, LOG\_ER and LOG\_INF are moderately skewed to the left suggesting a few low valued outliers. On the other hand, LOG\_GDP and LOG\_INTR are moderately skewed to the right which may be an indication that data contain few outliers.

### 4.3 STATIONARITY TEST RESULTS

Firstly, the study employs informal methods which are the visual inspection on determining stationarity in the series to be followed by formal methods. Time series plots for all variables are presented in Figure 4.2. The intention here is to determine the behaviour of variables and also to assess the series for stationarity. These plots are followed by the ADF and PP formal tests for stationarity presented in Table 4.2.



**Figure 4.2: Time series plot in logs**

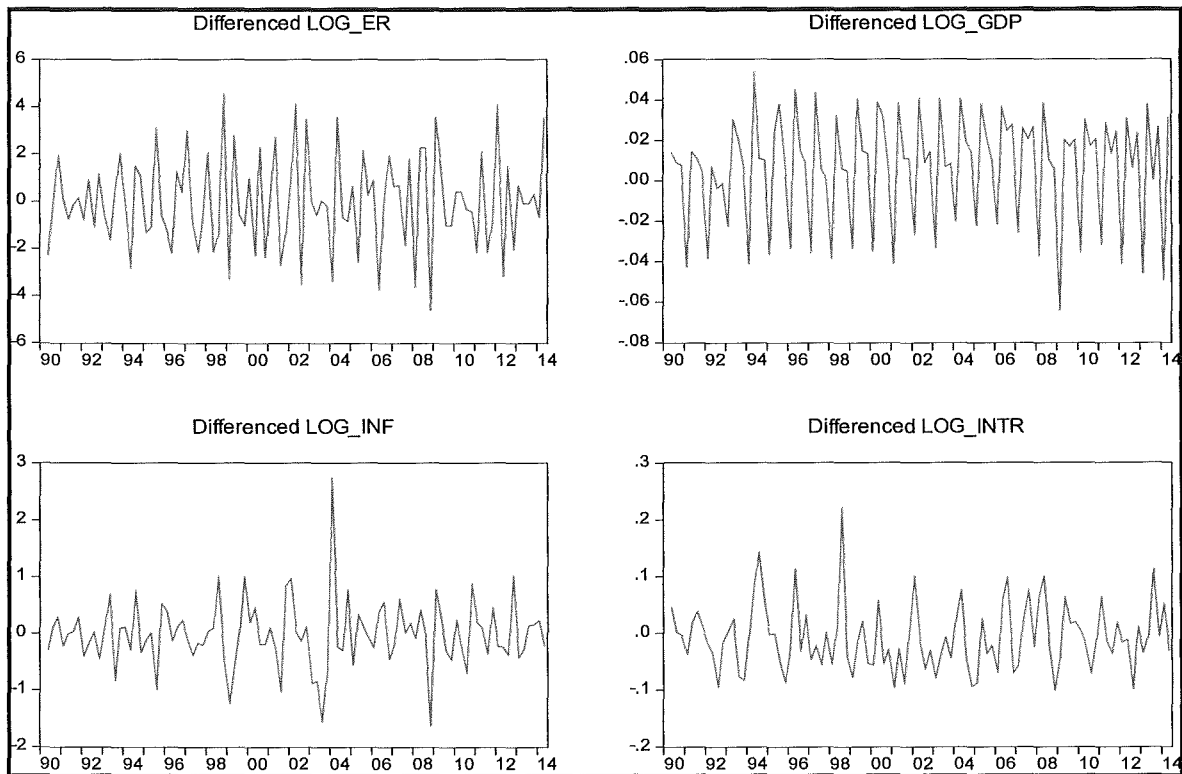
It is evident from figure 4.2 that LOG\_ER is explained by irregular components and has disturbance errors between the years 1993 and 1998. LOG\_ER also experienced Irregular components in the year 2000 and were last experienced between the years 2007 and 2008. Therefore the series appears to be stationary at level. According to the Industrial Development Corporation (2013), the South African rand exhibited excessive volatility from the year 1996 to 2001 and the pace of the depreciation was particularly strong but then again the rand strengthened between the years 2003 and 2006.

During the subprime mortgage crisis which took place in 2007 and the financial crisis in 2007 and 2008, the rand embarked on a generally declining trend but increased again in the years 2009 and 2010 (Industrial Development Corporation, *ibid*). A volatile exchange rate cause uncertainties in terms of foreign investment and therefore macroeconomic factors such as GDP, INTR and INF are affected negatively. The findings of the study by Ozturk (2006) highlighted that changes in exchange rate create uncertainty about the profits to be made and hence, reduces the benefits of international trade.

LOG\_GDP has an upward inclination or movement starting after the year 1992. Therefore, the series is non-stationary with an upward cyclical trend. The South African economy has undergone a substantial transformation since the advent of democracy and after the apartheid era. SA started to trade goods and services with other countries which favoured the country's economy (Industrial Development Corporation, 2013). Which could be an explanation for the upward movement in the plot.

LOG\_INF exhibits non-stationary showing a movement or disturbance between 2003 and 2005 which revolved around zero. Disturbances in inflation may be influenced by the turmoil in global stock markets in 2002 (Naraidoo and Raputsoane, 2013). Furthermore, the subprime crisis which took place in 2007, the financial crisis in 2007 and 2008 and the recession that followed in 2009 might have influenced disturbances.

LOG\_INTR appears to be non-stationary because there is a somewhat gradual downward trend starting after the year 1998 which is exhibited from the plot. During the year 1995, SA changed from the dual exchange rate regime to unitary exchange rate whereby interest rates experienced a generally declining trend (Mtonga, 2011). Economic fundamentals such as the inflation rate and interest rate have become more volatile in the 1980s and early 1990 (Oztuck, 2006). Due to inconsistencies in the series displayed on Figure 4.2, the study employs differencing to try to smooth these disturbances. The results are summarised in 4.3.



**Figure 4.3: Differenced time series plots**

The time series plots on Figure 4.3 are the results of first differences. The plots show no evidence of random walk in the series, different mean values at different points in time or considerable changing variances. The visual evidence provided by the diagrams proves that all variables achieved stationarity after first difference. Formal test are used to corroborate these findings and the results are shown in Table 4.2.

The formal testing procedures are considered in order to examine each variable. The Augmented Dickey Fuller (ADF) and Phillips Perron (PP) tests are used to test each variable for stationarity in levels, and then in the first difference form. Presented below is the ADF test result after first difference.

**Table 4.2: Stationary test results (ADF including intercept)**

Variable	Level of test	Number of lags	T-statistics (ADF test)	Critical value – 5%	Conclusion
LOG_ER	Level	0	-9.544059	-2.89155	Stationary
	1st Difference	1	-12.73441	-2.8922	Stationary
LOG_GDP	Level	4	-0.472878	-2.892879	Non stationary
	1st Difference	3	-2.789771	-2.892879	Non stationary
LOG_INF	Level	0	-4.72665	-2.89155	Stationary
	1st Difference	1	-9.489337	-2.8922	Stationary
LOG_INTR	Level	0	-1.037114	-2.89155	Non stationary
	1st Difference	1	-8.212624	-2.8922	Stationary

In Table 4.2, the ADF test results reveal the presence of stationarity for LOG\_ER and LOG\_INF at levels. The test indicates stationarity at a 5% significance level with the exception of LOG\_GDP and LOG\_INTR. Further differencing is required for stationarity to be acquired for all the variables. The variables were differenced once  $I(1)$  and stationarity was achieved for three variables, LOG\_ER, LOG\_INF and LOG\_INTR except for LOG\_GDP. However, after second differencing was applied to GDP, stationarity was achieved.

**Table 4.3: Stationary test results (ADF including trend + intercept)**

Variable	Level of test	Number of lags	T-statistics (ADF test)	Critical value – 5%	Conclusion
LOG_ER	Level	0	-9.493915	-3.456805	Stationary
	1st Difference	1	-12.66404	-3.457808	Stationary
LOG_GDP	Level	4	-3.130679	-3.458856	Non stationary
	1st Difference	3	-2.626282	-3.458856	Non stationary
LOG_INF	Level	0	-4.919734	-3.456805	Stationary
	1st Difference	1	-9.450032	-3.457808	Stationary
LOG_INTR	Level	0	-2.473451	-3.456805	Non stationary
	1st Difference	1	-8.171584	-3.457808	Stationary

In Table 4.3, the ADF test results reveal the presence of stationarity for LOG\_ER and LOG\_INF at levels. However, LOG\_GDP and LOG\_INTR are non-stationary at 5% significance level. Moreover variables were subjected to first difference whereby three variables (LOG\_ER, LOG\_INF and LOG\_INTR) are stationary except for LOG\_GDP.

**Table 4.4: Stationary test results (ADF including none)**

Variable	Level of test	Number of lags	T-statistics (ADF test)	Critical value – 5%	Conclusion
LOG_ER	Level	0	-9.593301	-1.944175	Stationary
	1st Difference	1	-12.80641	-1.944248	Stationary
LOG_GDP	Level	4	-2.261381	-1.944324	Stationary
	1st Difference	3	-1.590807	-1.944324	Non stationary
LOG_INF	Level	0	-1.568618	-1.944175	Non stationary
	1st Difference	1	-9.537733	-1.944248	Stationary
LOG_INTR	Level	0	-1.199044	-1.944175	Non stationary
	1st Difference	1	-8.080021	-1.944248	Stationary

In Table 4.4, LOG\_INF and LOG\_INTR are non-stationary at levels. LOG\_ER and LOG\_GDP are non-stationary at levels. The researcher considered first differencing and three variables (LOG\_ER, LOG\_INF and LOG\_INTR) are stationary except for LOG\_GDP. An additional formal test for stationarity was considered in order for the researcher to draw concrete conclusions. The Phillips Perron (PP) stationary test is considered to compare the results obtained through the ADF results. Discussed below are the results obtained through the PP test.

**Table 4.5: Stationarity test results (PP including intercept)**

Variable	Level of test	Bandwidth	T-statistics (PP test)	Critical value – 5%	Conclusion
LOG_ER	Level	3	-9.551906	-2.89155	Stationary
	1st Difference	29	-48.45519	-2.891871	Stationary
LOG_GDP	Level	15	0.447924	-2.89155	Non stationary
	1st Difference	20	-16.79365	-2.891871	Stationary
LOG_INF	Level	0	-4.72665	-2.89155	Stationary
	1st Difference	11	-13.4538	-2.891871	Stationary
LOG_INTR	Level	10	-0.895208	-2.89155	Non stationary
	1st Difference	15	-8.831559	-2.891871	Stationary

In Table 4.5, LOG\_GDP and LOG\_INTR are non-stationary at levels. The PP test indicated stationarity for LOG\_ER and LOG\_INF at 5% level of significance. In first difference, all variables are stationary.

**Table 4.6: Stationarity test results (PP including trend and intercept)**

Variable	Level of test	Bandwidth	T-statistics (PP test)	Critical value – 5%	Conclusion
LOG_ER	Level	3	-9.502677	-3.456805	Stationary
	1st Difference	28	-48.37721	-3.457301	Stationary
LOG_GDP	Level	96	-3.581054	-3.456805	Stationary
	1st Difference	19	-17.81744	-3.457301	Stationary
LOG_INF	Level	1	-5.053635	-3.456805	Stationary
	1st Difference	11	-13.46512	-3.457301	Stationary
LOG_INTR	Level	5	-2.421698	-3.456805	Non stationary
	1st Difference	15	-8.769829	-3.457301	Stationary

Table 4.6 provides the results of the PP stationarity test including trend and intercept. The results indicated that, only LOG\_INTR is non-stationary at levels. The other three variables (LOG\_ER, LOG\_GDP and LOG\_INF) are stationary at 5% level of significance. The test revealed stationarity for all variables after first differencing.

**Table 4.7: Stationarity test results (PP including none)**

Variable	Level of test	Bandwidth	T-statistics (PP test)	Critical value – 5%	Conclusion
LOG_ER	Level	3	-9.600284	-1.944175	Stationary
	1st Difference	29	-49.07497	-1.944211	Stationary
LOG_GDP	Level	15	5.087146	-1.944175	Stationary
	1st Difference	13	-12.72749	-1.944211	Stationary
LOG_INF	Level	8	-1.175144	-1.944175	Non stationary
	1st Difference	11	-13.52802	-1.944211	Stationary
LOG_INTR	Level	11	-1.489307	-1.944175	Non stationary
	1st Difference	12	-8.385467	-1.944211	Stationary

In Table 4.7, the results of the PP stationarity test including none are presented. The results indicated that, LOG\_INF and LOG\_INTR are non-stationary at levels. After all variables were subjected to first differencing at 5% level of significance, all variables were stationary. As highlighted by Brooks (2008), the ADF and PP often give the same conclusions and it has been proven in this study. For instance, both tests exhibit stationarity at 5% significance level for LOG\_ER and LOG\_INF in Tables 4.5 and 4.2. LOG\_GDP and LOG\_INTR are non-stationary.

Tables 4.4 and 4.7 exhibited non stationarity for LOG\_INF and LOG\_INTR not for LOG\_ER and LOG\_GDP. Variables exhibited stationarity for the ADF test except for LOG\_GDP which was stationary after second differencing. On the other hand, all variables in the PP were stationary after first differencing. Section 4.4 provides the test for statistical independence.

#### 4.4 TESTING FOR STATISTICAL INDEPENDENCE

The researcher assesses statistical independence using the Brock, Dechert and Scheinkmans (BDS) test statistic. The intention is to test whether or not time series are independently and identically distributed. The results are summarised in Table 4.8.

**Table 4.8: BDS test for independence**

Variable	BDS statistic	Prob. Value
ER	0.006166	0.1482
GDP	0.185807	0.0000
INF	0.059494	0.0000
INTR	0.171268	0.0000

Table 4.8 depicts the BDS test for independence. The BDS tests the null hypothesis that the elements of a time series are independently and identically distributed (*iid*). The null hypotheses of the BDS test cannot be rejected because the BDS statistic for all variables is less than 1.96. The results suggest that there is no remaining structure in the time series which could include a hidden non-linearity, hidden non stationarity or other type of structure missed by model fitting. Presented in Section 4.5 is the ARCH (1) and GARCH (1, 1) modelling results.

#### 4.5 The ARCH (1), GARCH (1, 1) AND GARCH (1, 2) MODELLING RESULTS

This Section provides a detailed analysis for the ARCH (1), GARCH (1, 1) and GARCH (1, 2) models. The intention is to construct a multivariate ARCH (1), GARCH (1, 1) and GARCH (1, 2) model of exchange rate in SA as one of the objectives of the study. To check the volatility of the exchange rate, the ARCH (1), GARCH (1, 1) and GARCH (1, 2) models are used simultaneously in order to draw conclusions. The study also identifies a model which best estimate or measure exchange rate volatility.



This study follows the approach of Ngailo (2011); Dickson (2012); Adeleke and Ogunleye (2013); Mayowa and Olushola (2013); Umaru et al., (2013). These authors did not log transform the variables when estimating the ARCH (1), GARCH (1, 1) and GARCH (1, 2) models so as to obtain simple and easy to interpret results. Presented below are the results for the abovementioned models. Variance equation coefficients exhibit low volatility when they are less than 1 and high volatility when they are greater than 1. Ngailo (2011) and Umaru et al., (2013) adopted the same criterion. Presented next in Table 4.9 are the summary results for ARCH (1) model.

**Table 4.9: Estimation results of the ARCH (1) model**

Dependent Variable: ER					
Method: ML - ARCH (Marquardt) - Normal distribution					
Sample: 1990Q1 2014Q2					
Presample variance: backcast (parameter = 0.7)					
Variable	Coefficient	Std. Error	z-Statistic	Prob.	
GDP	-2.13E-05	1.48E-05	-1.442250	0.1492	
INF	0.013084	0.129442	0.101079	0.9195	
INTR	-0.493796	0.359411	-1.373901	0.1695	
C	13.29741	8.850257	1.502488	0.1330	
Variance Equation					
C	20.31837	2.862861	7.097226	0.0000	
RESID(-1)^2	0.063162	0.164584	0.383769	0.7011	

#### ARCH (1) model construction

The modified ARCH (1) model is modified to suit this study and the resulting equation becomes:

$$ER_t^2 = 13.2974 (C) - 0.0000134 (GDP) + 0.013084 (INF) - 0.493796 (INTR) \quad [4.1]$$

This model is also estimated using exchange rate (ER) as a dependent variable while GDP, INTR and INF are independent variables. A multivariate ARCH (1) model of exchange rate in SA is presented in equation [4.1] to help determine relationships between the variables. All the three coefficients of the independent variables are negative suggesting that the three variables have negative effect on exchange rate. In the variance equation, RESID (-1) indicates that the ARCH (1) model gives a lower measure of volatility represented by 0.063162. This is an indication that exchange rate volatility is present but is lower when explained by the ARCH (1) model.

The ARCH (1) model is estimated and the results indicated that if GDP and ER have a negative relationship whereby a one million increase in GDP leads to 0.00213% decrease in exchange rate. These findings refute those by Khan, Sattar and Rehman (2012) who reported a positive relationship between these variables. A decline by 0.00213% in ER leads to a situation whereby imports in SA become artificially cheaper for foreign buyers while the volume of exports becomes relatively expensive for the country. This as a result reduces international competitiveness of SA.

INF has a positive coefficient suggesting that a 1% increase in INF leads to 1.308% increase in ER. Taking into account the results above, SA experiences an increase in ER when INF increases. High INF is influenced by higher INTR whereby a country increases the government's fiscal burden (Hnatkovsaka, Lahiri, and Vegh (2008). High INTR leads to INF rates which cause the exchange rate to appreciate. These results are not in accordance with a view by Chaudhary and Goel (2013) and Mirchandani (2013). Hnatkovsaka et al., (2008), assert that higher interest rate increases exchange rate. In the current study, INTR has a negative coefficient suggesting that a 1% increase in INTR lead to 49.379% decrease in exchange rate contradicting Chaudhary and Goel (2013) and Mirchandani (2013) notion. Presented next in Table 4.10 are the summary results for GARCH (1, 1) model.

**Table 4.10 Estimation results of the GARCH (1, 1) model**

Dependent Variable: ER					
Method: ML - ARCH (Marquardt) - Normal distribution					
Sample: 1990Q1 2014Q2					
Variable	Coefficient	Std. Error	z-Statistic	Prob.	
GDP	-1.34E-05	1.94E-07	-68.90339	0.0000	
INF	0.084388	0.106991	0.788739	0.4303	
INTR	-0.445474	0.163174	-2.730060	0.0063	
C	9.725797	1.681331	5.784580	0.0000	
Variance Equation					
C	0.141891	0.578135	0.245430	0.8061	
RESID(-1)^2	-0.060666	0.028355	-2.139496	0.0324	
GARCH(-1)	1.079670	0.075207	14.35607	0.0000	

**GARCH (1, 1) model construction**

The estimated GARCH (1, 1) model according to the results in Table 4.10 is:

$$ER_t^2 = 9.725797 (C) - 0.0000134 (GDP) + 0.0084388 (INF) - 0.445474 (INTR) \quad [4.2]$$

The GARCH (1, 1) model is estimated using exchange rate (ER) as a dependent variable while GDP, INTR and INF are independent variables. A multivariate GARCH (1, 1) model of exchange rate in SA is presented in equation [4.2] to help determine relationships between the variables. The objective was to determine the relationship between the dependent variable and independent variables.

GDP and INTR have negative values which suggest a negative effect on exchange rate while INF suggest a positive effect. GARCH (1, 1) model gives a high measure of volatility represented by the sum of the RESID (-1) and GARCH (-1)  $(-0.060666 + 1.079670 = 1.019004)$ . This is an indication that exchange rate volatility is present and is high in the South African context. These findings are in accordance with Ngailo (2011) and Umaru et al., (2013).

The results also confirm that a one million increase in GDP leads to 0.00134% decrease in exchange rate. According to Khan et al., (2012), theoretically there exists a positive correlation between exchange rate and economic growth (GDP of a country). For this study, GDP has a negative relationship and the results are not in agreement with those obtained by Parveen, Khan, and Ismail (2012) and Mirchandani (2013). When ER in SA decreases by 0.00134%, it leads to a situation whereby imports in SA become artificially cheaper for foreign buyers while the volume of exports becomes expensive for domestic markets.

INF has a positive coefficient suggesting that a 1% increase in INF lead to 8.438% increase in exchange rate (ER). The results are not in agreement with those obtained by Mirchandani (2013) where INF and ER have a moderate negative relationship but concur with those of Parveen et al., (2012). Theoretically, the Purchasing Power Parity (PPP) highlights that a relatively high inflation decreases the value of the currency (Moffatt, 2014). Taking into account the results above, SA experiences a decrease in ER when INF increases.

Chaudhary and Goel (2013) support Moffatt (2014) that, a country experiencing higher inflation will experience a corresponding depreciation of its currency, while a country with a lower inflation rate will experience an appreciation in the value of its currency. Mirchandani (2013) also points out that when a country consistently experiences lower inflation rate, it faces a rising currency value and high purchasing power as compared to other currencies.

INTR has negative coefficient and this implies that a 1% increase in INTR leads to 44.547% decrease in exchange rate. According to Mirchandani (2013), currencies with higher interest rates attract more investors in SA seeking better opportunities for their investment. The author further states that this makes currency more attractive as a form of investment and increases its demand. Chaudhary and Goel (2013) further highlight that higher interest rates attract foreign capital. Therefore, a decrease in exchange rate in SA by 44.547% is bad. This may discourage foreign investors as their investments will be a loss. Presented next in Table 4.11 are the summary results for GARCH (1, 2) model.

**Table 4.11: Estimation results of the GARCH (1, 2) model**

Dependent Variable: ER					
Method: ML - ARCH (Marquardt) - Normal distribution					
Sample: 1990Q1 2014Q2					
Variable	Coefficient	Std. Error	z-Statistic	Prob.	
GDP	-1.94E-05	1.44E-05	-1.353300	0.1760	
INF	-0.082878	0.119447	-0.693848	0.4878	
INTR	-0.267412	0.343521	-0.778446	0.4363	
C	10.64257	8.658751	1.229112	0.2190	
Variance Equation					
C	7.182738	0.889888	8.071511	0.0000	
RESID(-1)^2	0.030712	0.013008	2.361075	0.0182	
GARCH(-1)	1.625040	0.018053	90.01436	0.0000	
GARCH(-2)	-1.000319	0.019598	-51.04068	0.0000	

**GARCH (1, 2) model construction**

The estimated GARCH (1, 2) model according to the results in Table 4.11 is:

$$ER_t^2 = 10.64257 (C) - 0.0000194 (GDP) - 0.082878 (INF) - 0.267412 (INTR) \quad [4.3]$$

The GARCH (1, 2) model is also estimated using exchange rate (ER) as a dependent variable while GDP, INTR and INF are independent variables. A multivariate GARCH (1, 2) model of exchange rate in SA is presented in equation [4.3] to help determine relationships between the variables. The intension is to determine the relationship between the dependent variable and independent variables. GDP, INF and INTR are negative which suggest which suggest that these variables have a negative effect on exchange rate.

GARCH (1, 2) model gives a low measure of volatility represented by the sum of the RESID (-1), GARCH (-1), and GARCH (-2) ( $0.030712 + 1.625040 - 1.00319 = 0.62897$ ). This is an indication that exchange rate volatility is present but low in the South African context. The findings of the study are in agreement with Umaru et al., (2013) and Ngailo (2011).

The results also confirm that a one million increase in GDP leads to 0.00194% decrease in exchange rate. According to Khan et al., (2012), theoretically there exists a positive correlation between exchange rate and GDP of a country INF also has negative coefficient suggesting that a 1% increase in INF lead to 8.438% decrease in exchange rate (ER). The results are in agreement to those obtained by Mirchandani (2013) where INF and ER have a moderate negative relationship INTR has negative coefficient and this implies that a 1% increase in INTR lead to 44.547% decrease in exchange rate. Presented next in Section 4.6 are the model selection criterions.

#### 4.6 MODEL SELECTION AND ANALYSIS

The criteria used in selecting the best model from competing models is the Akaike information criterion (AIC) and Schwartz's information criterion (SIC) (Acquah, 2010). According to Gujarati and Porter (2009), the model with the smallest AIC and SIC is the one most supported by the data, and is regarded as the better the model. Table 4.12 gives suggested models with their respective criteria.

**Table 4.12: Model selection criterion**

<b>ARCH (1) model</b>	
AIC	6.029842
SIC	6.188105
<b>GARCH (1, 1) model</b>	
AIC	5.834335
SIC	6.018975
<b>GARCH (1, 2) model</b>	
AIC	5.943378
SIC	6.154396

The results provided indicate that the GARCH (1, 1) model proved to be the best model supported by data as compared to ARCH (1) and GARCH (1, 2) model. Next, the results describing volatility spill over effects is discussed. GARCH (1, 1) - BEKK and GARCH (1, 1) - CCC models are used to measure these effects. The results are summarised in Tables 4.13 and 4.14.

#### 4.7 GARCH (1, 1) - BEKK AND GARCH (1, 1) – CCC MODEL

This Section provides GARCH (1, 1) - BEKK and GARCH (1, 1) – CCC volatility spill over effects models. Summary results for GARCH (1, 1) - BEKK model are given in Table 4.13 followed by GARCH (1, 1) – CCC model in Table 4.14.

**Table 4.13: GARCH (1, 1) - BEKK MODEL**

Estimation Method: ARCH Maximum Likelihood (Marquardt)				
Covariance specification: Diagonal BEKK				
Sample: 1990Q1 2014Q2				
	Coefficient	Std. Error	z-Statistic	Prob.
ER	0.402509	0.469973	0.856452	0.3917
GDP	402308.4	14043.59	28.64712	0.0000
INF	5.810317	0.756301	7.682546	0.0000
INTR	9.811395	0.397090	24.70826	0.0000

Note: the standard error should be greater than 0.10 in order to conclude that high volatility spill over effects are present (Xu and Sun, 2010). Table 4.13 reports the estimated variance-covariance matrix of the GARCH (1, 1) - BEKK model. Firstly, the probability values indicate that the volatility spill over effects, namely, GDP, INF and INTR are statistically significant at 5% level of significance while ER is not statistically significant. The standard errors for all these variables are greater 0.10 which is an indicative of a high volatility spill over effect. Presented next are the results for GARCH (1, 1) - CCC) model.

**Table 4.14: GARCH (1, 1) - CCC MODEL**

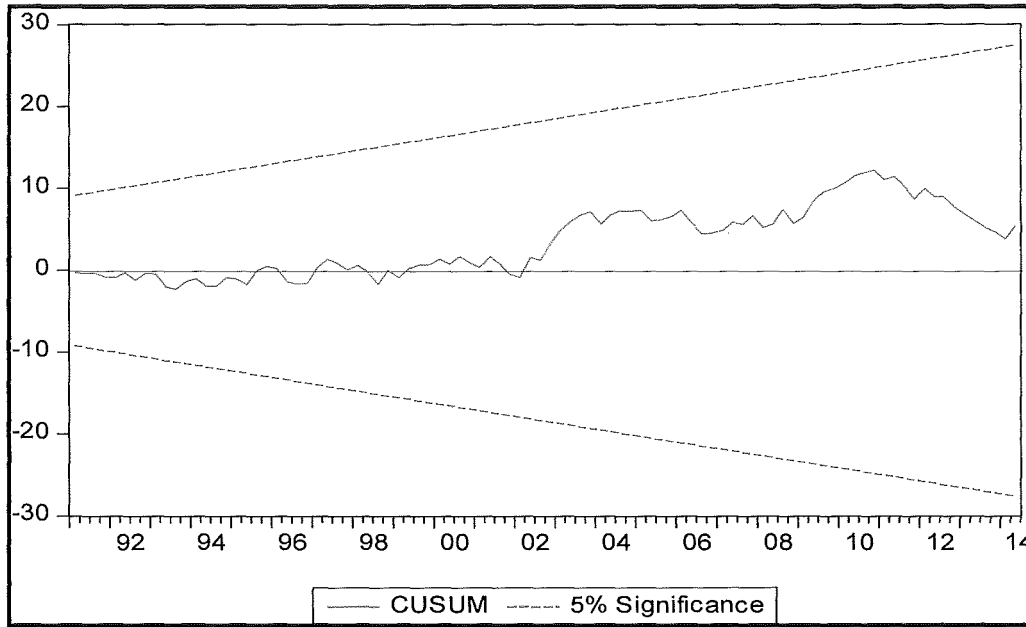
Estimation Method: ARCH Maximum Likelihood (Marquardt)				
Covariance specification: Constant Conditional Correlation				
Sample: 1990Q1 2014Q2				
	Coefficient	Std. Error	z-Statistic	Prob.
ER	0.411409	0.663604	0.619962	0.5353
GDP	363099.8	6728.099	53.96766	0.0000
INF	5.894201	0.542058	10.87374	0.0000
INTR	10.14694	0.218275	46.48701	0.0000

Table 4.14 depicts the estimated variance covariance matrix of the GARCH (1, 1) – CCC model. Firstly, the probability values indicate that GDP, INF and INTR are statistically significant at 5% level of significance, while ER is not. The magnitude of the coefficients of GDP, INF and INTR are large which represents the independent relationship between the conditional volatilities except for ER. The results suggest that ER is a volatility estimate conditional on today's volatility and can change daily, whereas GDP, INF and INTR have an unconditional volatility because they cannot change on a daily basis. Presented next are the diagnostic checking of GARCH (1, 1) model in Section 4.8.

#### **4.8. DIAGNOSTICS CHECKING OF THE GARCH (1, 1) MODEL**

Model diagnostics is provided in order to check if the parameters of the selected model are stable and fit. Firstly, stability of regression coefficients is tested using the CUSUM stability test given in Figure 4.4. Moreover, misspecification of a functional form is identified through the Ramsey RESET test. The results are presented on Table 4.15.





**Figure 4.4: CUSUM stability test**

Figure 4.4 depicts the results of the CUSUM stability test. For this study, the test is also applied to check the long run dynamics. The null hypothesis that all the coefficients in the regression model are correctly specified cannot be rejected at 5% level of significance. The plot of CUSUM statistic remains within the critical bound which suggests that the GARCH (1, 1) model is stable. Stability of the GARCH (1, 1) model implies that the explanatory variables are fit for the model. The plot indicates that even if in the long run the model will still be stable though the CUSUM changed a bit after the year 2002 but it remained in the critical bounds.

**Table 4.15: Ramsey RESET test statistic**

Ramsey RESET test			
	Value	Df	Probability
F-statistic	1.022155	(1, 93)	0.3146

The Ramsey's RESET test is used to test misspecification of the functional form. The null hypothesis is that there is no misspecification in the model ( $\phi_j = 0$ ). The Ramsey's RESET probability value of 0.3146 is greater than 0.05 or 5% significance level which suggest that the null hypothesis cannot be rejected. Therefore GARCH (1, 1) model is well specified. The model is used for further analysis whereby forecasting accuracy measures are given in Section 4.9.

#### 4.9 FORECAST EVALUATION AND ACCURACY CRITERIA

Table 4.16 presents measures of forecasting accuracy, namely the mean squared error (MSE) and mean absolute percentage error (MAPE). According to Bowerman et al., (2005), the smaller the error of the evaluation and accuracy measures the better the forecasting ability of the model. GARCH (1, 1) and GARCH (1, 2) models are adequate for modelling volatilities even over long sample periods (Bollerslev et al., 1992) in Ngailo (2011).

The researcher followed a recommendation by Bollerslev et al., (1992) as a point of reference. In Section 4.6, GARCH (1, 1) model proved to be the best model supported by data. Table 4.16 summarises results for the GARCH models and the corresponding forecast error measures.

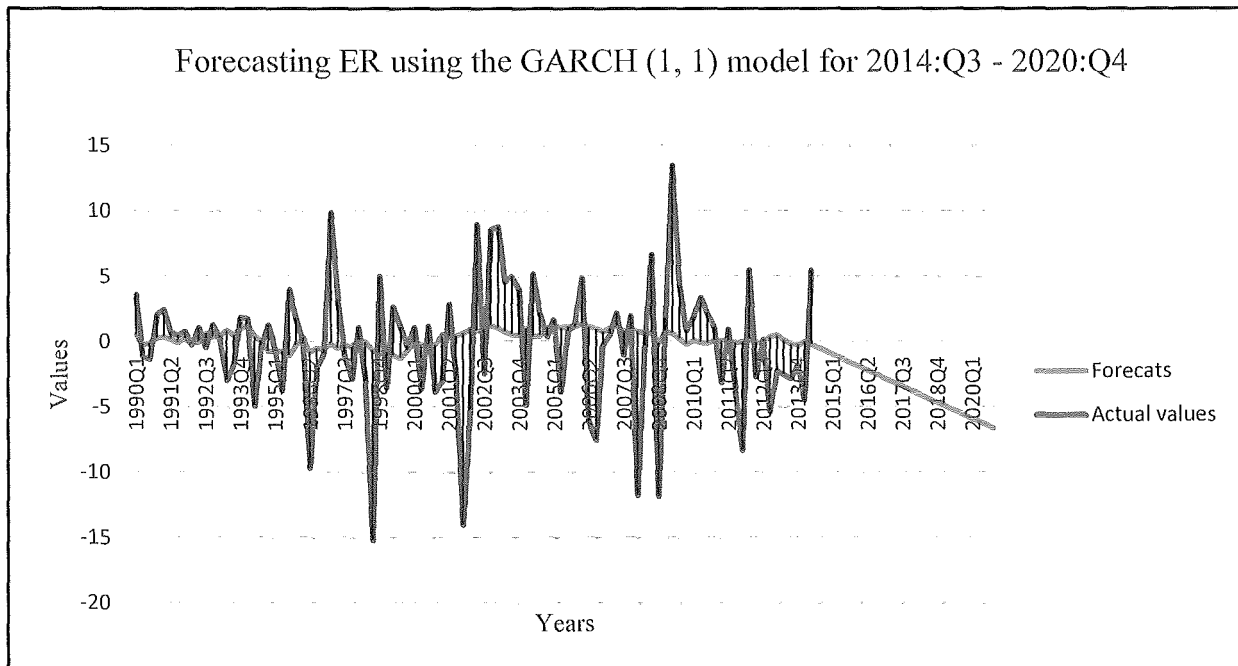
**Table 4.16: Forecasting evaluation and accuracy test on the GARCH models**

Model	MSE	MAPE
<b>GARCH (1,1)</b>	4.683858	105.3303
<b>GARCH (1,2)</b>	4.688341	113.8866

In table 4.16, the researcher compared two models namely the GARCH (1, 1) and GARCH (1, 2) in order to select the best model for forecasting. It can be seen that the accuracy test favours GARCH (1, 1) which has the smallest value for MSE and MAPE. Bowerman, et al. (2005) highlight that the smaller the error the better the forecasting ability of the model.

#### 4.10 FORECASTING WITH GARCH (1, 1) MODEL

Forecasting is very crucial as predictions of future events are used for decision making processes in many organisations (Bowerman, et al. 2005). One of the objectives of this study is to compute forecasts for exchange rate volatility. Presented in Figure 4.5 is the six years in sample forecasts of exchange rate volatility obtained from GARCH (1, 1) model.



**Figure 4.5: ER volatility forecasts for 2014:Q3 – 2020:Q4**

Figure 4.5 displays how the forecasted values of exchange rate volatility behave. It can be seen from the plot that exchange rate volatility forecasts has a downward trend or movement starting after the year 2014:Q3. SA depends largely on trade, therefore, this is good news for SA because a weak exchange rate makes currency more attractive as a form of investment and increases the demand for the currency (Mirchandani, 2013).

It could be concluded that these forecasts are legitimate because if one compares these forecasts with previous exchange rate movements in SA, the actual values of ER and ER forecasts slightly differ due to disturbances occurred in 1996, 1998, 2001 to 2002, 2005 to 2008, and 2011 to 2012. Downward trend starting from 2014:Q3 means currency in SA becomes weaker which leads to foreign investments favouring SA for the next 6 years. Therefore, the South African government should start identifying sectors where possible investments can be made.

#### 4.11 CHAPTER SUMMARY

Chapter four presented the results obtained through the E-Views version 8. The aim of this chapter was to provide the results on the exchange rate volatility in the South African context. Data is thoroughly scrutinized using informal and formal stationarity tests. The informal test indicated that LOG\_ER and LOG\_INF are stationary at 5% significance level, while LOG\_GDP and LOG\_INTR were not. It can be said that the results make economic sense because they give a clear trend of what happened after the apartheid era. Therefore the researcher performed the 1<sup>st</sup> difference and all variables were stationary.

Stationarity is then checked using the ADF formal test. The ADF test revealed the presence of stationarity for LOG\_GDP and LOG\_INTR at the first level at 5% significance level except for ER and INF. The PP test also applied in order to make concrete conclusions. The PP generated the same results as the ADF test which supported the statement made by Brooks (2008) that the ADF and PP often give the same conclusions and it has been proven in this study.

The BDS test is applied to test whether time series are independently and identically distributed. The findings indicated that time series are independently and identically distributed (*iid*). The Jarque – Bera (JB) test is also applied to test for normality of residuals and the test revealed that the residuals are not normally distributed. The researcher constructed a multivariate ARCH (1), GARCH (1, 1) and GARCH (1, 2) model of exchange rate in SA. From the constructed models, ARCH (1), GARCH (1, 1) and GARCH (1, 2) produced almost similar results whereby the independent variables have a negative relationship with the dependent variable.

ARCH (1), GARCH (1, 1) and GARCH (1, 2) models are compared in order to adopt the best model using Akaike information criterion (AIC) and Schwartz's information criterion (SIC). The GARCH (1, 1) model proved to be the best model because it produced the smallest values of AIC and SIC, compared to the ARCH (1) and GARCH (1, 2) model. The GARCH (1, 1) model is checked for misspecification of functional form and stability of regression coefficients. The results indicated that the model is stable and it is statistically well specified.

The researcher forecasted exchange rate volatility in SA using GARCH (1, 1) model. The results showed a downward trend or movement starting after the year 2014:Q3 which is good for SA because a weak exchange rate makes currency more attractive as a form of investment. Last but not least, MSE and MAPE forecasting accuracy tests were applied and the accuracy test favoured the GARCH (1, 1) model because the model has the smallest error, compared to the GARCH (1, 2). The next chapter provides summary of the study and recommendations, as one of the objectives of the study.

## **CHAPTER 5**

### **SUMMARY, CONCLUSION AND RECOMMENDATIONS**

#### **5.1 INTRODUCTION**

This chapter presents the conclusion, limitations of the study and recommendations based on the results. The chapter further provides findings from literature review and a summary of findings obtained from chapter four.

#### **5.2 STUDY FINDINGS**

This investigation explored the analysis of exchange rate volatility in South Africa. Empirical literature on exchange rate volatility in SA was given. The overall objectives of the study set in Chapter 1 were all achieved in this current investigation. With the help of the literature and relevant theory discussed in chapter 2, four variables were identified, namely exchange rate, gross domestic product (GDP), inflation rate and interest rate. Quarterly time series data was obtained from SARB and OECD databases covering the period 1990:Q1 until 2014:Q2.

The period is chosen mainly because it gives a clear trend of what happened before and after the apartheid era. Preliminary data analysis was given before the actual primary statistical data analysis. Descriptive statistics indicates that all the variables are normally distributed and are also independently and identically distributed (*iid*). Upon first differencing, all the series became stationary at one. However, second differencing was applied to GDP to render the series stationary.

The study used the ADF and PP tests to assess stationarity of the series. Brooks (2008) highlighted that ADF and PP often give the same conclusions and it has been proven in this study. The researcher further used the BDS test in order to test whether time series are independently and identically distributed. The results indicate that time series data is independently and identically distributed (*iid*) given that the BDS statistic for all variables was less than 1.96.

The results suggest that there is no remaining structure in the time series which could include a hidden non linearity, hidden stationarity or other type of structure missed by model fitting. A detailed analysis for ARCH (1), GARCH (1, 1) and GARCH (1, 2) model estimation was given. The intention was to construct a multivariate ARCH (1) GARCH (1, 1) and GARCH (1, 2) model of exchange rate in SA as it is one of the objectives of the study.

ARCH (1), GARCH (1, 1) and GARCH (1, 2) coefficients in the model were almost similar because all coefficients for the independent variables have a negative and positive relationship with the dependent variable. The GARCH (1, 1) model proved to be the best model because it has the smallest values of AIC and SIC compared to the GARCH (1, 2) model. The model was checked for misspecification of functional form and stability of regression coefficients. The results indicated that the model is stable and statistically well specified. Again, the study compared the ARCH (1), GARCH (1, 1) and GARCH (1, 2) models in order to identify a model which best estimate or measure exchange rate volatility in SA.

The GARCH (1, 1) model provided a high measure of volatility as 1.019004 indicating the presence of high volatility in ER in SA by this model. However, ARCH (1) and GARCH (1, 2) model provided a low volatility measure of 0.063162 and 0.62897 respectively. Finally, GARCH (1, 1) model was used to forecast volatility of ER in SA from 2014:Q3 and 2020:Q4. Forecasts exhibited a downward trend or movement starting after the year 2014:Q3. This means good news for SA because a weak exchange rate makes currency more attractive as a form of investment. This means good news for SA because a weak exchange rate makes currency more attractive as a form of foreign investment. Securing foreign investments implies that macroeconomic factors such as GDP, INTR and INF cannot be affected negatively by exchange rate volatility.

### **5.3 LIMITATIONS OF THE STUDY**

The absence of literature in factors affecting exchange rate volatility in SA was a challenge. For this reason, the researcher used both national and international papers. The study used secondary data obtained from SARB and OECD, therefore the researcher is not familiar with the data collection processes carried out by the sources and how well it was done. For instance, data collection processes and data capturing errors or any omissions regarding data cannot be traced. This may have influence on the results and the conclusion thereof.

### **5.4 CONCLUSION**

The current investigation evaluated exchange rate volatility in SA. The analysis took into consideration the objectives as outlined in Chapter 1. The quantitative research approach was used to conduct the study. Secondary data covering the period 1990:Q1 through 2014:Q2 was obtained from the SARB and OECD databases. Stationarity testing on the series was performed using the ADF and PP tests. The series were found to be non-stationary at their level but stationarity after first differencing was imposed. The AIC and SIC were employed to select an optimal lag one.

As a requirement, the variables were further checked for normality and statistical independence and these assumptions were honoured. For primary analyses, this study applied ARCH (1), GARCH (1, 1) and GARCH (1, 2) framework to assess exchange rate volatility in SA. This was done to determine the model which reveals high exchange rate volatility and GARCH (1, 1) outperformed the other two models. The GARCH (1, 1) model was found to be fit and stable for the data according to the diagnostic checking.

This model was recommended for further analysis and was later used for producing forecasts of exchange rate volatility in South Africa for the period 2014:Q3 and 2020:Q4. Exchange rate volatility forecasts exhibited a downward trend or movement starting after the year 2014:Q3. The downward trend of forecasts serves as good news for SA because a weak exchange rate makes currency more attractive as a form of investment.



GARCH (1, 1) – BEKK and GARCH (1, 1) – CCC models were also applied to check volatility spill over effects and conditional volatilities among variables. All variables for both models were statistically significant at 5% level of significance except for ER. The GARCH (1, 1) – BEKK model indicated a high volatility spill over effect for all variables while the GARCH (1, 1) - CCC indicated an independent relationship between the conditional volatilities for all variables except for ER.

## **5.5 RECOMMENDATIONS**

This Section provides the recommendations based on the findings of the study. These recommendations are for policy purposes and further study.

### **5.5.1 POLICY PURPOSES**

SA is a developing country and depends largely on trade with foreign countries. During periods of excessive volatility in exchange rate, foreign trade and investments are affected negatively. Currently SA uses the floating exchange rate system. Exchange rate in SA evolved from being fixed, to managed floating and finally the free floating system since the year 2000 (Mohr et al., 2008). Based on the assessment of exchange rate volatility in SA, the following is recommended:

- Based on the literature reviewed and the results of the study, the study recommends reimplementation of the fixed exchange rate system in SA. A volatile exchange rate affects the investor confidence in a host country and therefore foreign trade and investments are negatively affected. In the case where exchange rate fixed, investors have a clear idea of the rate of exchange rate they decide to invest and their rate of returns is not negatively affected in cases where the exchange rate is volatile. Nischith (2013) supports the abovementioned statement that in the case where an exchange rate is fixed, there is no volatility in exchange rate as it remains constant throughout.
- A fixed exchange rate would encourage government to implement a policy on import restrictions. A weak exchange rate will enable foreign countries to import more and uncontrolled imports tend to affect domestic industries (markets). Domestic markets will not be able to export mainly because foreign currency will be expensive as compared to the South African Rand.

- The GARCH (1, 1) model to be used for forecasting exchange rate volatility in SA. The model produces simple and easy to interpret results. The model is also recommended by Matei (2009) and Brooks (2008) that the model provides quality forecasts when compared to any other model.
- Policy makers in collaboration with the government should fund researchers and academicians to conduct a follow-up study where other GARCH family models will be estimated and the results compared with those obtained in this study. The successful implementation of the above recommendations will ensure that factors such as high inflation rate and interest rate, amongst others, are monitored.

## **5.6 FURTHER RESEARCH**

This study is not a conclusive one, rather it paves the way of future research. The current study used quarterly data, therefore the next study can be carried out using weekly or monthly data provided if data is available on these intervals to check if similar results may be obtained. The study further suggests an estimation of other GARCH family models in the analysis.

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## 7. LIST OF APPENDICES

### Appendix 7.1: ARCH (1) MODEL

Dependent Variable: ER					
Method: ML - ARCH (Marquardt) - Normal distribution					
Date: 11/01/14 Time: 12:36					
Sample: 1990Q1 2014Q2					
Included observations: 98					
Convergence achieved after 48 iterations					
Presample variance: backcast (parameter = 0.7)					
GARCH = C(5) + C(6)*RESID(-1)^2					
Variable	Coefficient	Std. Error	z-Statistic	Prob.	
GDP	-2.13E-05	1.48E-05	-1.442250	0.1492	
INF	0.013084	0.129442	0.101079	0.9195	
INTR	-0.493796	0.359411	-1.373901	0.1695	
C	13.29741	8.850257	1.502488	0.1330	
Variance Equation					
C	20.31837	2.862861	7.097226	0.0000	
RESID(-1)^2	0.063162	0.164584	0.383769	0.7011	
R-squared	0.021144	Mean dependent var	-0.128571		
Adjusted R-squared	-0.010096	S.D. dependent var	4.723095		
S.E. of regression	4.746877	Akaike info criterion	6.029842		
Sum squared resid	2118.087	Schwarz criterion	6.188105		
Log likelihood	-289.4622	Hannan-Quinn criter.	6.093856		
Durbin-Watson stat	1.922446				

## Appendix 7.2: GARCH (1, 1) MODEL

Dependent Variable: ER				
Method: ML - ARCH (Marquardt) - Normal distribution				
Date: 11/01/14 Time: 12:37				
Sample: 1990Q1 2014Q2				
Included observations: 98				
Convergence achieved after 20 iterations				
Presample variance: backcast (parameter = 0.7)				
GARCH = C(5) + C(6)*RESID(-1)^2 + C(7)*GARCH(-1)				
Variable	Coefficient	Std. Error	z-Statistic	Prob.
GDP	-1.34E-05	1.94E-07	-68.90339	0.0000
INF	0.084388	0.106991	0.788739	0.4303
INTR	-0.445474	0.163174	-2.730060	0.0063
C	9.725797	1.681331	5.784580	0.0000
Variance Equation				
C	0.141891	0.578135	0.245430	0.8061
RESID(-1)^2	-0.060666	0.028355	-2.139496	0.0324
GARCH(-1)	1.079670	0.075207	14.35607	0.0000
R-squared	0.006407	Mean dependent var	-0.128571	
Adjusted R-squared	-0.025303	S.D. dependent var	4.723095	
S.E. of regression	4.782476	Akaike info criterion	5.834335	
Sum squared resid	2149.975	Schwarz criterion	6.018976	
Log likelihood	-278.8824	Hannan-Quinn criter.	5.909019	
Durbin-Watson stat	1.890271			

### Appendix 7.3: GARCH (1, 2)

Dependent Variable: ER					
Method: ML - ARCH (Marquardt) - Normal distribution					
Date: 11/05/14 Time: 00:43					
Sample: 1990Q1 2014Q2					
Included observations: 98					
Convergence achieved after 69 iterations					
Presample variance: backcast (parameter = 0.7)					
GARCH = C(5) + C(6)*RESID(-1)^2 + C(7)*GARCH(-1) + C(8)*GARCH(-2)					
Variable	Coefficient	Std. Error	z-Statistic	Prob.	
GDP	-1.94E-05	1.44E-05	-1.353300	0.1760	
INF	-0.082878	0.119447	-0.693848	0.4878	
INTR	-0.267412	0.343521	-0.778446	0.4363	
C	10.64257	8.658751	1.229112	0.2190	
Variance Equation					
C	7.182738	0.889888	8.071511	0.0000	
RESID(-1)^2	0.030712	0.013008	2.361075	0.0182	
GARCH(-1)	1.625040	0.018053	90.01436	0.0000	
GARCH(-2)	-1.000319	0.019598	-51.04068	0.0000	
R-squared	0.004504	Mean dependent var		-0.128571	
Adjusted R-squared	-0.027267	S.D. dependent var		4.723095	
S.E. of regression	4.787054	Akaike info criterion		5.943378	
Sum squared resid	2154.093	Schwarz criterion		6.154396	
Log likelihood	-283.2255	Hannan-Quinn criter.		6.028730	
Durbin-Watson stat	1.920190				

### Appendix 7.4: GARCH (1, 1) – BEKK model

Estimation Method: ARCH Maximum Likelihood (Marquardt)				
Covariance specification: Diagonal BEKK				
Date: 11/03/14 Time: 15:22				
Sample: 1990Q1 2014Q2				
Included observations: 98				
Total system (balanced) observations 392				
Presample covariance: backcast (parameter =0.7)				
Failure to improve Likelihood after 288 iterations				
	Coefficient	Std. Error	z-Statistic	Prob.
ER	0.402509	0.469973	0.856452	0.3917
GDP	402308.4	14043.59	28.64712	0.0000
INF	5.810317	0.756301	7.682546	0.0000
INTR	9.811395	0.397090	24.70826	0.0000
Variance Equation Coefficients				
C(5)	0.483470	0.305361	1.583273	0.1134
C(6)	-63015.84	35526.87	-1.773752	0.0761
C(7)	-1.338193	0.694559	-1.926681	0.0540
C(8)	-0.237858	0.956097	-0.248781	0.8035
C(9)	4.22E+09	1.34E+09	3.141256	0.0017
C(10)	-11639.10	60302.66	-0.193011	0.8470
C(11)	-89208.74	33788.01	-2.640248	0.0083
C(12)	3.771981	1.819669	2.072894	0.0382
C(13)	1.495410	1.511254	0.989516	0.3224
C(14)	2.284446	0.927809	2.462194	0.0138
C(15)	-0.051671	0.102336	-0.504919	0.6136
C(16)	0.811828	0.204766	3.964664	0.0001
C(17)	0.511559	0.146757	3.485763	0.0005
C(18)	0.882637	0.196596	4.489604	0.0000
C(19)	0.996027	0.010815	92.09687	0.0000
C(20)	0.057998	0.223537	0.259453	0.7953
C(21)	0.714067	0.097647	7.312726	0.0000
C(22)	0.120405	0.189400	0.635718	0.5250
Log likelihood	-1912.638	Schwarz criterion		40.06271
Avg. log likelihood	-4.879179	Hannan-Quinn criter.		39.71713
Akaike info criterion	39.48241			

Equation: ER = C(1)				
R-squared	-0.012774	Mean dependent var	-0.128571	
Adjusted R-squared	-0.012774	S.D. dependent var	4.723095	
S.E. of regression	4.753166	Sum squared resid	2191.480	
Durbin-Watson stat	1.892305			
Equation: GDP = C(2)				
R-squared	-0.233564	Mean dependent var	363357.3	
Adjusted R-squared	-0.233564	S.D. dependent var	81011.26	
S.E. of regression	89975.90	Sum squared resid	7.85E+11	
Durbin-Watson stat	0.013772			
Equation: INF = C(3)				
R-squared	-0.132131	Mean dependent var	7.455102	
Adjusted R-squared	-0.132131	S.D. dependent var	4.548141	
S.E. of regression	4.839297	Sum squared resid	2271.624	
Durbin-Watson stat	0.645036			
Equation: INTR = C(4)				
R-squared	-0.335671	Mean dependent var	11.74071	
Adjusted R-squared	-0.335671	S.D. dependent var	3.347146	
S.E. of regression	3.868337	Sum squared resid	1451.511	
Durbin-Watson stat	0.036114			
Covariance specification: Diagonal BEKK				
GARCH = M + A1*RESID(-1)*RESID(-1)*A1 + B1*GARCH(-1)*B1				
M is an indefinite matrix*				
A1 is a diagonal matrix				
B1 is a diagonal matrix				
Transformed Variance Coefficients				
	Coefficient	Std. Error	z-Statistic	Prob.
M(1,1)	0.483470	0.305361	1.583273	0.1134
M(1,2)	-63015.84	35526.87	-1.773752	0.0761
M(1,3)	-1.338193	0.694559	-1.926681	0.0540
M(1,4)	-0.237858	0.956097	-0.248781	0.8035
M(2,2)	4.22E+09	1.34E+09	3.141256	0.0017

M(2,3)	-11639.10	60302.66	-0.193011	0.8470
M(2,4)	-89208.74	33788.01	-2.640248	0.0083
M(3,3)	3.771981	1.819669	2.072894	0.0382
M(3,4)	1.495410	1.511254	0.989516	0.3224
M(4,4)	2.284446	0.927809	2.462194	0.0138
A1(1,1)	-0.051671	0.102336	-0.504919	0.6136
A1(2,2)	0.811828	0.204766	3.964664	0.0001
A1(3,3)	0.511559	0.146757	3.485763	0.0005
A1(4,4)	0.882637	0.196596	4.489604	0.0000
B1(1,1)	0.996027	0.010815	92.09687	0.0000
B1(2,2)	0.057998	0.223537	0.259453	0.7953
B1(3,3)	0.714067	0.097647	7.312726	0.0000
B1(4,4)	0.120405	0.189400	0.635718	0.5250
* Coefficient matrix is not PSD.				



### Appendix 7.5: GARCH (1, 1) – CCC model

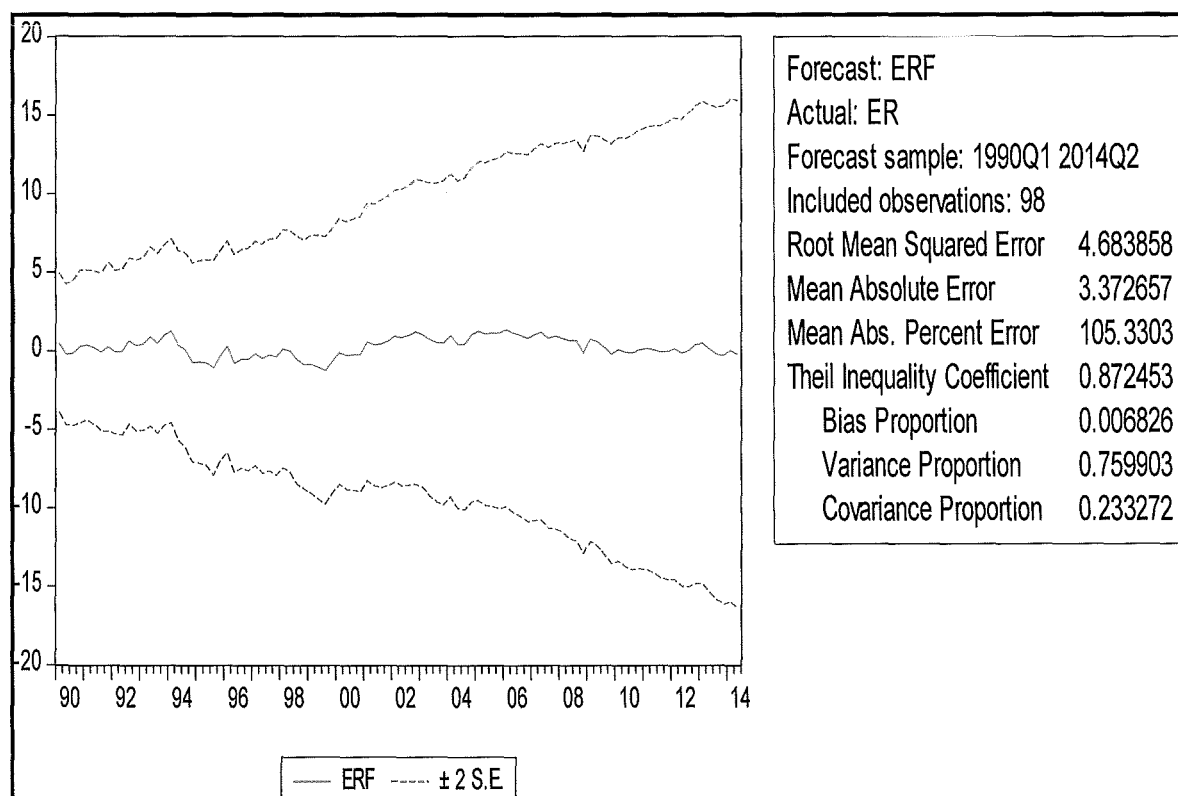
Estimation Method: ARCH Maximum Likelihood (Marquardt)				
Covariance specification: Constant Conditional Correlation				
Date: 11/03/14 Time: 15:23				
Sample: 1990Q1 2014Q2				
Included observations: 98				
Total system (balanced) observations 392				
Presample covariance: backcast (parameter =0.7)				
Convergence not achieved after 500 iterations				
	Coefficient	Std. Error	z-Statistic	Prob.
C(1)	0.411409	0.663604	0.619962	0.5353
C(2)	363099.8	6728.099	53.96766	0.0000
C(3)	5.894201	0.542058	10.87374	0.0000
C(4)	10.14694	0.218275	46.48701	0.0000
Variance Equation Coefficients				
C(5)	0.185205	0.706223	0.262247	0.7931
C(6)	-0.080504	0.042367	-1.900151	0.0574
C(7)	1.086366	0.083441	13.01959	0.0000
C(8)	4.22E+09	2.12E+09	1.993045	0.0463
C(9)	1.323595	0.952439	1.389690	0.1646
C(10)	-0.374196	0.263332	-1.421001	0.1553
C(11)	3.003930	2.167878	1.385654	0.1659
C(12)	0.245377	0.179914	1.363860	0.1726
C(13)	0.605425	0.166963	3.626113	0.0003
C(14)	2.599223	1.667782	1.558491	0.1191
C(15)	1.461983	0.930104	1.571848	0.1160
C(16)	-0.206242	0.219570	-0.939297	0.3476
C(17)	-0.025736	0.167988	-0.153203	0.8782
C(18)	-0.142238	0.140530	-1.012155	0.3115
C(19)	-0.052967	0.166604	-0.317921	0.7505
C(20)	-0.326536	0.184796	-1.767008	0.0772
C(21)	-0.955384	0.030591	-31.23100	0.0000
C(22)	0.472978	0.146725	3.223567	0.0013
Log likelihood	-1909.275	Schwarz criterion		39.99407
Avg. log likelihood	-4.870598	Hannan-Quinn criter.		39.64849
Akaike info criterion	39.41377			

Equation: ER = C(1)				
R-squared	-0.013206	Mean dependent var	-0.128571	
Adjusted R-squared	-0.013206	S.D. dependent var	4.723095	
S.E. of regression	4.754179	Sum squared resid	2192.415	
Durbin-Watson stat	1.891499			
Equation: GDP = C(2)				
R-squared	-0.000010	Mean dependent var	363357.3	
Adjusted R-squared	-0.000010	S.D. dependent var	81011.26	
S.E. of regression	81011.67	Sum squared resid	6.37E+11	
Durbin-Watson stat	0.016989			
Equation: INF = C(3)				
R-squared	-0.118997	Mean dependent var	7.455102	
Adjusted R-squared	-0.118997	S.D. dependent var	4.548141	
S.E. of regression	4.811146	Sum squared resid	2245.271	
Durbin-Watson stat	0.652607			
Equation: INTR = C(4)				
R-squared	-0.229066	Mean dependent var	11.74071	
Adjusted R-squared	-0.229066	S.D. dependent var	3.347146	
S.E. of regression	3.710755	Sum squared resid	1335.661	
Durbin-Watson stat	0.039246			
Covariance specification: Constant Conditional Correlation				
GARCH(i) = M(i) + A1(i)*RESID(i)(-1)^2 + B1(i)*GARCH(i)(-1)				
COV(i,j) = R(i,j)*@SQRT(GARCH(i)*GARCH(j))				
Transformed Variance Coefficients				
	Coefficient	Std. Error	z-Statistic	Prob.
M(1)	0.185205	0.706223	0.262247	0.7931
A1(1)	-0.080504	0.042367	-1.900151	0.0574
B1(1)	1.086366	0.083441	13.01959	0.0000
M(2)	4.22E+09	2.12E+09	1.993045	0.0463
A1(2)	1.323595	0.952439	1.389690	0.1646
B1(2)	-0.374196	0.263332	-1.421001	0.1553
M(3)	3.003930	2.167878	1.385654	0.1659

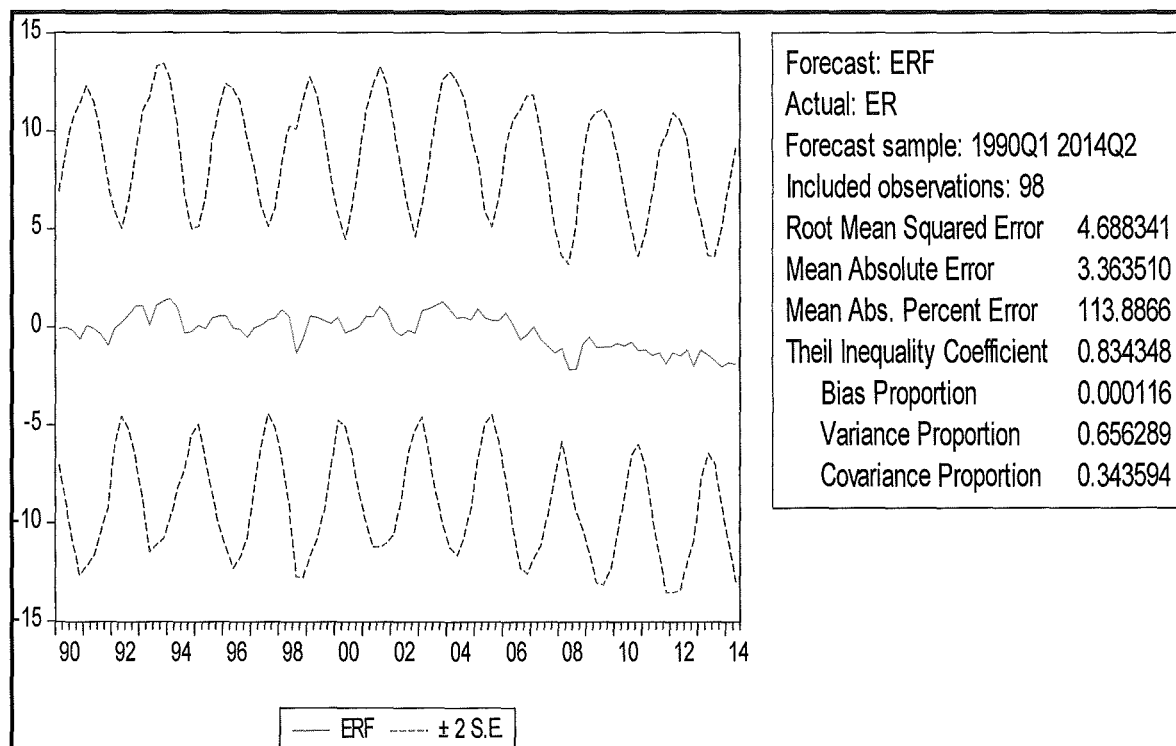
A1(3)	0.245377	0.179914	1.363860	0.1726
B1(3)	0.605425	0.166963	3.626113	0.0003
M(4)	2.599223	1.667782	1.558491	0.1191
A1(4)	1.461983	0.930104	1.571848	0.1160
B1(4)	-0.206242	0.219570	-0.939297	0.3476
R(1,2)	-0.025736	0.167988	-0.153203	0.8782
R(1,3)	-0.142238	0.140530	-1.012155	0.3115
R(1,4)	-0.052967	0.166604	-0.317921	0.7505
R(2,3)	-0.326536	0.184796	-1.767008	0.0772
R(2,4)	-0.955384	0.030591	-31.23100	0.0000
R(3,4)	0.472978	0.146725	3.223567	0.0013

## Appendix 7.6: FORECASTING EVALUATION

### Appendix 7.6.1: GARCH (1, 1)



### Appendix 7.6.2: GARCH (1, 2)



### Appendix 7.7: Ramsey's RESET test

Ramsey RESET Test				
Equation: UNTITLED				
Specification: LOG_ER LOG_GDP LOG_INF LOG_INTR C				
Omitted Variables: Squares of fitted values				
	Value	df	Probability	
t-statistic	1.011017	93	0.3146	
F-statistic	1.022155	(1, 93)	0.3146	
Likelihood ratio	1.071234	1	0.3007	
F-test summary:				
	Sum of Sq.	df	Mean Squares	
Test SSR	2.084368	1	2.084368	
Restricted SSR	191.7289	94	2.039669	
Unrestricted SSR	189.6446	93	2.039189	
LR test summary:				
	Value	df		
Restricted LogL	-171.9406	94		
Unrestricted LogL	-171.4050	93		
Unrestricted Test Equation:				
Dependent Variable: LOG_ER				
Method: Least Squares				
Date: 10/14/14 Time: 19:28				
Sample: 1990Q1 2014Q2				
Included observations: 98				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG_GDP	-1.672200	1.722956	-0.970541	0.3343
LOG_INF	-0.103391	0.285017	-0.362754	0.7176
LOG_INTR	-1.013252	1.350702	-0.750167	0.4550
C	23.96585	25.03308	0.957367	0.3409
FITTED^2	1.261042	1.247301	1.011017	0.3146
R-squared	0.044858	Mean dependent var		0.029166
Adjusted R-squared	0.003776	S.D. dependent var		1.430706
S.E. of regression	1.428002	Akaike info criterion		3.600102
Sum squared resid	189.6446	Schwarz criterion		3.731988

Log likelihood	-171.4050	Hannan-Quinn criter.	3.653447
F-statistic	1.091922	Durbin-Watson stat	1.954860
Prob(F-statistic)	0.365212		