VICTORIA UNIVERSITY
MELBOURNE AUSTRALIA

Identifying an Optimal Foreign Currency Reserve Composition to Mitigate the Volatility Spillover Effect of Declining Oil Price: The Case of Saudi Arabia

Mohanned Alharbi, MBA

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Abstract

Saudi Arabia, one of the Group of Twenty (G20) economies, has fascinated the world with its increase of foreign currency reserve based on oil revenues. The sharp rise in Saudi foreign currency reserves is one of the most important features of the nation's rapid wealth accumulation. Foreign reserves are viewed as a national source of economic growth security and financial stability. However, since the 2014–2016 oil price decline, foreign reserves have largely been spent; the depletion has been attributed to sustained government expenditure and declining oil revenues.

This study addresses the financial management of the composition of Saudi Arabia's foreign currency reserve (SFCR) during the 2014–2016 oil price decline. During this period, the Saudi government used its foreign currency reserve to cover government expenditure. Therefore, there is a need to develop a financial management strategy to mitigate foreign currency reserve depletion. The aim of this study is to identify the optimal foreign currency composition that provided a higher return during the examined period. Two approaches are considered regarding foreign currency reserve composition: univariate and multivariate generalised autoregressive conditional heteroscedasticity (GARCH) models for institutional management.

The focus of this work is the portfolio composition management viewpoint during the 2014–2016 oil price decline; it considers the suggested distribution of SFCR only during this period. In particular, the research examines SFCR allocation across three groups of currency pairs: major currencies; commodity currencies; and emerging countries' currencies. The currency groups are analysed and simulated to identify the optimal foreign currency reserve composition. Optimal weights and hedging ratios are used in this study to mitigate risk exposures of oil price volatility by adding currencies that negatively correlated with oil in the SFCR portfolio. This study provides recommendations as general comprehensive guidelines for strategic asset allocation options for consideration by Saudi Arabian Monetary Authority (SAMA) portfolio management authorities.

The study uses the GJR-GARCH model, proposed by Glosten, Jagannathan and Runkle (1993) and Lamoureux and Lastrapes (1990), to understand the dynamic behaviour for each currency pair and estimate the persistence in variance using the univariate mean-

variance analysis. Further, it employs the multivariate VAR(1)-GARCH(1,1) model, including the Baba, Engle, Kraft and Kroner, constant conditional correlation and dynamic conditional correlation models, to understand the interaction between oil prices and foreign currencies. In addition, cross-correlation function, introduced by Cheung and Ng (1996), also incorporates the univariate GARCH model in two steps to confirm the results of multivariate GARCH and test for the causes in variance between oil and currency pairs. Third, and finally, the optimal weight of the foreign currencies in this study is determined as suggested by Kroner and Ng (1998). The hedge ratio follows Kroner and Sultan's (1993) approach as a policy recommendation to the SAMA to rebalance the composition foreign currency reserve portfolio. Using the above econometric models, this study will identify and select the possible currencies that can be combined with existing currencies in SAMA's foreign currency reserve portfolio.

Using the result of univariate GARCH analysis for oil and each currency will help SFCR portfolio managers in SAMA to understand the dynamic behaviour of oil and currency exchange rates. Further, it will allow SAMA to introduce an efficient currency-selection strategy that mitigates the risk of depletion by investing in foreign exchange markets. Moreover, it enhances SFCR portfolio composition and maximises dynamic asset allocations when estimating the effect of volatility spillover between oil and the currencies. In this research, SAMA seeks to protect its foreign currency reserve portfolio against price fluctuation by investing in chosen foreign currencies. In addition, the results of the multivariate GARCH models estimate portfolio weights and hedge ratios by using variances and covariances matrices. The results of the multivariate analysis reveal that based on the optimal weights and hedge ratios estimation, SAMA portfolio diversification should increase its focus on some commodities and emerging countries' currencies to rebalance SFCR composition. This study recommends that, for example, the Japanese yen, Swiss franc, Swedish krona and Polish zloty be added to the current major currencies to reduce the impact of oil volatility.

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Declaration

I, Mohanned Alharbi, declare that the DBA thesis entitled ‘Identifying an Optimal Foreign Currency Reserve Composition to Mitigate the Volatility Spillover Effect of Declining Oil Price: The Case of Saudi Arabia’ is no more than 65,000 words in length including quotations and excluding tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work.

Signature Date

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List of Abbreviations

ADF	augmented Dickey–Fuller
AIC	Akaike information criterion
ARCH	autoregressive conditional heteroscedasticity
BEKK	Baba, Engle, Kraft and Kroner
BIC	Bayesian information criterion
CCC	constant conditional correlation
CCF	cross-correlation function
CPI	consumer price index
DCC	dynamic conditional correlation
DAA	dynamic asset allocation
EGARCH	exponential general autoregressive conditional heteroscedasticity
FCR	foreign currency reserve
G20	Group of Twenty
GARCH	generalised autoregressive conditional heteroscedasticity
GCC	Gulf Council Countries
GDP	gross domestic product
GED	generalised error distribution
GFC	global financial crisis
GJR	Glosten Jagannathan and Runkle
I.I.D	independent and identically distributed
IEA	International Energy Agency
IMF	International Monetary Fund
JB	Jarque–Bera
KPSS	Kwiatkowski, Phillips, Schmidt and Shin unit root test
LM	Lagrange multiplier
MENA	Middle East and North Africa
OHR	optimal hedge ratio
OLS	ordinary least squares
OPEC	Organization of the Petroleum Exporting Countries
PP	Phillips–Perron
SAMA	Saudi Arabian Monetary Agency

SDR	special drawing rights
SFCR	Saudi Foreign currency reserve
US	United States
USDAUD	USD versus Australian dollar
USDBRL	USD versus Brazilian real
USDCAD	USD versus Canadian dollar
USDCHF	USD versus Swiss franc
USDEUR	USD versus European euro
USDGBP	USD versus pound sterling
USDJPY	USD versus Japanese yen
USDKRW	USD versus South Korean won
USDMXN	USD versus Mexican peso
USDNZD	USD versus New Zealand dollar
USDPLN	USD versus Polish zloty
USDSEK	USD versus Swedish krona
USDZAR	USD versus South African rand

Chapter 1: Introduction

1.1 Introduction

A primary task of a country's central bank is to efficiently manage foreign reserves because these reserves play an important hedging role against any potential financial crisis. This importance was duly amplified after the Asian financial crisis in 1997–1998 (Nugée 2000). All nations began to build their foreign reserves in central banks following this economic crisis. According to one International Monetary Fund (IMF) report, global foreign reserves increased fivefold in the two years following the Asian financial crisis, rising from $2 trillion in 1997 to $10 trillion in 1999. This demonstrates the importance of foreign reserves to sovereign nations and the considerable responsibility on central banks to manage such reserves. During financial crises, the cost of holding reserves increases because the margin between return on investments in external assets 'if it is only contain bonds' and cost of debt issued becomes very thin. This occurs because interest rates fall to zero, bringing extremely low yields for central banks (Dominguez et al. 2012).

Moreover, lower interest rates at the global level and increasing foreign reserves increase the social cost for countries that have these reserves (Walter 2012). It is important to consider the responsibilities of a central bank to determine the required level of foreign reserves and the form in which these reserves should be held (Roger 1993). Many countries keep their reserves in United States (US) dollars, while some prefer to opt for euros or gold as well. The practice of keeping the US dollar as the main currency for retaining foreign reserves has declined in the last few years (Click 2006). Saudi Arabia holds 70% of its reserves in US dollars. This is a significant concern for countries who have similar or larger foreign reserves than does Saudi Arabia. Therefore, the hedging of foreign reserve currencies is crucial for any country, including Saudi Arabia. This is achieved by diversification in the form of foreign reserves. This has higher significance for Saudi Arabia because it is one of the largest holders of foreign reserves; research shows that composition of reserves is of greater significance than the level of reserves (Beck & Weber 2011).

Saudi Arabia, a G20 economy, has fascinated the world with its steady increase in foreign currency reserve derived from oil revenues. The rapidly increased size of Saudi foreign exchange reserves is one of the most important features of the nation's rapid wealth accumulation. According to the Saudi Arabian Monetary Authority (SAMA), reserves rose from US$37.4 billion to US$731.2 billion in 2002–2013. Thus, it is important to ask how to manage this enormous volume of wealth effectively. Foreign reserves are viewed as a national source of economic growth security and financial stability. However, since the oil price decline of 2014–2016, the foreign reserve has been consumed, dropping to US$496.8 billion in August 2019 because of government expenditure. Can this important function be managed to meet SAMA objectives satisfactorily? Would the massive amount of foreign currency reserves carry a heavy burden of opportunity costs and huge investment benefits? Moreover, many other developing countries perceive Saudi Arabia's method of accumulating resources as an effective alternative for raising living standards compared with the approaches of Western developed countries. The beneficiaries of investment, typically the developed countries, often pay close attention to the world's largest foreign reserves. There is a need to examine how this enormous national wealth can be managed; this is a great interest not only to Saudi Arabia, but also to the world.

The focus of this work is the portfolio composition management viewpoint during the 2014–2016 oil price decline period. Thus, only the suggested distribution of Saudi Foreign currency reserve (SFCR) in this time will be examined. In particular, the research examines the SFCR allocation across three groups of currency pairs: major currencies; commodity currencies; and emerging countries' currencies. The currency groups will be analysed and simulated to identify the optimal foreign currency reserve composition. Optimal weights and hedging ratios will be used in this study to mitigate risk exposure of oil price volatility through adding currencies that negatively correlated with oil in the SFCR portfolio. This study provide recommendations as general comprehensive guidelines for strategic asset allocation choices that SAMA portfolio management authorities should consider.

The rest of this chapter is organised as follows: First, the research background is explained. Research questions and hypotheses are represented in Section 1.3. The key academic and practical contributions of this work will be summarised in Section 1.5, while the research methodology will be outlined in Section 1.8.

1.2 Research Background

During 2002–2011, high oil revenue created substantial budget surplus in all Gulf Cooperation Council (GCC) countries (KPMG 2017). This significantly increased government spending in those countries (IMF 2016). As part of the GCC, Saudi's economic activities were affected by this oil price boom. Saudi Arabia is considered one of the largest oil-producing and exporting countries and has 22% of the world's total oil reserves (OPEC 2017). Over the past several decades, its economy and especially the government budget have been highly dependent on oil revenue. In 2015, the contribution of the oil industry to fiscal revenue was over 90% (IMF 2015).

Consequently, the recent oil price decline in mid-2014 affected the Saudi economy. The Saudi government budget had a deficit of −2.3% in 2014, −15% in 2015 and −17.3% in 2016. While the country had a current account surplus of 9.8% in 2014, it reported a current account deficit of −8.3% in 2015 and −6.4%[1] in 2016 (IMF 2016). Thus, Saudi Arabia faced its highest budget deficits of US$98 billion in 2015 and US$79 billion in 2016. As a result of using Saudi foreign reserves to finance the deficit, the reserve has declined by around US$200 billion since August 2014 (KPMG 2017). This triggered urgent economic reforms in Saudi Arabia, beginning with immediate plans for reductions in government spending on subsidies, including electricity, water and petroleum products (*The Guardian* 2015).

Currently, as the Saudi economy is heavily dependent on oil revenues, the Saudi government uses economic diversification and management of its foreign reserve assets accumulated from oil revenue to mitigate oil price decline. The main aim of economic diversification is to build sustainable economic growth that has little dependence on oil revenue. However, this effort (which began in the 1970s) failed to achieve this objective (Albassam 2015; Nusair 2016). For example, even in the second quarter of 2017, oil revenue accounted for 62% of total fiscal revenue in the country, compared with 51% in the second quarter of 2016 (Nereim 2017). Despite the slight increase in oil prices, the IMF stated that Saudi Arabia needs oil to be traded at $70 a barrel to meet government expenditure (Dipaola 2017). Further, non-oil revenue shrank by 17% in the second quarter of 2017 (*Reuters* 2017). The shares of the non-oil-based and private sectors of the

[1] As projected by the IMF country report.

economy have increased by only 10% in the past 15 years (IMF 2016). The high dependency of the Saudi economy on oil industry revenue means the SFCR needs to be managed efficiently to mitigate the impact of any long-term decline in oil price that affect government expenditure. Thus, this research will explore how SFCR needs to be managed effectively.

Oil prices considerably decreased in the middle of 2014 because of many factors, including US domestic oil production, shale oil production, innovative new energy-efficient technology, slowed global economic activity and a reluctance of GCC countries to reduce their excessive oil supply (*Economist*, 2014). This event could reoccur in the future. Thus, it is required to identify how the adverse impact of oil price decline can be managed to maintain stable SFCR and continuing government programs without having problems of fiscal revenue.

1.3 Research Questions and Hypotheses

As explained previously, the SFCR is accumulating mainly through oil revenue (Naser 2016). There are two factors causes the recent decline in SFCR: the decline in oil revenue and financing the government expenditures through the foreign currency reserve (Nagy & Szép 2016). The main motivation for this study is to reduce the impact of SFCR depletion caused by oil price decline and government expenditures by developing the optimal SFCR composition to rebalance the reserve. This research aims to minimise the impact of oil volatility risk on the SFCR by developing a SAMA currency portfolio that identifies the currencies that are negatively correlated with oil price. It will use SFCR simulated portfolios associated with oil price volatility and explore different currencies and how portfolios can be used to achieve currency diversification to help the Saudi government to manage its foreign currency reserve. The following main research questions are:

1. identify currencies that are negatively correlated with oil price to combine with the current major currencies to develop the SFCR?
2. To identify the optimal weight of SFCR to manage the risk of a downturn in oil prices?

Oil price fluctuation can affect macroeconomic factors in both oil-exporting and importing countries. Thus, a change in oil prices can affect exchange rate volatility. Based on the existing literature reviewed in this study, four hypotheses have been derived:

Hypothesis H_A: There is a persistence in variance to shocks of oil prices and currencies to return back to its mean value in different time horizons.

Hypothesis H_{B1}: There is volatility spillover from oil prices to exchange rates in major currencies, including the US dollar.

Hypothesis H_{B2}: There is volatility spillover from oil prices to some other currencies (such as emerging markets currencies).

Selecting the optimal weight and determining hedging strategy provides a cushion against the exchange rate risk. The relevant hypothesis is:

Hypothesis H_C: There is are optimal weights and hedge ratios to mitigate oil price risk for the SFCR.

1.4 Study Aim

Economic diversification is the long-term plan of Saudi Vision 2030. However, the Saudi government needs to consider an alternative short-term solution for establishing a sustainable economy to meet Saudi government expenditure through the foreign reserve. Effective foreign reserve management is required to mitigate the effects of oil price decline. According to SAMA, the total foreign reserve of the country is around SR 1.876 trillion in 2014. The largest revenues that prompted increases in the foreign assets of GCC countries, including Saudi Arabia, particularly in 2011–2013. Accordingly, this thesis aims to develop a currency composition to rebalance the SFCR to help Saudi authorities manage the foreign currency reserve. This can be used to mitigate the decline in the foreign currency reserve triggered by considerable government expenditure in times of oil price decline.

Thus, the main focus of this thesis is the recent large decline in foreign currency reserve caused by falling oil prices, and the management of the SFCR, which represents around 31% of Saudi reserve assets. The study will analyse how to manage the decline in foreign currency reserve by building the optimal currency composition in the SFCR. This model will be used as a new approach by adding more currencies that are negatively correlated with oil price, such as commodity currencies (Chen & Rogoff 2003; Cashin et al. 2004). Identifying and refining this approach could help diversify SAMA's foreign currency reserve portfolio to minimise oil volatility risk.

1.5 Contribution to Knowledge

Emerging economies provide a fertile ground for investment and offer investors high returns. Moreover, the existing literature does not contain guidelines for managing the depletion of foreign currency reserve as a result of oil revenue decline. Consequently, this study will provide a starting point for an emerging area of academic research—managing the depletion of foreign currency reserve to counter the adverse impact of oil price declines. This study focuses on the interaction between oil prices and currency exchange rates to develop an SFCR model, selecting major currencies to mitigate the depletion of SFCR in Saudi Arabia. This study will identify the currencies negatively correlated with oil price, such as commodity currencies, to determine the optimal weight to develop this model. The hedge ratio will also be considered in this study as a policy recommendation for Saudi authorities to rebalance the foreign currency reserve.

The research will contribute to academic knowledge by filling the gap between empirical research and the current depletion of Saudi foreign reserves caused by increased government expenditure resulting from the fall in oil prices. Almost all studies on the economic effects of oil price drops have concentrated only on the relationship between oil prices and exchange rates. Several studies have investigated this relationship over the last two decades (Wu et al. 2012; Amano & Van Norden 1998; Benhad 2012; Mohammadi & Jahan-Parva 2012; Akram 2004). However, few studies (Chen & Chen 2007; Chen et al. 2010) have explored whether oil prices can predict exchange rates by examining the volatility between these two markets. Further, Oana and Alexandra (2013) discussed portfolio diversification and investment in the currencies of emerging economies. They concluded that holding a clustered index of currencies is the best approach for developing an efficient portfolio. Thus far, based on the researcher's knowledge, no research has focused on managing the foreign reserve through rebalancing the foreign currency reserve, especially in the Middle East and North Africa (MENA) region context.

In terms of the methodology used in this thesis, based on the literature reviewed, this is the first study to estimate the persistence through the half-life approach obtained from univariate analysis. The power of this approach is it allows understanding of the dynamic behaviour of individual study variables before estimation of volatility spillover between oil and currencies. Further, the half-1ife approach has been used in limited studies in stock markets, but not in currency exchange markets. Thus, univariate generalised autoregressive conditional heteroscedasticity (GARCH) and half-life have not been used together in forex markets research.

The second academic contribution of this study's methodology is its combination of the cross-correlation function (CCF) model with the multivariate analysis to understand the causality between oil and currencies in both directions using daily data. Thus, multivariate GARCH and CCF approach have not been used in exchange rate intensely, especially in foreign currency reserve investigations.

1.6 Statement of Significance

The problem in this study is managing the depletion of the SFRC caused by the significant downturn in oil price since mid-2014. There is little chance of a quick recovery from this problem (*Economist*, 2014). This research will build a new approach to counter the decrease in the foreign reserve caused by government expenditure. This approach can be analysed by employing an ideal and effective management strategy for the foreign currency reserve as a hedging tool to mitigate the risk of oil price decline.

The depletion of the foreign reserve has the potential to seriously affect the economies of oil-exporting countries such as Saudi Arabia. The benefits of this research are multidimensional because the findings apply to Saudi Arabia specifically and oil-dependent countries with economies highly dependent on oil revenue. Moreover, the country's foreign currency reserve choices will be explored by studying the US dollar; Saudi riyal is pegged to US dollar and moves in the same direction. This research will also indirectly benefit the Saudi government by allowing it to manage the foreign reserve efficiently. Thus, this model could be used to create more wealth for the Saudi government, liberating it from continued dependence on oil revenues.

1.7 Conceptual Framework

To meet the objectives of this study, a conceptual framework was established to analyse how to manage foreign currency reserve decline by building the optimal currency composition of SFCR. Consideration of the composition was based on:

1. There is a persistence in variance to shocks of oil and currencies to return to their mean value in different time horizons.
2. There is volatility spillover from oil prices to exchange rates in major currencies, including the US dollar, and some other currencies (such as emerging markets' currencies).
3. There is a need to determine the optimal weights and hedge ratios to mitigate oil price decline risks for the SFCR.

Veal (2005) stated that, since analysis is empirical in nature, a conceptual framework should be implemented to explain how empirical studies examine topics. Hussey (1997) claimed that an effective research study can be developed based on a conceptual framework. Thus, the construction of a conceptual framework allows researchers to formulate hypotheses and examine the interdependence between related variables. Figure 1.1 presents a simplified version of the study framework.

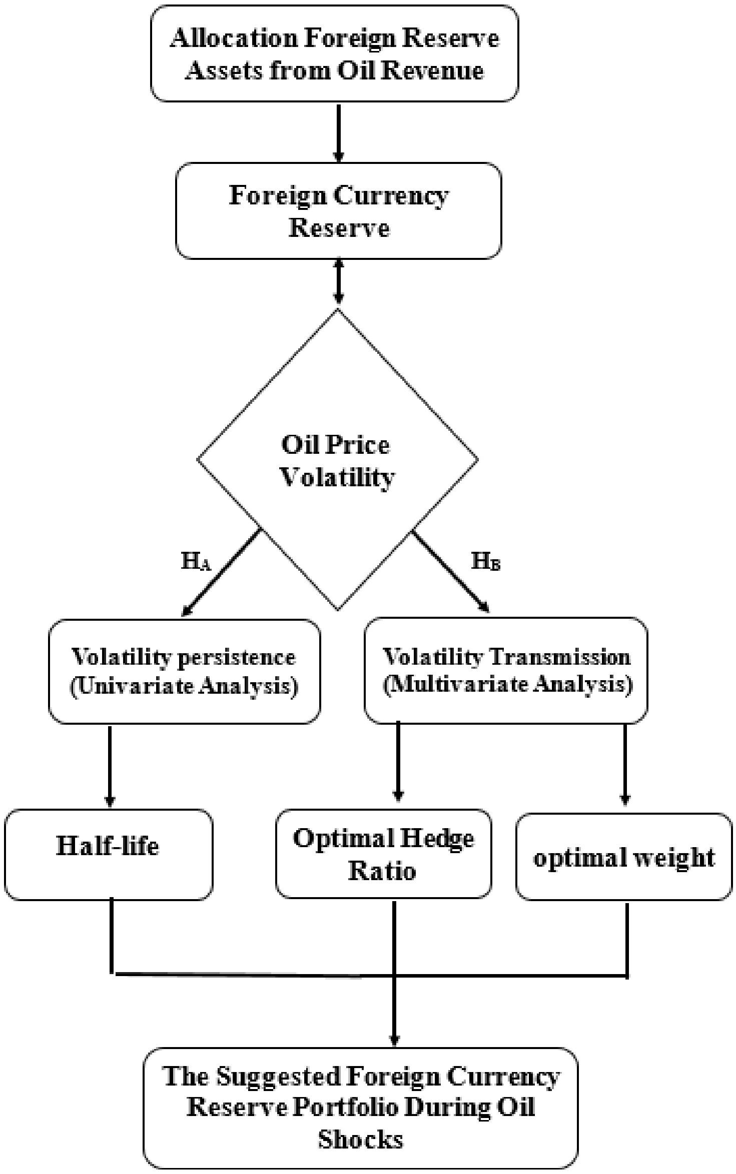


Figure 1.1: Conceptual framework

1.8 Research Methodology

Oil revenue is the main contributor to the SFCR. Thus, any changes in oil prices affect Saudi reserves. To develop the currency composition of SFCR, this study aims to investigate the spillover effect of oil market volatility on foreign exchange reserves. Moreover, optimal weights, hedge ratios and diversified portfolios will be identified for the various currency pairs. The study will test the data stationary because the econometrics models used require the stationarity of time series. Unit roots must be accounted for in the presence of non-stationary variables. In this regard, previous research shows that most variables may not be stationary or may be integrated of first order I(1). A unit root test should be conducted before any empirical estimation to avoid spurious regression. It is first necessary to test the roots to determine if the exchange rates' series and prices of stocks are stationary or not.

To test for the presence of unit roots, the augmented Dickey–Fuller (ADF) (Dickey & Fuller 1970, 1981) and Phillips–Perron (PP) tests (Phillips & Perron 1988) are frequently utilised. For each of these, the null hypothesis is that a unit root is present. However, ADF and PP tests are often criticised because they may have less power and can accept the null hypothesis more than allowed, compared with the alternative stationary (Schwert 1987; DeJong et al. 1992). This study has also used a mean stationary test, which was suggested by Kwiatkowski et al. (1992), called the Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test. The null hypothesis is rejected if value of $\mu(u)$ is greater than its critical value.

After the implementation of unit root tests, standard econometric models such as autoregressive conditional heteroskedasticity (ARCH) and GARCH, rely on the homogeneity of the variance within error. That is, the conditional variance is assumed to be constant. As with most models, ARCH is not without limitations. Perhaps the greatest limitation that restricts its use in financial analyses is the uncertainty in determining an appropriate number of lags to be inserted into the equation for conditional variance. Thus, to fully capture the dependence in the conditional variance, a very large number of lags may be required; this may violate the condition that no term in the equations can be negative. To avoid this pitfall, Bollerslev (1986) and Taylor (1986) proposed the GARCH model, which allows conditional variance to depend on lags. As a well-developed econometric tool, the GARCH model will be used in this thesis.

GARCH models are most frequently utilised to model various financial markets, although the interrelationship between said markets may also be modelled differently depending on the user's preference. Initially proposed by Bollerslev (1986), the GARCH model stood to overcome obstacles in the modified ARCH model developed by Engle (1982).

Having considered the usefulness of the GARCH model, it is essential to note that it exists in two key forms: univariate and multivariate GARCH. Both will be explained in greater detail in Chapters 3 and 4 to allow for their subsequent application. The GARCH is a popular model used to describe the dynamics of conditional volatility; it follows the work of Engle (1982).

To identify the optimal foreign currency reserve composition, this study will use various advanced econometric models (see Figure 1.2). This study will also use univariate GARCH models to select currencies to be added to the existing SFCR assets. Moreover, multivariate GARCH modes will be used to estimate volatility spillover between oil and currencies.

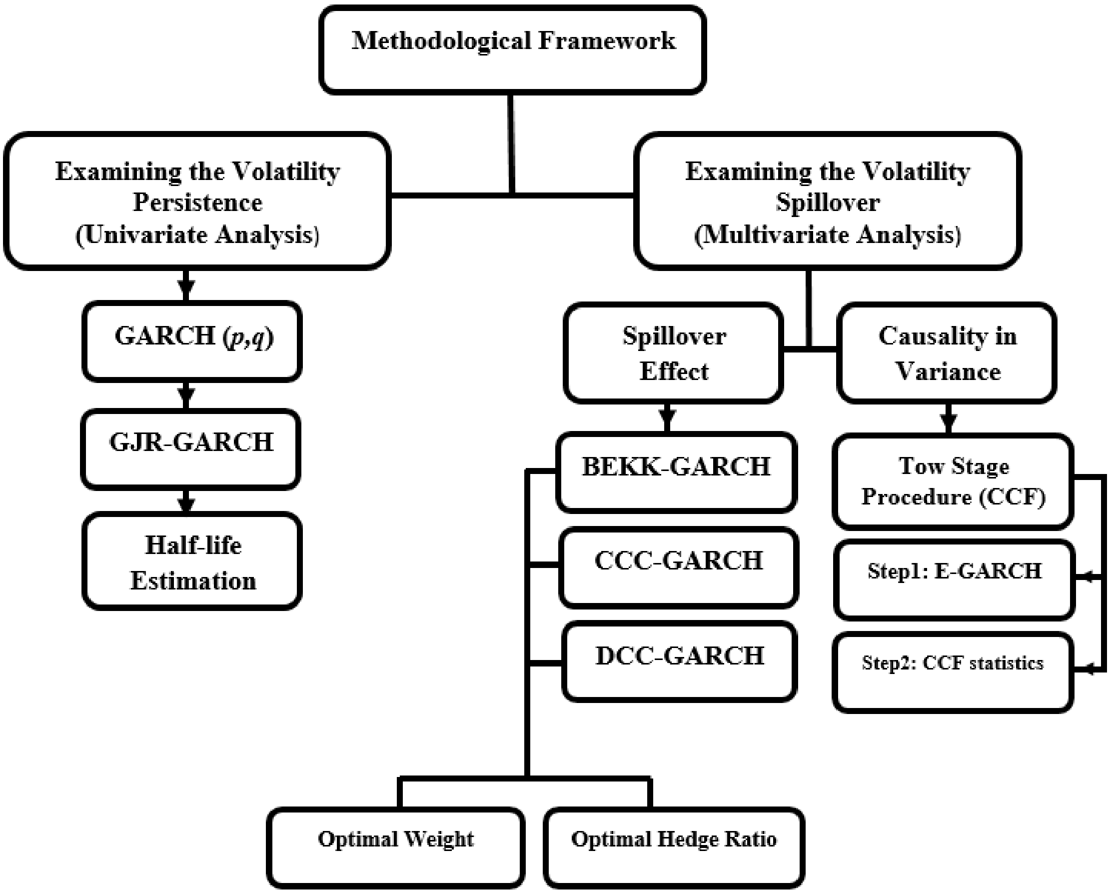


Figure 1.2: Methodological framework

As outlined in Figure 1.2, this thesis will use the univariate GARCH (GJR-GARCH) model proposed by Glosten, Jagannathan and Runkle (1993) and Lamoureux and Lastrapes (1990) to understand the dynamic behaviour for each currency pair and estimate the persistence in variance using the univariate mean-variance analysis. Using the GJR-GARCH results, the half-life method will be applied to measure the persistence to find the mean period necessary for the volatility to fall back into its long-term mean value.

Also employed in this thesis is the multivariate VAR(1)-GARCH(1,1) model, including the Baba, Engle, Kraft and Kroner (BEKK), CCC, and dynamic conditional correlation (DCC) models to understand the interaction between oil prices and foreign currencies. In addition, CCF, introduced by Cheung and Ng (1996), serves as another model that incorporates the univariate GARCH model in two steps to confirm the results of multivariate GARCH and identify causes in the variance between oil and currency pairs. Third, and finally, the optimal weight of the foreign currencies in this study will be determined as suggested by Kroner and Ng (1998). The hedge ratio will be considered following Kroner and Sultan's (1993) approach as a policy recommendation to the SAMA to rebalance the composition of its foreign currency reserve portfolio.

Thus, using the above models, this study will identify and select the possible currencies that can be combined with existing currencies in the SFCR portfolio to develop an ideal composition. Oil price volatility and major, commodity and emerging countries' currency pairs' volatility will be the portfolio variables considered.

1.9 Thesis Structure

Chapter 2 discusses the recent history of oil price fluctuations and the economy of Saudi Arabia from a historical perspective. It provides important details on the Saudi economy's dependence on oil export revenues. It also explores how oil production plays an important role in the Saudi Arabian economy as a natural resource. Further, it highlights why the Saudi government pegged its currency to the US dollar to avoid currency fluctuations and eliminate situations in which oil prices fluctuate highly in international transactions. Since oil as a commodity is priced in the US dollar, this chapter illustrates that oil price volatility has an impact on both the world economy and Saudi Arabia in particular. The position of oil revenues and accumulation of foreign assets in Saudi Arabia are discussed and their economic importance emphasised. In the first five decades, oil revenues helped fund government expenditure for much-needed infrastructure. However, there is evidence that at some stage, the economy had to diversify to avoid a government deficit as oil revenues declined. The reason for establishing SAMA was to effectively manage two concerns: the accumulation of surpluses in the current account and the reserve of foreign currency. Then, the history of SAMA as the second central bank to begin operation in the Middle East is explained; it has continued to play an essential role in the Saudi economy in the management of foreign reserves. In addition, the chapter discusses how the SFCR could benefit the country's economy when oil prices decline. It explores different ways central banks manage their foreign currency reserves.

Chapter 3 investigates the selection of currencies for the SFCR portfolio based on a mean-variance approach using univariate analysis to rank the preferred currency composition of Saudi foreign reserves based on univariate analysis. In the distributions of currency returns, the asymmetric GARCH and half-life approach are analysed. SAMA needs to understand the dynamic behaviour of financial assets to ensure their portfolios can be clearly allocated and rebalanced as financial markets shifts. In addition, SAMA tends to measure its overall asset portfolio on this basis instead of understanding the opportunity for global diversification to achieve significant growth in SFCR. The SAMA must allocate large portions of foreign currency reserve to foreign currencies to self-insure against the risks associated with falls in oil prices. This chapter suggests that SAMA may be more susceptible to cumulative shocks that can be hedged through the holding of foreign assets.

The riskiness of each asset is expected to change as new information is processed on the market. Therefore, SAMA is likely to prefer to consider the dynamic behaviour of oil and currency exchange rates by applying the univariate analysis individually for each time series. Thus, univariate analysis will help SAMA use an effective currency-selection strategy that diversifies the SFCR. Therefore, the results in this chapter help SAMA portfolio managers in strategic portfolio management. The development of dynamic optimal portfolio allocations and hedging efficacy can have significant implications for calculating the dynamic behaviour of oil and currencies.

In a half-life approach, it is shown that SAMA, through this method, can make significant value in SFCR composition. It has been hypothesised that this strategy would lead to an optimal currency structure that would allow Saudi Arabia greater capacity for international currency diversification and minimised risk of volatility persistence.

Chapter 4 studies currency composition for the SFCR based on a multivariate approach. For effective risk management, the spillover between oil and three groups of currencies is investigated A mean-variance is developed to examine the dynamic interdependence between oil and currencies. The model used in this chapter is VAR(1)-GARCH-BEKK. For greater restriction, GARCH-CCC and GARCH-DCC are applied. The CCF, another model that uses univariate GARCH model in two steps, is applied to confirm the results of multivariate GARCH for more robust results. The benefit of the models used is that they highlight the interaction between the two security assets.

To achieve portfolio diversification and risk management, time-dependent conditional variance and covariance must be accurately measured. This chapter considers SAMA as an investor with oil who wants to hedge their position against price volatilities; this is done by investing in foreign exchange markets. For this purpose, the analyses of Kroner and Sultan (1993) and Kroner and Ng (1998) are utilised by estimating portfolio weights and hedge ratios using variances and covariances derived from multivariate GARCH results. Empirical analysis shows that when diversifying SAMA's portfolio, the focus is emerging countries' currencies rather than major currencies to help SAMA reduce the impact on oil revenues.

The overall conclusion and recommendations for SAMA are outlined in Chapter 5 based on the findings of previous chapters. The study limitations are addressed in this chapter. To manage SAMA's FCR portfolio properly, this study provides detailed recommendations for SAMA portfolio managers who need to categorise their portfolio frequently into investment and liquidity segments because most SAMA assets are equities and bonds. Such a mixture ensures that the required level of cash and diversity helps mitigate risk and improve risk-adjusted return. The characteristics of SAMA's portfolio and asset class selection for the reserve portfolio are discussed in detail.

Chapter 2: Oil Price Volatility: The Reliance of the Saudi Economy and Adequacy of the Foreign Reserve

2.1 Introduction

Saudi Arabia is one of the largest countries of the Middle East, in terms of population and geographical size. Its land area is 2.15 million km^2 and its population is around 33 million. Therefore, it is the Middle East's largest sovereign country and shares its national borders with seven other Middle Eastern countries: Iraq, Oman, United Arab Emirates, Qatar, Kuwait, Jordon, Bahrain and Yemen. Moreover, Saudi Arabia is situated along two seas, the Red Sea and Arabian Gulf. Saudi Arabia is one of the world's fastest growing economies and currently the world's largest oil exporter.

The country became a sovereign nation in 1932 and its founder was King Abdul Aziz Al-Saud. Crude oil was discovered in Saudi Arabia soon after and within six years, oil production began. This revolutionised the country's economy and brought tremendous wealth. Income from oil production and exports was used to modernise the country's infrastructure and economy. For this reason, five-year economic plans were implemented to achieve economic targets that emphasised growth and diversification. These five-year plans have resulted in continuous economic growth in the Saudi Kingdom. As previously stated, Saudi Arabia is the world's leading oil-producing country, producing over a tenth of global oil output and owning a quarter of all global reserves. As a founding member of the Organization of the Petroleum Exporting Countries (OPEC), Saudi Arabia has a prominent role in decision-making. According to Belu Mănescu and Nuño (2015), the combined spare capacity of all other oil-producing countries is second to Saudi Arabia's. Nakov and Nuño (2013) asserted that the Kingdom is able to increase its production when supply disruptions occur. The high demand for oil means that although its price falls occasionally, Saudi Arabia's economic security is not threatened.

This chapter presents the recent history of oil price volatility and the economy of Saudi Arabia. The importance of oil price volatility and its impact on the world's economy in general and Saudi Arabia in particular are also explained. Moreover, the strength of the Saudi currency (i.e. Saudi riyal) is explained in terms of its historical exchange rates. In addition, this chapter discusses SFCR and the potential benefit to the country's economy when oil prices decline. It explores the different ways central banks manage their foreign currency reserves. In the conclusion, the main themes covered are summarised.

2.2 Recent History and Development of Oil Price Volatility

This section examines the recent history of oil price downturns from 1998–2014 (see Figure 2.1) and assesses the causes of price declines focusing on: the Asian financial crisis, 1997–1998, Iraq War and oil workers' strike in Venezuela, 2003, the global financial crisis (GFC), 2008 and the global oversupply in 2014.

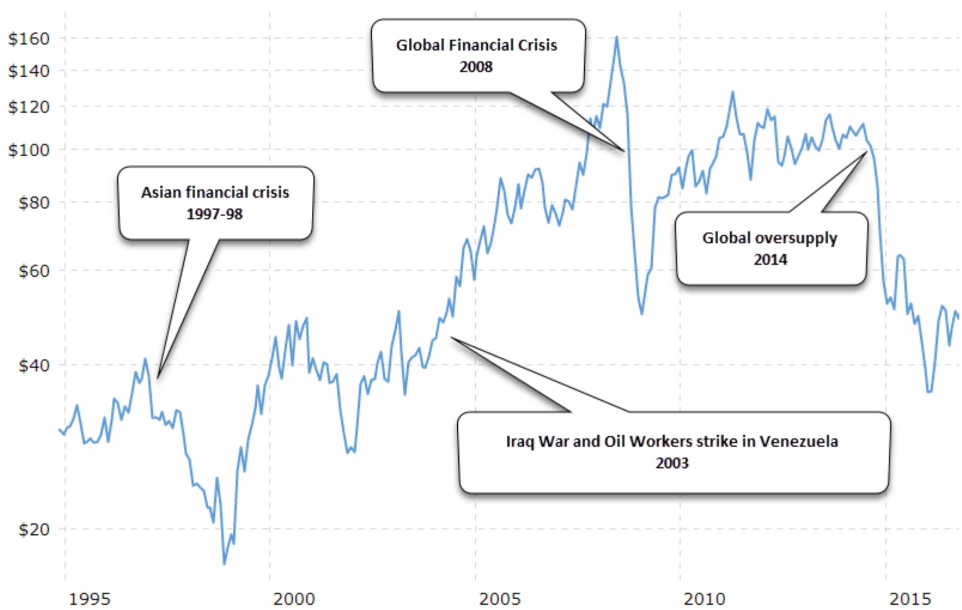


Figure 2.1: The recent history of oil price decline events

2.2.1 Asian financial crisis, 1997–1998

The huge decline in oil price hit $12 in 1998, inviting uncertainty in business not only between the oil-exporting nations, but throughout the world generally. There are various reasons for this. Concern and less demand stemming from the lengthy financial crisis in Asian countries triggered an increase in oil inventories. Countries most affected in Asia were Malaysia, South Korea and Thailand, where in 1997, currency instabilities and strains on financial systems were a major issue. Investors were uncertain about growth within the Asian nations given the levels of debt and the likely effect of these on other Asian countries. In addition, per-barrel oil prices reached their lowest point since 1972, an event not anticipated to happen again; this aggravated the situation further.

2.2.2 Iraq War and oil workers' strike in Venezuela, 2003

World crude oil prices were seriously eroded following an oil worker strike in Venezuela at the end of 2002, which led to a loss of about three million barrels per day (mb/d) of crude oil. The situation was worsened by the brief second Iraq War in 2003, led by the US; a further 2.2 mb/d was lost between April and July. These events, according to Kilian (2008), were portrayed as exogenous geopolitical events and included on the list of postwar oil shocks. As result, oil prices rose by 106.5% from 2002 to 2005, meaning that the price rose from $21.13 to $69.91. Between 2004 and 2005, the IMF estimated real gross world product growth at an average yearly rate of 4.7%, indicating a steady rate of global economic growth. This period saw a 5 mb/d growth in world oil followed by an annual 3% increase. Demand was high during this period, enabling increased production and the ability for demand to be satisfied. After 2005, there was a lack of growth in production up to August 2006 (IMF 2007).

The International Energy Agency (IEA) viewed the increase in oil price at the end of 2003 as a positive oil shock that had a knock-on effect on oil prices (Hamilton 2009). Prices began rising slowly in 2004. The price per barrel in April 2003 was $25 and $74 per barrel by the end of July 2006. The increase in oil prices during this period was attributed to increased demand from Asian nations, including China. Crude oil prices rose sharply from $34 per barrel in January 2004 to higher levels because China's gross domestic product (GDP) growth was at 10% in 2000–2008. Investors concentrated on oil matters, with the general assumption that oil was underpriced at the time; so, from 2004 onwards, oil prices began increasing.

2.2.3 Global Financial Crisis, 2008

The year 2007 saw a much higher rise in oil prices, with prices increasing from $92 to $147 per barrel between the start of 2008 to July of the same year. However, prices fell to $40 a barrel in December of the same year, betraying a highly volatile and unstable price fluctuation, mainly attributed to increases and decreases in crude oil prices, respectively. Deeper analysis of the fluctuations in prices attributed blame to structural factors and market events. Some of these included but were not limited to: (1) institutions investing more in the crude oil market; (2) a decline in the value of the US dollar; (3) an increase in Asian demand for oil, including from China; (4) an increase in the number of global oil companies; (5) regional political factors that affected the production and distribution of oil in leading oil producers, such as the MENA region, Venezuela and Nigeria; (6) an increase in the costs incurred in producing oil; (7) growth in supplies by countries that did not belong to the OPEC group; (8) reduced production by OPEC member countries. Hamilton (2009) agreed that 2007–2008 was the most volatile of oil shocks in history, mainly brought by an increase in global demand for oil, yet production had fallen.

These reasons are partly to blame for the great global recession that began in the second half of 2008. During this period, unlike in the periods above, demand for oil decreased, even in industries such as construction, manufacturing and transport. According to an IEA report (2010), demand fell by 1.3 mb/d from 86.2 mb/d in 2008 to 84.9 mb/d in 2009. Decreased demand was definitely a major cause of oil price decline between early 2008 and 2009. This was evident in the price drop from $147 a barrel in 2008 to $39 a barrel in December of the same year. Considering the importance of oil for world business, OPEC implemented measures to prevent the continued rise of global crude oil prices. A cut in production from 4.2 mb/d was ordered in 2008; this was the highest cut in production ever undertaken to address oil price recovery. Target prices for oil were also adjusted to balance prices between all OPEC member states (i.e., from $70 to $80 for each barrel of crude oil).

The decision for OPEC to control oil prices was justified because by April 2010, a barrel was trading for $80, a twofold increase on the December 2008 price. This increased demand for oil, which resembled the boom of the 1970s and early 1980s between the North Sea and the Gulf of Mexico. Use of technology was quite cost effective given the high prices of oil in the 1970s, which were attributed to oil production from offshore fields that had been using technology dating back to the 1950s. Combined production between these two locations increased the amount of oil globally by up to 6 million barrels a day. However, some sources of oil were unconventional, such as Canadian sand oil and US shale oil. Nonetheless, worldwide supplies increased in 2007–2014.

2.2.4 Global oversupply, 2014

Demand and supply wield certain effects on oil prices. Studies have argued that supply parameters started from the fourth quarter of 2014 to the middle of the first quarter of

2016. Rabah and Blanchard (2014) reported that between demand and supply factors, decreased demand made a 20–35% contribution to reduction. Conversely, OPEC did not curtail production because of supply-related factors. While Hamilton (2015) concurred with Rabah and Blanchard's findings (2014), this author proposed that reduction in global demand for oil, particularly in the second half of 2014, only contributed to 40% of the reduction in the global price of oil. Baumeister et al. (2016), while agreeing with the above views, contended that the combination of demand and supply shocks caused a reduction in the price of oil of over 50%. They acknowledged that other factors, such as a decline in the global economy, were contributing elements. This occurred in January–June 2014.

Supply and demand shocks between markets play a significant role in the extent of market integration. Negative shock in demand and supply may cause an unexpected slowdown in the global economy. It is argued that because China is a dominant force in the global economy, its use of steel and ore also contributed to the decline in oil prices. This is evident from the weakened demand for steel and iron ore in China by 2014, leading to the reduction in the price of both metals. The reduction of iron ore with 62% ferrous content is an example—reduction in demand was evident from reduced delivery of the product to Qingdao port in China. As prices fell in 2014, so too did the oil prices at the end of the same year.

Khan (2017) argued that two countries are responsible for the major increase in production, from a demand perspective: the US and Iraq. Oil production in the former rose from 5.6 million barrels per day (mb/d) in 2010 to 9.4 million barrels per day (mb/d) in 2015. This meant that oil import quantities declined. Oil producers and sellers to the US, such as Algeria, Nigeria and Saudi Arabia, had their major buyer (the US) removed from the equation, forcing them to consider Asian markets as clients. However, they had to compete with other countries who were already reducing their prices. The US imported less crude oil, from 8.5 mb/d in 2012 to less than 6.6 mb/d in October 2015. For years, there had been a gradual but steady 28-year fall in the level of US imports of oil from OPEC member states. Fracking and horizontal drilling made the shale oil boom possible. This has been attributed to the development and use of sophisticated technology in the production of oil, extending to the production of gas with a rise in US self-produced gas by 2007. The US has ventured more into the production of natural gas, which will reduce imports, further reducing the country's reliance on oil to produce electricity, and support chemical manufacturing, transport and heating (Khan 2017).

2.3 Oil Price Volatility and the World Economy

Oil is one of the most important traded commodities in the world. Any changes in the price of oil have far-reaching effects on the economy, brought by increased production costs or the uncertainty caused by price volatility. Oil is a US dollar-denominated commodity; therefore, increases in the value of the US dollar adversely affect oil-importing countries (Zhang et al. 2008). It is essential to understand how the economy and various macroeconomic factors are affected by oil price changes. Awokuse and Yang (2003) discussed how an increase in commodity prices can trigger increases in interest rates under a contractionary monetary policy. To test the hypothesis that commodity prices can forecast macroeconomic variables such as the inflation rate, Granger causality among commodity prices (CRB), federal fund rates, inflation (as measured by the consumer price index [CPI]), money stock (M2) and industrial production (IP) are used. Results indicate that changes in commodity prices have, in fact, led to changes in policies maintained by the Fed. According to Gormus and Atinc (2016), oil is subject to inelastic demand, since people cannot easily switch to another source of energy at short notice. Therefore, any changes in oil prices have dramatic effects on the economy.

Hamilton (1983) reported a negative relationship between oil prices and economic output. He concluded that an oil price increase is an exogenous change and leads to a decrease in the output of the US economy. Other literature has attempted to estimate the effect of oil price changes on macroeconomic variables. Bachmeier et al. (2008) reviewed a range of variables to determine how oil price movements affect the economy and how these effects lead to changes in macroeconomic variables, such as inflation, output and monetary policy. Further, Akram (2009) determined, using structural VAR models, that oil price shocks lead to large shocks to economic output. This relationship only holds true for oil prices, not for other commodity prices.

In terms of GDP, Kilian (2008) concluded that the effect of oil price shocks on GDP growth and inflation are essentially short term. Further, the source of the shock is important for determining the true extent of its repercussions (Kilian 2008). Katircioglu et al. (2015) reported the link between oil price changes and macroeconomic factors, such as GDP, CPI and unemployment rate, for 26 Organisation for Economic Co-operation and Development (OECD) countries. Using a Durbin-H panel and cointegration tests, they demonstrated the long-term relationship between oil prices and macroeconomic variables. An oil price increase has a negative effect on the economy; however, this negative effect is greater on the CPI in the long term than it is on the unemployment rate and the GDP. In fact, the relationship between unemployment rate and oil price changes might not be highly visible, even in the long term, but this relationship might be more significant in future studies. According to Turhan et al. (2014), because oil is a direct input for several industries that manufacture consumer products, oil price changes are believed to have a large effect on CPI. Statistics show that when oil prices increased from $15/barrel in 1998 to $140/barrel in 2008, the CPI rose from 164.30 to 214.82. Studies by Kiptui (2009), Misati, Nyamongo and Mwangi. (2013), Kargi (2014) and Abounoori, Nazarian and Amiri (2014) provided evidence for this positive relationship between oil prices and CPI. Kilian (2014) also discussed how, through a number of different channels, an increase in oil prices can have an inflationary effect on the economy.

Following up on the importance of oil price shocks and their effect on macroeconomic variables, several studies have reported persistent effects on the unemployment rate, inflation rate and real wages. According to Davis and Haltiwanger (2001), oil price shocks contributed to nearly 25% of variability in the employment growth rate for manufacturing jobs in the US from 1972 to 1988. An increase in oil prices also slows economies because of interest rate effects (Balke, Brown & Yücel 2002). Lee and Ni (2002) reported how oil price shocks lead to lower output in industries relying heavily on oil. Sill (2007) also discussed how oil price increases have been followed by recessions in the US. Gronwald (2008) used the standard VAR framework and a Markov-switching price specification to conclude that oil price shocks have had considerable effects on real GDP growth rate on three occasions: 1973–1974, 1979 and 1991.

In their paper on how oil price affects inflation, Wu and Ni (2011) discussed the extant literature on the relationship between oil prices and economic activity. Further, a study from Ireland reported that increases in oil prices led to rises in the inflation rate (Bermingham 2009). Similarly, Jacquinot et al. (2009) discussed the relationship between oil prices and inflation in Europe and concluded that the long-term effects are complex because they depend on the origin of the shock. According to Castillo et al. (2010), the higher the volatility of oil prices, the more volatile the average inflation rate. Moreover, Lowinger, Wihlborg and Willman (1985) stated that only large changes in oil price lead to any significant change in global interest rates.

Kallis and Sager (2017) discussed how the market forces of supply and demand determine oil prices, which in turn affect the economy. Further, increases in oil reserves and production have been associated with decreases in US GDP because of the negative relationship between them. Moreover, monetary policy and inflation rates affect exchange rates. For instance, a nation that implements an expansionary monetary policy or high inflation rate will experience depreciation, leading to higher oil prices. Developing countries that have pegged their currency to the US dollar will also have to address depreciation according to the 'dollar bloc' theory (Erceg, Guerrieri & Kamin 2011).[2]

Chen et al. (2014) expanded on Kilian's (2009) model to understand how an exogenous change in the financial market can lead to macroeconomic consequences. They stated that financial shocks are an essential determinant of oil prices, and thus, macroeconomic fluctuations. Positive oil supply shocks lead to an increase in the Index of Industrial Production (IIP) in the US, while positive demand shocks lead to an increase in IIP in all countries. If the positive aggregate demand shock is specific to the oil industry, there is an increase in IIP only for European countries. For the US and Japan, the effect is statistically insignificant. In other words, as financial stress increases, there is more uncertainty; this slows down the economy. It also leads to a statistically significant decline in CPI for the US.

Non-performing loans (NPLs) in oil-exporting countries, including Saudi Arabia, were a serious consequence of the decline in oil price in the second half of 2014. This decline contributed to the quality of banks' loan portfolios, which affected the financial stability of Saudi banks. Al-Khazali and Mirzaei (2017) studied the effects of oil price shocks on NPLs. A dynamic GMM model was used on data from 2,310 commercial banks from 30 oil-exporting nations for 2000–2014. The results revealed an inverse relationship between oil prices and NPLs. Negative oil price shocks have a larger impact than do positive price shocks. Moreover, large banks have to manage a larger impact caused by oil price shocks.

[2] When a group of countries peg their currencies temporarily to the US dollar without having close economic affinities with the bloc (Federal Reserve Bank of Dallas).

In economies highly dependent on oil revenues, oil price declines affect the performance of companies in these countries and undermine their efforts to meet financial obligations. Therefore, these declines contribute to raising the rates of NPLs. As a result, NPL rates will reduce banking financial stability in oil-exporting countries. A recent study by the IMF (2015) showed that this is what happened in the oil-rich Arab countries, where a 1% reduction in oil price led to an increase of 0.1% in NPLs. In Saudi Arabia in particular, Miyajima (2016) documented that NPLs steadily increased as oil prices grew at a lower rate.

2.4 The Historical Impact of Oil Price Volatility on the Saudi Economy

This section examines the history of oil price downturns and their impact on the Saudi economy during 1998–2014 and assesses the causes of the price decline.

Table 2.1: The impact of oil price on the Saudi economy

Year	Major events	Consequences	The impact on Saudi economy
1997-1998	Asian financial crisis	The oil price per barrel from $24 to 12 causing the lowest decline since 1972	The Saudi budget was significantly impacted with a deficit of SR 48 billion.
2002-2003	Iraq War and Oil Workers Strike in Venezuela	Led to a loss of about 5 million barrel per day (mb/d) of the production of crude oil.	contributed towards a surplus national budget over SR 36 billion after many years of a deficit
2008	Global Financial Crisis	Oil price decline from $99.16 to $30.28	the budget was again faced a deficit by SR 87.9 billion after surplus
2014	Global oversupply	Oil price fell from $110.62 to $26.21 in 2016	Saudi Arabia faced its highest budget deficits of US$98 billion in 2015 and $79 billion in 2016

Source: Saudi Arabian Monetary Agency Reports

The growth in the Saudi economy was marked by a 4% increase in private sector contribution to GDP and 7% from the public sector after the Gulf War, which lasted from 1990–1990. The budget deficit was reduced significantly by up to SR 6 billion by 1997. While there were positive signs for the economy during the early 1990s, the subsequent Asian financial crisis resulted in a sharp decline in oil prices in 1997–1998. Crude oil prices fell from $24 to $12 per barrel; this significantly diminished oil export revenues for Saudi Arabia (see Table 2.1). Therefore, national income fell substantially during 1998 and the budget deficit increased again to SR 48 billion. The previous decade's budget deficit had not significantly diversified the Saudi Arabian economy and the country's dependence on oil exports continued. Therefore, in 1998, the Supreme Economic Council was established—led by the crown prince—to modernise the economy and reduce dependence on oil export revenues. However, this dependence on oil export revenues was difficult to overturn and other sectors of the economy grew very slowly.

In 2003, because of the imbalance between supply and demand, Saudi oil revenue reached SR 293 billion because oil prices continued to rise and revenues from oil export continued to increase in the Saudi budget. This resulted in reduction of the budget deficit in this year. The low level of government expenditure also contributed towards the budget surplus in 2003. These factors contributed to a surplus national budget after many years in Saudi Arabia (i.e. SR 36 billion; see Table 2.1). The trend continued until 2006, when the oil product reached nine million barrels per day and the GDP growth rate increased significantly (i.e., 11% increase in 2006 on 2005 figures). The real growth in GDP was higher—by 4.3%—in 2006 than in 2005. This resulted in a huge budget surplus of SR 289.7 billion in 2006.

The Saudi government during 2002–2005 spent considerable money on infrastructure projects, education, hospitals and the financial sector. Spending reached an all-time high in the Kingdom's history (SR 596.6 billion) and the budget was again in deficit by as much as SR 87.9 billion after 2002. After 2006, the GFC of 2007–2008 led to a reduction in oil prices and a budget deficit (see Table 2.1). However, in 2010, the Saudi economy had recovered and began growing again as oil prices increased. The oil sector during that period was the major contributor to GDP (32%), while the non-oil sector contribution to GDP increased by only 7.5%.

In the period of global oversupply in 2014, Chaoul (2014) fixed this as a crude oil price of $67/bbl at a production rate of 9.7 mb/pd. This was at an actual price of $95.8/bbl on average, which was 43% higher than that used/stated in the Saudi government budget. In 2015, rising prices were estimated by analysts because of the government's failure to release the prices of oil used to calculate yearly budgets. These assumptions extended to predicted production for the next year and planned oil exports. The prices, as reported by four different analysts, ranged between $55 and $63 (Alturki et al. 2014; Saudi 2015; Shaikh et al. 2014; Tully 2014). This opened the doors to a deficit of $98 billion in the Saudi government budget. Media releases (Ministry of Finance 2015, 2016) showcased economic developments for these fiscal years. Considering an oil price of $45 per barrel, it was expected that subsequent years would experience budget shortfalls predicted to be $87 billion for 2015 and 2016 fiscal years. This deficit meant that the country required $80+ /barrel oil to balance the budget for both social and fiscal reasons.

2.5 Oil Price and the US Dollar

Oil is a major source of energy and serves as a raw material for many industries all around the world. The market forces of demand and supply interact to determine the market price of oil. There are large fluctuations in these market forces, leading to volatility in oil prices. This instability in the market for oil has repercussions for the current accounts of countries importing oil. Significant changes in the current account lead to changes in the exchange rates for the respective countries. Industrialised nations rely heavily on crude oil and any variations in oil prices significantly affect the industrial process. Despite efforts to find alternative sources of energy, crude oil remains an important raw material and will continue to do so for many more decades.

Crude oil, a US dollar-denominated commodity, continues to remain the most traded commodity throughout the world. As its value is stated in terms of the US dollar, an appreciation of the US dollar puts a toll on other countries that have to pay larger amounts of local currency to import valuable crude oil reserves. It can be observed how changes in exchange rate lead to changes in the market of crude oil. Akram (2009) demonstrated how depreciation of the US dollar leads to higher commodity prices. Therefore, attention should be paid to studying the dynamics between oil prices and currency exchange rate fluctuations and the spillover from one to the other (Reboredo & Rivera-Castro 2013). For instance, historically, a depreciation in the US dollar decreased oil prices for countries; this subsequently generated capital inflows in the oil market. Contemporaneous movements have been observed between oil prices and the US dollar since 2000. This relationship can have far-reaching effects on the economy in terms of inflation rate, monetary policy and trade imbalance. Thus, it is important for policymakers to understand the dynamics of this relationship. As noted previously, oil is an important vehicle that affects both micro and macroeconomy contexts. Thus, any changes in oil prices can influence prices in other industries because oil is such an important raw material and factor in macroeconomics. Variations in oil prices can also be observed in terms of changes in exchange rates between countries.

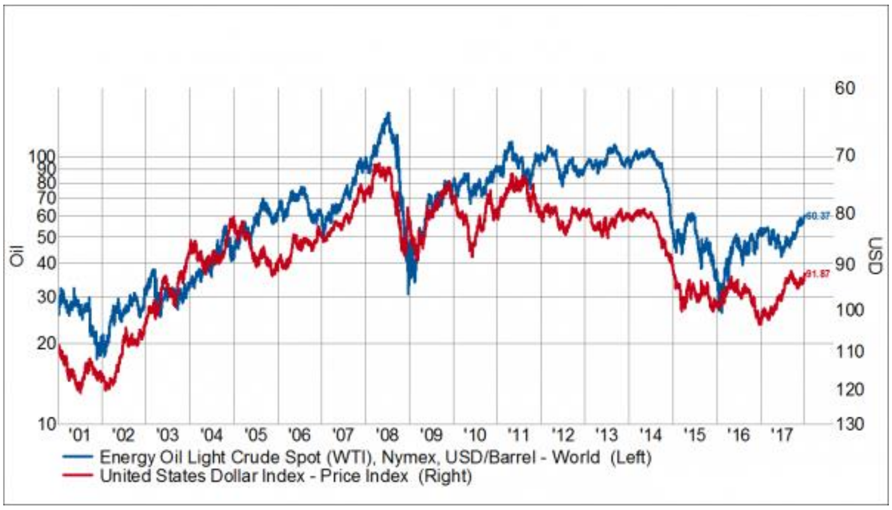


Figure 2.2: Oil and USD index movement

Source: Bloomberg (2018).

Oil price and the US dollar are deemed critical economic variables that influence the global economy. A strong relationship exists between crude oil prices and the US dollar. The US dollar has undergone several changes since the 1970s and oil prices have changed immensely since that time. Countries now depend on each other for importing oil. When oil price increases, one can expect the output in an economy to decline as a result of increased production costs. A recession can occur, leading to an appreciation of the US dollar. Thus, it makes sense to study the relationship between crude oil prices and the US dollar to better understand how one variable affects the other and vice versa. To this end, cointegration and causality tests conducted for 1990–2013 exhibit an inverse relationship between these two variables. In other words, the value of the US dollar will decrease if an there is an increase in the crude oil price (Shokohyar, Tavallaee & Karamatnia 2016).

Oil prices demonstrated increased volatility after the global oil crises of 1973 and 1979. Oil prices declined significantly in the 1980s, further adding to the fluctuations. On the whole, oil prices rose from $42/barrel in 2005 to $147/barrel in 2008. There has been a substantial increase in oil prices in just three years. More recently, the fall in oil prices has been followed by a decrease in the currency value of oil-exporting countries. The 50% decrease in oil prices in the latter half of 2014 was followed by a 50% reduction in value of the Russian ruble, a 20% decrease in the value of the Brazilian real and a 15% fall in the Mexican peso. For Russia, Brazil and Mexico, oil exports are a major source of valuable capital. When oil prices do fall, these nations have to manage budget deficits that further aggravate economic uncertainty and social unrest.

Oil price changes can affect the exchange rate through various channels such as GDP, inflation rate and interest rates. As the price of oil is recorded in US dollars, any change to the value of the US dollar appreciates or depreciates the domestic currencies of oil-exporting and importing countries. Volkov and Yuhn (2016) studied the effect of oil price changes on the exchange rate values of five oil-exporting countries: Russia, Brazil, Mexico, Canada and Norway. They used a GARCH-M model to show that a rise in oil prices leads to an increase in the value of the local currency relative to the US dollar. The R^2 values for Russia and Brazil 'as emerging markets' double when oil prices are included in the model. Moreover, any disturbance caused by oil price shocks takes longer to dissipate in Russia, Brazil and Mexico than in Norway and Canada. Differences in the efficiency of financial markets may lead to such asymmetric behaviour between countries. Volkov and Yuhn (2016) reported that an oil price increase leads to appreciation of the local currency but a depreciation of the US dollar because oil is priced in US dollars.

It is evident that oil price and the US dollar have experienced record fluctuations in the last two decades. This volatility deserves greater attention from academics, central banks, policymakers and investors because the inverse relationship between oil commodity prices and the US dollar plays an important role in planned asset allocation and risk management.

2.6 The History of the Saudi Riyal and the Fixed Exchange Regime with the US Dollar

Oil is the main source of income of the Saudi government and it is priced by the US dollar. For this reason, the Saudi government pegged its currency to the US dollar to avoid currency fluctuation and eliminate uncertainties in international transactions in instances of significant oil price fluctuations.

SAMA was established in 1952; it superseded the Saudi Hollandi Bank, which had operated since 1926. The SAMA is the second-oldest central bank in the Middle East. SAMA plays an important role in the Kingdom's economy, such as in the allocation of government expenditure, currency regulation, supervision of the financial sector (both commercial and Islamic banks) and management of foreign exchange reserves. Moreover, SAMA, after its inception, promoted a paper currency in Saudi Arabia that was introduced in 1950. The Kingdom pegged the Saudi riyal with special drawing rights (SDR) to the equivalent of US$10.90.

The first step towards the public's acceptance of paper currency was taken by SAMA in 1953, when it issued five million pilgrims' receipts in various languages. These receipts were helpful for people coming to Saudi Arabia for the Hajj because they had to carry many coins, which led to heavy loads. In 1956, SR 10 notes were issued along with more pilgrims' receipts. This strategy proved successful and SAMA issued more currency notes up to 1961; pilgrims' receipts ceased to be issues by the end of 1964.

SAMA's currency policy shifted in 1975 when it used the SRD of IMF to establish the exchange rate of the Saudi riyal with a free-floating margin of 2.25%; this increased the value of the riyal in comparison with the US dollar. The currency remained stable and the floating margin of SDR increased to 7.25%. However, the currency peg with SDR ended in 1981 and SAMA pegged its currency to the US dollar (i.e., 3.75 Saudi riyal would be equal to US$1). Moreover, SAMA permitted commercial banks to charge 25% higher or lower than its official interest rate. This SR-USD peg has been maintained to date and is unlikely to change anytime soon.

2.7 The Saudi Economy's Reliance on Oil Revenue

The Saudi economy has exhibited changes because of the influence of market variables over the past five decades. Historically, the economy was largely agricultural and trade-based; incomes were derived from grazing and other farming activities. Pilgrims travelling to or within Saudi Arabia to honour Islam generated a high percentage of government revenue from trade and services. By the early 1970s, the export of oil was booming and trading activities during the mid-1970s meant that the country could generate huge financial returns from ventures as oil prices rose (Said & George 1974). Based on this upswing in financial circumstances, various infrastructure projects were executed and, importantly, the private sector was promoted through economic policies that supported the provision of loans and services and companies' exemptions from paying taxes and customs duties. As a result, the industrial sector in Saudi was enhanced, boosting economic growth.

Oil production and export resulted in significant changes in the financial system of Saudi Arabia. Previously, very few Saudi people used banks and the supply of paper money was limited. However, with the implementation of modern financial systems, the use of proper banking transactions significantly increased, especially after the establishment of the first national bank in 1938. Many local and foreign banks started operating in Saudi Arabia following the founding of the National Commercial Bank of Saudi Arabia. The Saudi Central Bank was established in 1952, formally known as SAMA. Before the establishment of SAMA, the Saudi Hollandi Bank was the de facto central bank of Saudi Arabia; it operated from 1926 to 1952. SAMA oversees the Saudi riyal and is responsible for the management of national reserves that have significantly increased in line with oil export revenues over the past few decades. SAMA is also responsible for supervising commercial banks in Saudi Arabia. The monetary and fiscal policy of Saudi Arabia is also controlled by SAMA. Revenues from oil experts became extremely significant after 1970, when oil prices began to rise significantly and increased by 400%. This resulted in a significant economic transformation. Moreover, the public sector became highly active, with the construction of airports, a more modern telecommunications system and large road networks. Therefore, strong infrastructure was built in Saudi Arabia with the help of accumulated national wealth and the unemployment rate was reduced.

Oil as a major source of national income would have major repercussions for the economy of the nation. Research suggests a significant and positive relationship between growth rates and stability in oil-exporting countries, and greater diversity of the business activities on which the economy of a nation is dependent. However, oil revenues remain the major source of income in the Saudi economy (IMF 2015; Alsamara et al. 2017). This is more rampant in situations in which natural resources form the main source of national income. There is the possibility of a major economic risk, particularly given that natural resources are finite and will be depleted at some point. Simultaneously, oil prices are dependent on the political and economic situation of a country.

Against this backdrop, developing countries reliant on primary exports as key sources of income and foreign exchange revenue suffer a huge decline when prices drop. Depending excessively on a commodity, such as oil, is a major risk because commodities are subject to extraordinary volatility in the market when oil prices are at the mercy of selling behaviours. For instance, as in Table 2.2, government income shifted to be highly dependent on oil revenue as it rose from SR 7.0 billion in 1970 to SR 319 billion in 1980. A massive decline in oil prices from $121 to $24 occurred in 1986. This represented a 72% decline in government revenue and compelled the Saudi government to diversify the country's economic base and expand other industries, even when the share of oil revenue remained high (SAMA 2011, 2016).

Table 2.2: The dependency of the Saudi budget on oil revenue

Year	Nominal oil price (In US$ per barrel)	Annual government Oil Revenues (Millions US$)	Crude Oil Production (Daily average-Million Barrels)	Crude Oil Exports (Million Barrels)
1970	1.3	1,896.53	3.8	1,174.17
1975	10.72	24,928.27	7.08	2,409.39
1980	28.67	85,148.00	9.9	3,375.72
1985	13.73	23,580.00	3.17	780.72
1990	20.82	32,839.47	6.41	1,642.42
1995	16.73	28,194.13	8.02	2,269.13
2000	29.81	57,179.73	8.09	2,282.38
2005	50.15	134,544.00	9.35	2,631.24
2010	77.75	178,737.33	8.17	2,425.09
2015	49.85	119,050.67	10.19	2,614.50

Source: Saudi Arabian Monetary Agency Reports.

From the previous discussion and data in Table 2.2, it is evident that high dependency on oil exports is risky when considered the main source of income. For instance, volatility in the oil industry exerts a negative impact on government revenues and expenditure because total income is influenced negatively by changing oil prices, while liquidity is affected by a reduction in revenue. The government, like any other institution, incurs operational expenses, borrowing money and paying back loans with interest among other costs. First, a lack of revenue will lead to government debt. Second, to meet the set goals for a given financial year in line with sustainable development and specific industry objectives, the Saudi government faces challenges in implementing such plans. They have to be abandoned or paused in times of poor government revenues.

The higher oil prices that marked the 1970s began to decline during the mid-1980s, when prices, and consequently, revenue dropped (Ministry of Planning 2011). Oil prices began to decline because of the Cold War and for the first time in its history, in 1983, Saudi

Arabia experienced a current account deficit of SR 23.8 billion. This led to a cut in government spending on public projects. The private sector was also rolled back because of a lack of investment in public sector projects. The budget deficit increased and reached up to SR 70 billion by 1987. This led to a further reduction in government spending and the budget deficit reached SR 34.9 billion in 1989.

However, the second Gulf War that erupted in 1990 following Iraq's misguided invasion of Kuwait led to a significant increase in government spending (SR 275 billion in 1990), which resulted in a budget deficit of SR 160 billion in the same year—the highest in the Kingdom's history. However, the economy began to boom again when oil prices rose in 1996 and the budget deficit started to improve. Therefore, the GDP began to increase after more than 10 years (by 8.6% in 1995 from SR 470 billion to SR 510 billion in 1996).

Table 2.3: Saudi government revenues, expenditures and budget

Year	2011	2012	2013	2014	2015	2016	2017
Actual Government Revenue	**298.08**	**332.64**	**308.36**	**278.50**	**164.24**	**138.51**	**184.40**
Actual Government Expenditure	**220.45**	**232.88**	**260.27**	**295.97**	**260.83**	**221.47**	**248.00**
Budget Deficit/Surplus	**77.63**	**99.76**	**48.09**	**-17.47**	**-96.58**	**-82.96**	**-63.60**

Source: Saudi Arabian Monetary Agency Reports

Overall, the oil production industry in Saudi Arabia tends to experience higher government deficits when oil prices drop. This affects the level of government spending and vice versa when oil price hikes (see Table 2.3). A knock-on effect is felt within the private sector, which depends on government spending for expansion and subsequent job creation. However, Saudi Arabia may have the ability to survive oil price fluctuations in the short term because it can borrow from its US$737 billion sovereign wealth fund for revenue. In the long term, the nation would require close to US$104 billion to ensure a balanced budget. This is evident from the 2015 reports that show a government deficit of approximately $98 billion (15% of GDP); the IMF estimated a budget deficit of 20% of GDP (approximately $140 billion). Hence, research has reported on Saudi Arabia's economy diversifying exports and revenues to mitigate against oil volatility risk. In 2015, the government spent approximately $9.8 billion in a military build-up, which made the Kingdom the leading importer of defence equipment (see Table 2.4).[3]

Table 2.4: Saudi Arabian government expenditures by sector

Sector	2012 %Share of GDP	2013 %Share of GDP	2014 %Share of GDP	2015 %Share of GDP	2016 %Share of GDP	2017 %Share of GDP
Human Resources Development	24.3	24.8	24.5	25.1	22.8	22.5
Transport and Communications	3.0	2.7	2.7	2.6	1.5	2.8
Economic Resources Development	6.0	5.7	5.8	5.6	3.1	5.3
Health Services and Social Development	8.9	8.7	9.1	9.5	9.5	10.7
Infrastructure Development	1.5	1.4	1.6	1.5	0.9	2.9
Municipal Services	3.7	3.9	4.0	4.0	2.5	5.4
Defense and Security	30.7	30.6	35.4	35.7	25.4	32.3
Public Administration, Public Utilities and General Item	15.6	14.6	9.9	9.4	8.2	14.3
Government Specialized Credit Institutions	1.6	1.8	1.8	1.7	0.5	0.1
Subsidies	4.8	5.8	5.1	4.9	3.9	3.6
Budget support provision	---	---	---	---	21.8	---

Source: Saudi Arabian Monetary Agency Reports

Following the reduction in oil prices in 2014–2015, the Kingdom maintained its oil prices to not flood the market with oil, so that it could be in a position to beat competitors. Oil output increased from 9.7 mb/d (July 2014) to 10.6 mb/d (November 2015). Thus, oil prices dropped worldwide in the second half of 2014. This led to fiscal deficits and a decline in foreign exchange reserves. This defied previous patterns in which revenues increased and fiscal surpluses and reserves increased.

However, given the prowess in financial capability and healthy reserves, Saudi Arabia was able to withstand 2–3 years of poor oil revenue. Its foreign exchange reserves were valued at $800 billion in mid-2014; they fell to $500bn in the second half of that year. The debt-to-GDP ratio was low, which led the country to seek debt financing in 2017; Saudi public debt represented 21% of GDP by end of 2018 (Aljazira Capital 2018). Nonetheless, commentators and policymakers warned that the nation should not be comfortable with the foreign assets held by SAMA because raising debt could present challenges in the long term.

A second risk to Saudi Arabia is its over-reliance on oil through the structure and distribution of the country's exports; oil and by-products dictated the growth in exports from the mid-1990s to now (Hausmann et al. 2013). They indicate that crude oil, refined

[3] The International Institute for Strategic Studies 2016.

oil and petroleum gases account for the following respective percentages of exports: 76%, 6% and 3%. Saudi Arabia imports most consumables, including intermediate goods, cars, clothing, medical supplies, foodstuffs, technology, household items and machinery. This emphasises the importance of export earnings. Moreover, it recognises the uncertainty concerning the external balance and export earnings, which can stall economic growth and place economic diversification at risk. Greater focus is placed on how these impediments affect the private sector and organisations' investment decisions and expectations of returns. An important factor to note when Saudi Arabia exports oil and imports most products is that the Saudi riyal is pegged to the US dollar, requiring the government to ensure there are adequate foreign assets to preserve a fixed exchange rate. If reserves are seriously compromised by an imbalance between the country's exports and imports, the stability of the riyal will be affected, triggering grave macroeconomic outcomes.

Cyclical movement in oil prices directly influence the Kingdom's debt movements. When oil prices and revenue maintain a low level of growth, for instance during the late 1970s, the Kingdom's Ministry of Finance tends to issue large amounts of debt. This was evident in the mid-1980s and the later 1990s. By 1999, the debt-to-GDP ratio increased to 103% of GDP. Rising oil prices and revenue in 2005–2015 led to a significant fall in public debt to 1.6% GDP. This created 'the burden of adjustment' and the responsibility for this rested on capital spending, which means there was an increase in spending when revenue took a negative turn.

2.8 Oil Revenue and Saudi Arabia's Foreign Assets Accumulation

Macroeconomic variables affect the economic stability of a nation. For this reason, we continue to observe a high level of fluctuations in macroeconomic variable effects as a result of the Kingdom's high dependence on oil. Hence, any economic activities in the mid-term will depend on the behaviour of oil prices. This would affect government spending based on the amount of revenue realised. When revenue drops, the government is forced to engage in debt financing or employ previously saved/acquired assets to overcome complications arising from fiscal policy; this strategy is meant to smooth spending when revenue falls below predicted or expected amounts/levels.

Countries hold reserves for several reasons; these mainly involve precaution (Lee 2004; Mendoza 2004)—for example, to protect against volatile capital flows and avoid the need to resort to funding from the IMF (Stiglitz 2006). Over the last two decades, some countries have accumulated reserves as insurance against financial crises (Jeanne 2007). The share of global reserves held by Asian countries has increased over the years; the majority is held in the form of US Treasury bonds.

To avoid current account deficits, countries have maintained foreign exchange reserves to guard against private sector capital flow. There is no doubt that holding such reserves provides a form of self-insurance (Obstfeld, Shambaugh & Taylor 2010). Countries also want to ensure that their domestic currencies are not freely floating; hence, they need to hold reserves for when shocks disturb exchange rate dynamics. After the financial crisis of 2008–2009, the importance of holding foreign reserves was attributed to the way countries hold reserves to 'lean against the wind' in the case of appreciation. The interconnectedness of global financial markets is believed to have led to the spread of the 2008–2009 financial crisis. Despite the fact that emerging economies had a good stock of international reserves before the crisis, they chose to let their currencies depreciate for fear of losing their reserves arising from the floating regime. The aim could have been to achieve or at least maintain competitiveness in the global market during turbulent times. Aizenman and Hutchison (2012) discussed how the financial crisis of 2008–2009 was followed by a global recession because depreciated currencies were useless to emerging economies during decreased global demand.

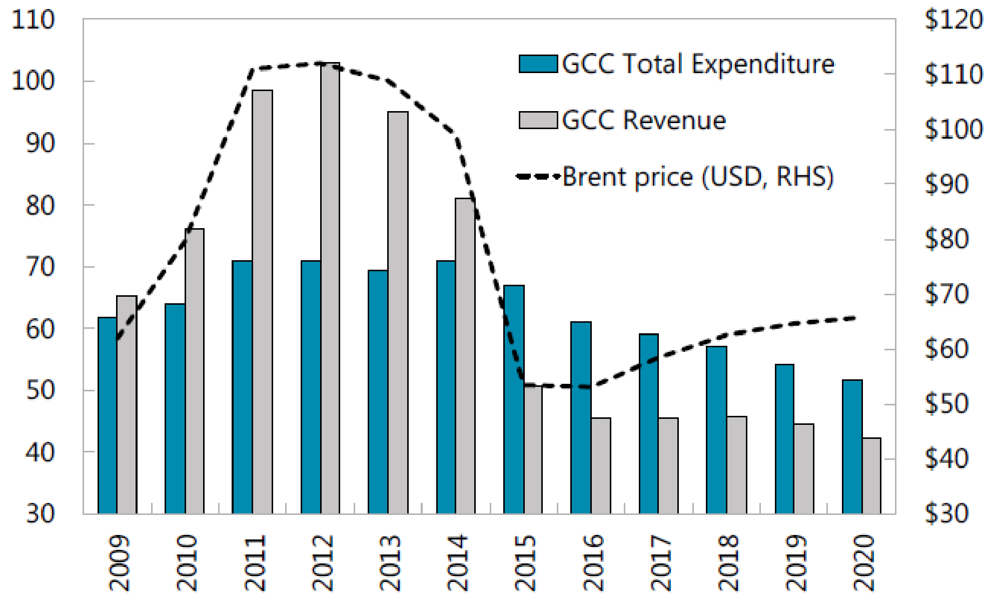
Some leading oil-producing countries have low break-even prices (e.g., Norway, Abu Dhabi and Kuwait), indicating that the break-even price for the Kingdom was the highest within the Gulf region. The three abovenamed countries named are said to share three features: (1) their revenue, government spending and wealth funds are large; (2) They maintain discipline in spending and save revenues, reflecting the existence of fiscal policy frameworks that adhere to strict rules; (3) the investment of assets and funds are handled by recognised independent investment authorities who provide well-informed and professional advice on avoiding downtowns during dips in oil prices.

All countries depend on oil revenue, but Kuwait and Abu Dhabi have a greater dependence than Norway. However, even when they drew on their sovereign wealth funds and investment, three key factors are observed and upheld: sustainability, adherence to rules and the decoupling of spending patterns from oil revenues. Only 25% of revenue is considered to come from oil revenue in Norway.

Saudi Arabia's government spending is very high, but it has sustainable policies and rules that govern the utilisation of sovereign wealth assets and income. For these reasons, the Kingdom needs high oil prices to achieve financial harmony. Therefore, the sustainability of accumulated assets in the wealth fund are in limbo. Chapter 5 provides suggestions on reforms that could be implemented to position the Kingdom in line with other countries that have been successful in doing this, such as Kuwait, Norway and Abu Dhabi.

Saudi Kingdom spending shifts with the rise and fall of oil prices, such that a rise in oil prices increases government spending while a drop leads to a reduction. In 2004, capital expenditure was $73 billion, but there was a rise in capital expenditure from 2005 to 2013 onwards as a result of a rise in oil prices (increasing expenditure to $83 billion). Substantial funds were said to have been directed towards social and physical infrastructure improvements. Nevertheless, a fall in oil prices will automatically trigger a reduction in expenditure. This is a valuable strategy for reducing fiscal pressure in the medium term and stabilising government expenditure. Demographic trends influenced by present expenditure influence the direction and level of long-term spending pressures.

According to SAMA, the total foreign reserve of the country was around SR 1.876 trillion in mid-2017. Figure 2.3 shows the largest revenues that prompted increases in the foreign assets of GCC countries, including Saudi Arabia, particularly between 2011 and 2013. SAMA has followed a conservative low-risk investment strategy by investing in US bonds; 85% of Saudi foreign reserves are invested in US fixed-income securities (Bahgat 2008). A major drawback of this hedging approach is that the Saudi government has invested heavily in US bonds and other securities, such as stocks. The bond liquidation process, if and when required, will take a considerable amount of time and incur additional costs, particularly if a large number of bonds, or high-value bonds, must be liquidated (Alhumaidah 2015).



Sources: WEO; and IMF staff estimates.

Figure 2.3: GCC government revenue and expenditure

SAMA records show how the reserve assets were distributed at the end of July 2017. Figure 2.4 shows that 67% of the assets were invested in securities abroad, 31% in foreign exchange and deposits, 1.6% in SDR, 0.3% in the IMF and 0.1% in gold reserves (SAMA 2017). IMF statistics show that the Saudi current account faced a deficit after the negative oil price shock at the end of 2015. This reduced SAMA net foreign reserves from $724 billion to $609 billion, representing a decrease of $115 billion (IMF 2016). This shock changed the Saudi current account from a surplus to a deficit and caused the country to lose around one-third of the value of its foreign exchange reserves over the last 2.5 years (IMF 2016).

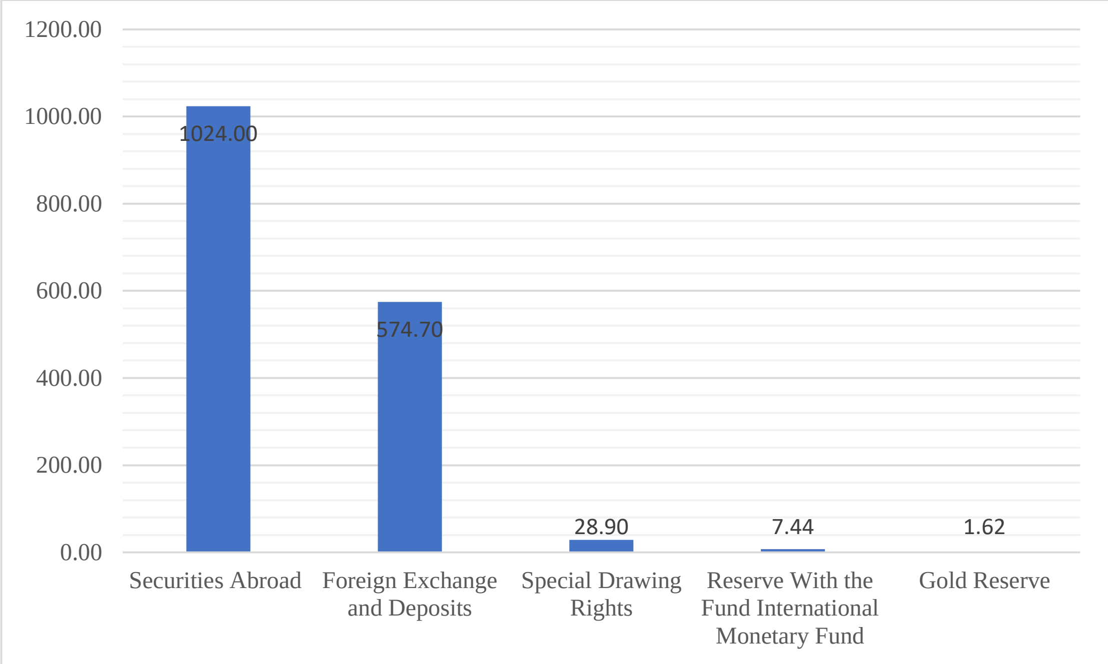


Figure 2.4: Saudi foreign assets by billion dollars

Source: Saudi Arabian Monetary Agency Reports

In early 2014, SAMA had $800 billion of accumulated assets, while there was $750 billion in the second quarter of 2014. The assets held by SAMA are considered a buffer for Saudi Arabia when oil prices dip and revenue is reduced. This may be safe in the short term, but in the long term, the Kingdom could face challenges. For instance, the 2015 Saudi budget involved expenditure of $230 billion (860 billion riyals), which translates to a third of the foreign exchange reserves held by SAMA against $190 billion (715 billion Saudi riyals) in revenue. This deficit of $40bn, realised after revenues reduced by 16%, was not as severe as that of 2014, when SAMA had to raise finance to counteract a huge deficit. This was caused by actual spending exceeding the revenues.

2.9 Saudi Foreign Currency Reserve and its Economic Benefits

As one aspect of Saudi foreign assets, SFCR revenue windfalls from oil exports have been the main source of revenue accumulation for the Saudi government. For instance, in 2005–2008 and 2011–2013, the Kingdom enjoyed high oil prices—approximately $750 billion were accumulated in foreign reserves. The role played by all countries' central banks is well known and recognised, particularly in the context of managing foreign reserves. Foreign reserves are defined in various ways depending on the term and context in which it is used. The IMF defined foreign reserves as assets, denominated in foreign currency, available at all times and monitored and controlled by designated monetary authorities (which in most countries is the central bank).

Regardless of the economic status of a country (developed or developing), foreign reserves are a paramount macroeconomic element because bolstering reserves promotes the confidence held in the financial stability of a nation. Both types of countries experience external shocks; hence, the macroeconomic position of a nation depends on the stability of foreign exchange reserves, which are considered a pillar of stability. The IMF (2013) reported that the role played by foreign exchange reserves enables the direct financing of external imbalances, management of balance of payments, and the administration and management of exchange rates since they influence international trade.

Foreign reserves comprise (marketable) foreign assets that can be converted into foreign currencies. Some examples include reserve positions in the IMF, foreign securities, deposits in foreign banks, monetary gold and SDR. For countries that do not want to adjust exchange rates and insist on constantly fairly priced exchange rates, foreign exchange reserves are viewed as critical. They are considered an integral part of a country's wealth. Sterilising bonds (i.e., increasing the sum of domestic currency to sterilise the effects of local currency) allows governments and their appointed authorities to gain foreign currency reserves. A proper sterilisation of bonds would help central banks reduce net assets, thereby indicating that total reserves are not a reflection of net national assets. According to Dominguez et al. (2010), foreign currency reserves in most cases are held as foreign government bonds that attract interest rates and foreign exchange risks. This is because foreign currency reserves in central banks are held in foreign currencies. It is up to central banks' discretion to decide how to proceed with foreign exchange reserves investment and how these should be managed.

Detemple and Rindisbacher (2010) indicated that the two main approaches used by most central banks include the assumption that an already-existing structure that is appropriately functional would not need to be changed. Nevertheless, this would depend on several issues, including: (1) the role to be played by foreign exchange reserves in maintaining local currency (keeping its value with the pegged currency or when it is floated) and any other related factors/elements included in the balance sheets of any central bank; (2) if foreign exchange reserves are essential in the management of national monetary policy (of this is the case, details will be reflected in the central bank's financial report); (3) the role to be played by foreign exchange reserves in protecting risks relative to the hedging responsibility of the government (if they have a primary role, it is imperative for a government to own foreign currency reserves); (4) establishing how the operations of the central bank would be funded, which in most cases is through foreign exchange reserves (Detemple & Rindisbacher 2010).

Therefore, the management of foreign exchange reserves is the responsibility of the central bank of any nation. The responsibility could be directly awarded to the central bank or the institution is assumed to act as a government agent. Hence, the IMF or systems of international currency reserves would consider the institution/person responsible for managing foreign exchange reserves. In this sense, central banks make decisions and monitor various domestic currency remits, such as intervention 'in countries like Japan', regarding exchange rate policy and the dollarisation system.[4] Decisions will have either positive or negative consequences on the national reserves based on the rules and frameworks in place to govern the management of foreign exchange reserves. Coordinated action by governments and their central banks will then take precedence over the legal ownership of reserves (IMF 2013).

From the discussions above, it is evident that the use and purpose of foreign exchange reserves make them of paramount importance to the economy of a nation. Borio et al. (2008) further explained the usefulness of these reserves. First, interaction with the foreign exchange market is important, especially because of how this interacts with the domestic currency exchange rate, and the effects of maintaining or market conditions. Second, when external financing is unavailable, methods of payment for goods and services must be considered. Third, the provision of liquidity support to key sectors within the economy, such as the financial sector, and approval for this will have to be considered. Fourth, there is the issue of taking responsibility for reducing the costs of external financing and the possibility of a currency crisis. This can be done by ensuring the promotion of investor confidence in a nation's ability to uphold its foreign currency obligations. Fifth, the management of the external debt of the country will enable payments to be made on behalf of the government. Sixth, support is also needed for

[4] 'Dollarisation' describes when a foreign currency is accepted in business transactions in a country.

liquidity management via currency swaps, managing national monetary policy and the administration of foreign currency claims.

According to the IMF (2013), further details are available on the primary role of foreign exchange reserves in nations' economies. It is indicated that these reserves are available for governments in the event of emergencies and national disasters. Each nation has justifications for holding foreign reserves and will balance the above reasons based on its priorities. Key pointers that determine a country's proper management of foreign exchange reserves are reflected in its ability to meet its financial obligations, the economy's financial readiness to manage any uncertainties, and finally, the financial rules and/or frameworks that govern the management of the reserves in any country.

2.10 Managing Foreign Currency Reserves

Foreign exchange reserves equate to foreign assets that belong to the people of a nation but are governed by monetary authorities appointed by the leaders of a nation. These assets have to be available for public use as and when required. Nugée (2009) defined the management of national foreign exchange reserves as a consolidation of techniques, procedures, management procedures and control mechanisms to acquire a sizeable level of foreign exchange reserves. The levels of risk have to be observed such that they balance the amount of reserves acquired with the level of accompanying risk. These have to meet the requirements of the IMF. The ability of a nation to resist and effectively manage uncertainty depends on how well the foreign reserves are controlled and administered. Evidence has emerged from countries where the management of foreign exchange reserves was not effective enough to counter shocks within the system during a financial crisis. Nugée (2009) asserted that reputational risk can increase based on how a nation manages risk relative to foreign exchange reserves because they will incur high financial costs.

In this sense, it is important that management of foreign reserves adheres to: (1) attaining a sustainable risk-averse level of foreign reserves; (2) controlling three risks: liquidity, market and credit; (3) limiting risk, acquiring a particular level of yield. The economic and monetary policy dockets of a country also involve management of foreign exchange reserves. Policy dockets operate on set objectives that reserves are supposed to help achieve. This includes achieving high amounts of reserves, which have to be invested wisely to yield returns. Globally, most countries own foreign currency reserves, but the objectives of owning them differ between countries. Before deciding to own foreign reserves, it is a requirement that each government establishes reasons, goals and processes for reserve management. For instance, in some cases, reserves are not for investment; they are simply a backup plan for local currency. This is mostly evident among countries that mainly invest in gold reserves. During World War II and in line with the Bretton–Woods system, the gold standard was popular.

Other countries position foreign reserves instrumentally for monetary gain, and therefore, touch on the exchange rate policy of a nation. Most countries that take this line set fixed exchange rates to protect the local currency. The trading here would be between local currency exchange rates and foreign exchange rates, which affects interest rates and local currency markets. Hence, it is a popular option for countries that want to develop their domestic markets. Even in fully developed markets, some countries adopt a floating exchange rate for the local currency/money market. This is not popular on the foreign exchange market, in which countries can freely trade in their own currencies.

Governments also own and maintain foreign reserves so that they can make money to service foreign currency responsibilities. Any country with foreign debts definitely requires foreign currency to enable payments. This responsibility of governments can be achieved through the sale of domestic/local currency. However, Nugée (2009) argued that several reasons account for some governments not following this format: (1) when foreign currency is necessary, the exchange rate and foreign exchange market may not be operating at a suitable value; (2) when large sums of foreign exchange transactions need to take place, upsets in the foreign exchange market could arise; (3) the risks are high in foreign exchange reserves; (4) there is a negative effect on national confidence. Considering that the nation that issues the bonds also lends them, rating agencies are affected, and the cost of borrowing in foreign currencies rises.

Other countries use returns from foreign exchange reserves to pay foreign state expenditure. This is common among countries that have to make payments in foreign currencies but fund these activities from returns realised from foreign exchange reserves. Seasonal fluctuations, irregular inflows and outflows can account for this. Further, profits can be obtained from foreign reserves when they are maintained as investment funds. However, this is dependent on the role a country deems that their reserves play (e.g., the role of reserves in enabling monetary stability and protection). Nugée (2009) asserted that reserves can also be used for making a profit, which could be a logical policy in some countries for several reasons, including: (1) in situations in which local economies are unable to absorb further consumption in the absence of overheating; (2) when the economy of the country is beset by declines in profit-making; (3) in scenarios of early or advanced preparations for unpredictable futures (e.g., when natural resources are in danger of depletion); (4) when small nations wish to diversify their asset base. Global foreign exchange reserves operate on various frameworks based on why they are held, their management and their structure.

Debates have ensued about the economic prowess of a country (developed and developing) and the sizes of foreign exchange reserves to be held. Some claim that there are fewer than required foreign exchange reserves globally, while others believe the present sum is lower than it should be. The latter view is more rampant among countries that view a large sum of foreign exchange reserves as appropriate to meet their economic objectives. This does not mean that the foreign exchange reserves should be excessive or too small because extremely large or small quantities can also expose a nation to risks. However, determining the 'correct' amount of reserves is still a challenging matter.

Two main factors have to be considered in terms of the optimal size of reserves. One is the intended use of foreign exchange reserves and the minimum level needed to meet the objectives of the reserves. These two key elements must be addressed before considering matters relating to administration and control. The second is an appropriate analysis of the costs incurred in the financing of foreign reserves. In this case, the cost of reserve accumulation becomes extremely important. The above elements allow control of reserve size to ensure they do not exceed the stipulated or manageable amount or fall below the required level. However, it is argued that determining an accurate level or reserves remains a challenge; therefore, nations tend to maintain a particular margin to suit both the lower and upper limits—a balance of levels. Jeanne and Ranciere (2006) argued that some governments still operate foreign exchange reserves without limits, especially maximum limits.

2.11 Saudi Foreign Currency Reserve Management

The accumulation of financial reserves in Saudi Arabia is a real-world business necessity; policy decisions are concerned with oil receipts as opposed to portfolio inflows. It remains essential for SAMA to dispose of groups of assets at regular intervals because high oil prices cause increases in SAMA's reserve growth and budget surplus. However, low oil prices lead to such reserves being drained. About five decades ago, central banks of various countries used to employ tractable, one-year investment methods to retain the actual value to ensure maximal liquidity. Nowadays, many tools and benchmarks serve as a measure of performance.

By managing assets portfolios, SAMA resembles both SWF and a traditional central bank: a reserve portfolio reflecting the standard needs of a central bank, and an investment portfolio that deploys excess reserves over a normal period. The central bank has retained a firm distinction between the two portfolios since the 1960s, when it first began to accumulate assets on a wide scale. That SAMA has a dual role allows particular emphasis to be placed on liquidity and returns. Upon the creation of liquidity, the generated additional surplus may be invested in long-term financial assets.

Prior to the 1973 oil crisis, SAMA conducted asset allocation to spread deposits among the major international banks. When considerable reserves were gathered, SAMA benefited from the experience of investment experts at White, Weld & Co. and Baring Brothers to help manage these reserves and train individuals. During this time, international capital markets (excluding the US) lacked liquidity, prompting SAMA to agree to a memorandum with the US, Germany and Japan to invest based on the direct addition of government bonds. As liquidity within markets increased, SAMA invested in G7 countries by undertaking private placements. Simultaneously, it invested in global entities, adding to emerging market debt in 2002. Following the GFC in 2008, SAMA redirected its efforts to alternative investments to enhance returns in a market in which traditional asset classes performed poorly because of artificially depressed bond yields. The development of SAMA helped form its investment culture. With an incremental approach, there is a low turnover of investment staff, which means that senior staff at SAMA are experts who have spent decades managing money and can help train new staff. These experts may help explain the importance of risk-adjusted returns, considering the fact that investments are successful if they avoid large losses (Banafe 2013).

Increased oil prices have enabled the Saudi economy to boom during certain decades. In 2005–2014, the economic benefit received was approximately US$1 trillion, resulting from oil revenues. However, matters worsened in 2014–2016, when oil prices dropped and did not increase. Except for 2009, when a crisis reduced demand for Saudi oil, the budget surplus overcame deficits until 2014, and SAMA enjoyed ever-increasing foreign reserves peaking in 2014. Similar to the 1970s, a percentage of returns was utilised to diversify the economy. The Saudi government simultaneously prompted state-owned entities like Yansab to borrow from international banks.

Excessive public expenditure resulted in inflation and SAMA struggled to manage the problem, leading to the revaluation of the riyal after the GFC. Before the banking collapse in 2008, inflation stood at nearly 10%. The following year also experienced world recession and negative growth was widespread. As oil prices declined, the government provided economically by managing a deficit, similar to the pattern of 2014. Conversely, other economies were also jeopardised. Economic government stimulus or activities became dependent on social spending or indirect government control of businesses. Revenues were strictly dependent on oil, sales and income taxes that did not exist. The non-oil income doubled between 2005 and 2014, but it still counted towards a small amount of the revenue compared with 20 years earlier.

Excessive public spending was dedicated to different projects, including hospitals, schools, universities and communications (e.g., the Riyadh Metro and high-speed Haramain project between Makkah and Madinah). Demand for steel and cement was much greater than local production capacity, so prices increased drastically. This added to inflation. Revenue and spending were considerable when the oil price was high, and vice versa. Thus, the state of the economy and SFCR management were directly linked to oil prices. Consequently, the government made a decisive shift from oil through the national transformation program known as Saudi Vision 2030.

2.12 SAMA's Investment Objectives, Philosophy and Method

The three main aims listed by SAMA are to preserve capital, retain liquidity and reach an investment rate compatible with the risk inclination. This is, SAMA seeks to invest assets that help reach investment objectives. The central bank aims to have an internationally diversified portfolio by using top-to-bottom asset allocation combined with in-house investment and outside fund managers. Such a strategy is based on the relative weights against the strategic benchmark kept confidential by SAMA.

Contrary to its past practice of asset allocation by class, SAMA has moved to asset allocation by risk, based on asset roles. Investment teams formulate long-term macro themes (such as the tendency of emerging markets to display higher returns than do developed markets) by forecasting revenues for bonds, equities and a variety of asset groups based on currency hedging and unhedging. The process yields a matrix of expected returns in the form of suggestions; these are relayed to SAMA's governor. The total expected returns matrix serves as the basis for SAMA's tactical asset allocation, which is calculated in terms of its difference from the base position on the strategic benchmark. Put simply, this refers to whether it is overweight or underweight with reference to the strategic asset allocation. When meetings are held, there is potential for additional tactical asset allocation decisions by amending investment programs. This is a direct reflection of unpredictable developments in financial markets and price actions (Banafe 2013).

2.13 Summary and Conclusion

This chapter provided important details on the Saudi economy's reliance on oil export revenue. It explored how oil production as a natural resource plays a significant role in the Saudi economy. Moreover, it highlighted why the Saudi government pegged its currency to the US dollar to avoid currency fluctuation and eliminate uncertainties in international transactions in times of significant oil price fluctuations. As oil is priced in the US dollar, this chapter showed how oil price volatility has an impact on both the world economy and the Saudi economy in particular. The role of oil revenue and accumulation of Saudi foreign assets was explained, and its economic significance highlighted. Oil revenues in the country's first five decades funded government spending on much-needed infrastructure, but it was evident that the economy at some point had to diversify to avoid budget deficits when oil revenues shrink. The rationale for the establishment of SAMA was to effectively manage two factors: the flow of current account surpluses and the foreign currency reserve. Finally, SAMA was the second central bank to begin operation in the Middle East. It has continued to play an essential role in the Saudi economy, especially in terms of managing foreign reserves. This chapter also explored SFCR management and its investment objectives, philosophy and methods. SAMA needs to understand the dynamic behaviour of both oil and currencies in its portfolio to be able to choose the optimal currencies composition to construct the SFCR portfolio and manage this portfolio effectively when oil shocks occur.

Chapter 3: Selecting Currencies for the Saudi Arabian Monetary Authority Foreign Currency Reserve Portfolio Based on the Mean-Variance Approach: A Univariate Analysis

3.1 Introduction

It is necessary for central banks to understand the dynamic behaviour of financial assets, including foreign currency reserves, so that they have a clear vision for allocating and rebalancing their portfolios as situations change in financial markets, particularly in an increasingly evolving but unstable global economy. Central banks and investors are inclined to measure their sum asset portfolio based on this instead of considering the potential of international diversification to make considerable gains. Central banks are keen to hold more assets, even when they have diversified portfolios. Such behaviours have encouraged scholars and economists alike to search for optimal portfolios.

Oil is important globally because it is a major source of energy, used as a raw material in several industries. All countries around the world use oil as a trading item. Macroeconomic variables have been significantly affected by the increase and fluctuations in oil prices. Such variables include, but are not limited to investor decisions, production costs, growth and decline of industries, inflation, countries' balance of payments status, aggregate spending and levels of national income. According to Cleaver (2007), large amounts of money are used, which affects levels of international debt, the global financial sector and how it operates, and the economic growth of all countries.

SAMA should allocate large portions of the country's foreign currency reserve to such assets (i.e., US Treasury bonds) and include foreign currencies that may be considered self-insurance against the risks associated with oil price decline. SAMA may be more susceptible to aggregate shocks that may be hedged by holding foreign assets. Nevertheless, the financial assets have been justified by many theoretical explanations, such as information asymmetries, exchange rate risk, risk aversion, explicit trading cost and risk aversion (Gehring 1993; Brennen & Cao 1997; Coval & Moskovitz 1999; Grinblatt & Keloharju 2001).

As new information is processed in the market, the riskiness of each asset is expected to change. Therefore, it is likely that SAMA would prefer to understand oil and currency exchange rates' dynamic behaviour by applying univariate analysis for each time series individually. Using the result of univariate GARCH analysis for oil and each currency will help SFCR portfolio managers in SAMA understand the dynamic behaviour of oil and currency exchange rates. Further, it enables SAMA to introduce an efficient strategy for selecting currencies that mitigate the risk of depletion by investing in foreign exchange markets. Moreover, it enhances SFCR portfolio composition and maximises dynamic asset allocation (DAA) when estimating the effect of volatility spillover between oil and currencies. Several studies have reported issues with hedging strategies across different asset classes by using the risk-minimising hedge ratio (Kroner & Sultan 1993; Kroner & Ng 1998; Olson et al. 2014; Arouri et al. 2015). Thus, by building dynamic optimal portfolio allocations and hedging effectiveness, there may be considerable implications for measuring the dynamic behaviour of oil and currencies in the interests of strategic portfolio management.

3.2 Related Literature

This section will discuss the definition and importance of volatility. It will explore the extant literature in terms of analysing and forecasting volatility using mean-variance analysis.

3.2.1 Definition and importance of volatility

The idea of researching volatility spillover began in 1987 after the international stock market crash in financial equities. Recent papers have investigated intermarket relationships, such as correlations between market volatilities and intermarket volatility. Changes in the investment flows at the global level are explained by spillover volatility through analysing the mean and variance for variables. Moreover, it explains the higher level of supply and demand in markets that result in interdependence between various market volatility returns. Therefore, volatility spillover provides important insights by explaining the flow of information between various markets.

Volatility has been defined as the degree of uncertainty or risk towards change in the asset value. This means that sudden changes in asset prices result in higher volatility and vice versa. The literature using time series (i.e., equity markets) and exchange rate markets (i.e., the return movement behaviour) takes multiple forms. They reveal a tendency for returns to appear in bunches (i.e., higher returns are followed by higher returns and vice versa). Volatility clustering is defined as the variation of the amplitude of return series with time; the ARCH and GARCH models aim to capture this variation. As such, they are popular tools for dealing with time-variant heteroskedastic models and can provide good variance estimates for high-frequency data.

In the literature, volatility has been discussed in different models. Earlier models were about historical volatility; these used standard deviation and returns variance over a period. It was a simple model classically used for future volatility forecasting. Later literature, such as Akgiray (1989) and Chu and Freund (1996), provided more complex models of volatility that are more accurate than the classical version in terms of predicting volatility spillover. Moreover, modelling of volatility can be done on current market price using derivatives instead of historical price. The Black–Scholes model (1973) is an important example of this model.

Daly (1999) explained volatility as ‘a statistical measure of the tendency of a security’s price to change over a period of time’. He outlined explanations that point to volatility as a matter to monitor for in oil price issues. First, the fluctuation of asset prices over short periods of one year or less affects price levels because of available information on important economic factors. Information is important for maintaining market confidence; a lack of it can seriously undermine this confidence and reduce the flow of capital into equity markets. Second, volatility within companies can determine the likelihood of bankruptcy because given a high volatility in capital structure, there is a greater chance of default. Third, the bid–ask spread is dependent on volatility in that when volatility is higher in financial assets, the chances are greater of this spreading between the bid and market prices, thereby affecting market liquidity. Fourth, volatility levels also affect hedging techniques by increasing prices (e.g., in terms of portfolio insurance, in which prices can increase in a highly volatile market). Fifth, in light of financial and economic theory, the assumption is that consumers are risk averse—they would avoid engaging in highly risky economic activities. This affects investment. Sixth, Daly (1999) indicated that regular suppliers of agencies of capital may be influenced by volatility, thereby compelling companies to award a large portion of their available capital to cash-equivalent investments. This is not an efficient allocation of capital.

Hence, *volatility* is a standard deviation from a particular continuously compounded return over a particular period (e.g., price differences of a security on a daily, monthly or annual basis). Therefore, a high price fluctuation equals high volatility and vice versa. Financial markets globally are vital for national economies; they are now more integrated and volatile: hence, the increase in research interest in financial market volatility. The vulnerability of economies and financial markets is compounded by financial volatility, and subsequently, estimates offer guidance to policymakers. An example provided by Nasar (1992) was that of the Federal Reserve in the US, which considered the stock, bond, commodity and currency volatility to develop its monetary policy. However, researchers in the finance field have not reached a consensus on a definition of 'volatility'. Altman and Schwartz (1970) and Brailsford (1994) argued that various definitions all depend on the context of each individual study, approach and application. Goldstein and Taleb (2007) argued that the concepts and models of volatility are of paramount importance in guiding financial decision-making, risk management and/or interpreting market conditions because misinterpretation of any information can lead to serious outcomes.

Despite the many definitions in the literature, two are the most favourable for financial market participants, regulators and investment theory. In terms of market participants, Reilly and Brown (2012) defined volatility as the asset risk that could occur as a result of uncertainty of future returns. The measurement of volatility in this case would be by variance or standard deviation of expected returns of an asset during particular periods of market time (Bodie et al. 2008). Hence, in this case, risk is deemed higher or more volatile in asset returns when variance or standard deviation of returns are also high. From a market regulator's perspective, the volatility of individual financial asset or markets is of greater concern. According to Schwert (1989, 2011), volatility became important in the US market after the 1929–1939 Great Depression because stock prices reached a high level never been experienced before. From this experience, the US Securities and Exchanges Commission resorted to defining the market as volatile when they observed extraordinary or unexpected changes in prices (SEC 2012). In Australia, volatility is defined as 'a measure of how wild or quiet a market is relative to its history' (Australian Stock Exchange 2014). Further, volatility is 'the rate when the price of a security moves up and down' (Australian Securities and Investments Commission 2014). The above definitions depict the importance of volatility in research and market predictions. The volatility concept allows investors/policymakers to quantify risks in portfolio selection, risk management and asset pricing models.

On a larger scale, although it is also debatable, volatility is a danger because it symbolises risk and uncertainty in the market. It also has a positive effect when investors take advantage and make large purchases when prices are low and sell them when prices rise. This view is supported by Liu et al. (1999), who argued that volatility quantifies risk and is of benefit to traders since they can identify underpriced and overpriced financial assets and take advantage of low and peak times. Financial liberalisation coupled with capital mobility makes a boom-bust cycle possible. This is argued by Wyplosz (1999) as highly probable in emerging markets, but appropriate financial policy frameworks to support financial globalisation are in short supply. Wyplosz (1999) stated that market disequilibrium and volatility are included in the operations of the global financial market. Das (2004) suggested that high volatility can be managed and proposed financial integration to open doors to institutions and nations so that they can borrow from and lend to the global market. This strategy not only manages volatility, but also creates diversification of portfolios. Other authors have also attributed fluctuations in financial assets prices to changes in discount rates or information received by shareholders and investors on predicted cash flows.

Three varied study areas have researched volatility: exchange rate, oil price and community price volatility. Standard deviation is the main measure used to test volatility and is defined as changes in the value of financial assets over a period, which could be a day, week or month. Market volatility can emerge for various reasons. The most common are reasons are domestic economic factors, which range from fiscal policies (inflation and interest rate) to proxy of monetary, internal factors (e.g., oil prices, trade-weighted world exchange rate, the world index and the US Treasury bill), to economic factors (e.g., CPI, money supply, real activity and IP). Kalev et al. (2004) and Poon and Granger (2003) emphasised the importance of patterns of volatility in determining variations in market efficiency or demonstrating the vulnerability of a financial market. Signalling of probable financial crises and/or instability or guidance in monetary decision-making can both be signalled by volatility.

The measurement of market volatility is one of two volatility models that have been consistently used in financial research studies: the ARCH model and the stochastic volatility (SV) model. These two are deemed time series volatility forecasting models. SV and ARCH, and GARCH models, can be measured using standard deviations; GARCH is more parsimonious and the most effective model for examining time series.

High-frequency data are vital in financial market research as they touch on three key areas. First, it is possible to measure and estimate asset returns and volatility in shorter intervals (e.g., daily, hourly and by the minute) using high-frequency data. Researchers hailed this data for improving sample size and the importance of a particular study (e.g., Dacorogna et al. 2001; Muller et al. 1997). Two, short-term behaviours of asset prices can be obtained when high-frequency data are analysed. Biais et al. (2005) indicated that seasonality matters benefit best here since short-lived increases in asset prices can be observed and obtained in long-term time series. When new information is received during trading hours, these authors assert that asset prices and behaviour of financial markets can be understood much better when high-frequency data are utilised. However, when different variations of information and other influencing factors are received simultaneously, Dacorogna et al. (2011) asserted they could be corrupted; information announcements should be separated from other factors to better observe their impact.

3.2.2 Forecasting volatility through the mean-variance analysis

The univariate GARCH model was used frequently throughout the 1990s and has become a standard practice of scholars studying financial assets; it considers oil price volatility and exchange rates. This type of GARCH model has been very popular, despite the rise of other variants made possible by faster, local maximum coverage and good forecasting performance for an individual time series. ARCH models were formulated by Engle (1982) and Bollerslev (1986). The latter provided a more general model to that of Engle, clearing the path for a new age of models to demonstrate effective capture of the dynamics of time series and GARCH models. Over time, variations of GARCH models have prompted scholars to group them into two categories: univariate and multivariate models.

Univariate models consist of the T-GARCH model (threshold GARCH) formulated by Glosten, Jagannathan and Runkle (1993), the EGARCH model (exponential GARCH) by Nelson (1991) and the Q-GARCH model (quadratic GARCH) suggested by Sentana

(1995). Multivariate versions include the BEKK model of Engle and Kroner (1995), the VECH model developed by Bollerslev, Engle and Wooldridge (1988), the O-GARCH (orthogonal GARCH) model developed by Alexander and Chibumba (1996) and the GO-GARCH model (generalised orthogonal GARCH) suggested by Van der Weide (2002). The aim of this chapter is to understand the dynamic behaviour of each time series; the multivariate series will be discussed in Chapter 4.

For analyses of volatility, ARCH/GARCH models have served as the standard tools. Simplifications and modifications have been presented extensively in literature. The simplistic version of the ordinary least squares (OLS) model states that, when squared, the expected value of all error terms can be assumed as constant. This assumption is termed homoskedasticity, a quality that financial data frequently contain when variances of error terms are not equal such that error terms may be too large at some points and too small at others. When homoskedasticity is assumed, standard errors and confidence intervals estimated would be too restrictive, yielding a false precision (Engle 2001). When ARCH and GARCH models are utilised, they consider homoskedasticity a variance that must be modelled. When these models are applied, they seek to correct irregularities associated with the OLS model and find the predicted variance for each error term.

Before the advent of ARCH and GARCH models, there were no such methods to compute variance using past information for the mean and variance. Engle (2001) pointed out that traditional descriptive tools, like the rolling standard deviation, rely on a specific number of observations, which are usually recent. Such tools assume that the variance of any given day’s return is a weighted average of squared residuals of the last few instances, and such assumptions are not considered valid. However, the ARCH and GARCH models, represent the weighted average of past squared residuals that yields easy-to-use models, as suggested by Engle (2001). As such, these models permit data to determine weights to be used for forecasting the variance; applications of these models have generated successful results.

Engle and Bollerslev (1986), Bollerslev (1987), Baillie and Bollerslev (1989), Diebold and Pauly (1988) and Diebold and Nerlove (1989) are among several authors who have described the validity of univariate ARCH/GARCH models in studying the dynamics of exchange rates. The occurrence of volatility clustering for financial data of high frequency has been recognised by many studies. It has also been realised that volatility clustering is a characteristic of exchange rates, and large changes are preceded by large changes, followed by periods of relative tranquillity and again followed by large changes, in an alternating pattern.

Hamao et al. (1990) were early researchers who applied the two-step univariate approach in their analysis of correlations between changes in prices and volatility in New York, Tokyo and London. Their methodology consisted of the authors reviewing daily and intraday prices for stocks for countries, from April 1985–April 1988, and testing the obtained data for conditional mean and volatility exhibiting spillovers. Analyses were undertaken using correlation studies with lagged returns. Further, squared residuals obtained from different stock markets were utilised in the ARCH model to estimate residuals, and the MA(1)-GARCH(1,1) model was applied to each stock market. Subsequently, the initially estimated squared error term was inserted as an independent variable into the variance equation for various markets. Results from this study showed that volatility spillover from US and UK markets affected the Japanese market significantly, whereas vice versa, it had a weaker impact.

This study also used the two-step univariate GARCH to isolate causes of volatility, in which the null hypothesis was the heatwave hypothesis, claiming that volatility has only country-wide implications and does not affect other markets. The alternative hypothesis is that of the meteor shower, which assumes that spillover from one market to other markets may be possible in certain circumstances. To test the validity of these two hypotheses, Engle et al. (1990) analysed daily dollar/yen exchange rates in both markets from October 1985 to September 1986 to test whether news content that promoted volatility in the New York market had the same effect on the Tokyo market on any given day. When tested against the heatwave hypothesis, results indicated a significant positive effect of volatility in the New York market affecting its Japanese counterpart, albeit with a one-day lag on the current volatility. However, when tested against the meteor shower hypothesis by using aggregate international news content, the null hypothesis was rejected with a 5% significance level in both the US and Japanese markets.

The study showed results obtained by applying the meteor shower hypothesis to test if the previous day's local news affected markets more than would foreign news; predictably, foreign news was the more important factor in determining market volatility. This study concluded that the alternative hypothesis—the meteor shower hypothesis—

was empirically more justifiable in explaining volatility spillovers compared with the heatwave hypothesis for the New York and Tokyo markets. The same two-step approach was adopted by Peña (1992) and Wang et al. (2002), who discovered evidence supporting the meteor shower hypothesis. Studying the New York and London markets, Susmel and Engle (1994) used the GARCH model in the mean equation as a specification, finding the heatwave hypothesis to be valid, since evidence revealed that volatility spillovers to other markets were minimal. Several others used varying specifications in their mean equations, but Susmel and Engle's (1994) approach to using the GARCH model was adopted by Kim and Rogers (1995) and by Kim (2005).

Several other studies into volatility spillovers have used dummy variables in their mean or variance equation, or in both equations, which was done to monitor crises' effects on any given day, or on the end of a particular week. Connolly (1989), using dummy variables, found minimal evidence of the phenomenon termed 'day-of-the-week effect' and the 'weekend effect'. In what little evidence was present, the effects tended to disappear when GARCH was applied. This is in line with previous studies, such as that of Susmel and Engle (1994), who did not find the day-of-the-week effect significant. Variance equations of GARCH were employed by Aggarwal et al. (1999), who applied changes of variance of return as dummy variables in the equations estimated by quasi-maximum likelihood. Iterative cumulative sums of squares, which identifies any changes in the variance of return for emerging markets, was used to compute these changes. Apart from the global crash of 1987, most volatilities within emerging markets were a product of local events. It was realised that GARCH coefficients were negligible for cases in which the changes regime was introduced. This held true for Susmel (2000), in which the changes regime, introduced into the study as the ARCH effect, proved negligible in the face of the exponential regime known as switching ARCH (E-SWARCH).

Black (1976), Schwert (1990) and Nelson (1991) claimed that unexpected positive shocks produce less volatility than their negative counterparts and GARCH specifications may fail to capture such variability. Susmel and Engle (1994) expanded on this, stating that models that do not account for such variability will provide inaccurate estimates. Here, several analyses have aimed to modify the GARCH model to address concerns of variability in the univariate form. Examples include the EGARCH, introduced by Nelson (1991), or GJR-GARCH, proposed by Glosten, Jagannathan and Runkle (1993). These became quite popular in tacking the variability issue in a two-step approach. Studies like Peña (1992) and Pyun et al. (2005) sought to express the relationship between the asset traded and its volume; the volume was introduced as a regressor variable in the conditional variance equation, since trade volume can be viewed as a source of volatility. Others, such as Kim (2005), introduced trade volume into the conditional variance equation to reduce the persistent volatility, while investigating the relationship between different stock markets.

Black (1965) studied the effect of news on return volatility in a stock market and found that negative information wielded a greater effect than did positive information. This asymmetric effect of positive and negative news having the same numerical values can be explained through the leverage effect (Bauwens et al. 2006). The leverage effect was suggested by Enders (2010); it claims that the rise in returns will lead to less volatility in the coming years, and lower return may lead to higher volatility. This was claimed to be applicable to many financial assets. This negative relationship among volatility and return is called leverage effect.

Negative news indicates that higher volatility may be present and result in greater risk. Investors find it essential to simulate the subsequent asymmetric effect that cannot be captured well through standard GARCH models. Consequently, researchers in the 1990s suggested that asymmetric GARCH models would better integrate and account for the impact of news, including the GJR-GARCH model (Glosten, Jagannathan & Runkle 1993), the EGARCH (Nelson 1991), QGARCH (Sentana 1995) and others (Lütkepohl & Krätzig 2004).

To analyse return and volatility, a univariate EGARCH approach was adopted by Wang et al. (2005), who sought to study two developed markets and three South-Asian emerging markets (Sri Lanka, India and Pakistan) between January 1993 and December 2003. It is essential to note that, for each of the five countries, daily data were used for the aforementioned variables. The link between the developed and emerging markets was demonstrated by the results of the study, which showed that the developed markets affected the returns and volatility of the three South-Asian markets to a great extent, with the greatest affect observed for the US for all three countries. Masih and Masih (1999) found that spillovers increased in number and intensity after the Asian crisis in 1997. This reinforces the idea that greater cointegration was observed among markets as a result of increased spillovers during the crisis.

It is evident that shock for volatility is dependent upon a function of exponential decay. Another innate feature of exponential decay is its time requirement—the decaying variable reduces to half its original value, termed 'half-life'. Shocks to conditional variance are said to persist across a period if the sum of coefficients in a traditional GARCH approach is nearly 1.

Lamoureux and Lastrapes (1990) laid out a logical detailing for the continuing variance, suggesting that continued conditional variance for stock returns may be a product of the neglected sudden shifts in volatility. By considering such shift points, there may be a considerable reduction in the persistence of conditional variance, given that GARCH-family models are used. This idea was also studied by Hammoudeh and Li (2008), who studied volatility in Gulf stock markets. Saudi Arabia, Kuwait, Oman, Muscat, Abu Dhabi and Bahrain, reported a considerable decrease in the volatility persistence for valid sudden breakpoints in variance. Similar results were reported by Kang et al. (2009), Kang et al. (2011), Çağli et al. (2012) and Ewing and Malik (2013).

Univariate and bivariate models have often been used by researchers to study the effects of spillovers. To model the conditional variance, univariate volatility approaches use the model independently for each series, without regard to other series, before the bivariate GARCH can be applied.

For developing and emerging markets, the mean-reversion phenomenon is studied and compared using Ahmed et al. (2018). A central objective is the comparison and measurement of the rate of mean reversion and the half-life of volatility shocks for both types of markets. Five developed and seven emerging markets were chosen for study, using daily data from 1 January 2000–30 June 2016. Models used for the research were ARCH: Lagrange multiplier (LM), GARCH (1,1) and half-life volatility shock models.

Conclusions from the study demonstrated that the mean-reverting process existed in both types of markets. In South Korea, the lowest mean reversion was observed, pointing to the highest comparative volatility over the period under consideration. Conversely, the fastest mean reversion was observed in Pakistan. The trends allowed for the conclusion that emerging markets demonstrated higher relative volatilities and their counterparts showed lower volatilities. Thus, the mean-reversion process is more fast-paced for emerging markets, excluding South Korea and China. The study suggested that investors consider emerging markets if their aim is to obtain higher returns over less time.

Chaudhuri and Wu (2003) considered 17 emerging markets and the conduct of their stock returns. The study showed that mean reversion was present, and its pace was demonstrated through the half-life method. It was concluded that, following a period spent in emerging markets, equity returns return to their previous mean values.

A GARCH model, instead of the traditional ARCH approach, was adopted by Li and Li (1996) for the conditional variance. The GARCH is more popular and allows a more elaborate representation of persistent volatility series. A useful diagnostic for the comparative usefulness of permanent and transitionary components is afforded by Cochrane's (1988) consistent estimates for the measurement of persistence. Excluding Poland's market, the point estimates represent the notion that every market possesses some extent of mean reversion.

Ding and Granger (1996) introduced the GARCH model, allowing for the half-life of the decay coefficient to represent the persistence in variance. Such a method is innate and open to flexibility, allowing investors to choose the decay coefficient half-life according to their own risk preference and critical value. A long memory property is inherent for portfolio volatility if it fulfils the condition that the decay coefficient's half-life is too much. For such a case, shocks in the present conditional variance would be long lasting.

Additional studies for the sudden changes in variance of security prices include that of Poterba and Summers (1986), who demonstrated that the presence of the time-varying risk premium hinges largely upon the extent of persistence in volatility shocks. Evidence of the exchange rate volatility being affected by US monetary policy regimes was recorded by Lastrapes (1989). Evidence of the systematic behaviour of sudden volatility changes in common stock prices was explored by Kim, Oh and Brooks (1994), who showed that they are not diversifiable, so the applicability of a hedging strategy may be affected.

The importance of GARCH models for practitioners interested in financial markets and related subjects is dependent upon the interesting behaviour of changing volatility, volatility clustering and persistence. As suggested by Lamoureux and Lastrapes (1990), the life shock—the number of days taken for a shock to conditional variance to reduce to half its initial value—was also given.

A total of 93 papers were reviewed by Poon and Granger (2003), who studied forecasting in financial markets. They found that the volatility in markets was clearly predictable. It is difficult to draw generalisations that rank the forecasting power of various models since different authors use various assets, datasets and their own objectives to arrive at their own models and evaluation techniques.

The volatility of exchange rates, as predicted through different models, was studied by West and Cho (1994). In particular, six models were compared for forecasting volatilities (conditional variance, dealing with homoskedasticity and heteroskedasticity [GARCH]) for currencies of five countries: the UK, Japan, Germany, France and Canada. The period 12 March 1973–20 September 1989 was considered, and total weekly data were taken to estimate the weekly conditional variances, forecasted for 1-week, 12-week and 24-week periods.

Evaluation techniques were relied upon and the predictive ability of models was used for out-of-sample forecasting. GARCH models provided smaller error than other models under the mean squared prediction error statistic, though this error was not statistically significant. The advantages of one over the other were not apparent for the conventional test of forecast efficiency for the other two horizons, and all models were observed to be statistically similar under the root mean squared prediction error testing statistic. Thus, for this study, the forecasting ability of GARCH was not significantly superior to the other models, and it was perceived that heteroskedasticity must be considered for time series.

The predictive ability of 330 volatility-GARCH models for exchange rate and IBM stock prices was explored by Hansen and Lunde (2005), who considered the intraday (one minute and five minutes) returns estimation of realised volatility at the daily exchange rate to provide a precise volatility comparison. The EGARCH model is sufficient for t-distributed standardised residuals in univariate analysis. Nevertheless, it was possible to reach a general conclusion: ARCH proved the most unsuitable model when accounting for benchmarks, while GARCH (p, q) was statistically better than other models considered, even though the original GARCH model was much simpler than the following modifications of GARCH.

The forecasting ability of GARCH models for the dynamic behaviour of financial assets was explored by Andersen and Bollerslev (1998) from a theoretical and practical perspective. These authors defended the ability of ARCH and SV models to forecast and produce correct interdaily forecasts. Between October 1987 and September 1992, they forecasted the volatility of Deutschemark-USD and Japanese yen-USD exchange rates. Daily, monthly, hourly and minute-based one-step-ahead forecasts were tested for both exchange rates by employing the MSE measure to evaluate the error of forecasts.

Using rolling data, it was observed that the 20-day-ahead GARCH estimation was the most unbiased, and forecasting was superior when volatility was high. In fact, the 1-day-ahead GARCH model forecasted a considerable tracking system of the pre- and post-volatility situations for the two markets. R^2 value of daily squared return increased from 10% to 50% for 5-minute squared returns. Theoretically, a higher R^2 value should be yielded than it was the case of 1-day-ahead out-of-sample 5-minute return for the dollar versus the yen. This discrepancy was explained as resulting from unusual apparent volume expansion during the specified period. R^2 value monotonically increased with increasing data frequency, and the forecasts errors decreased drastically. Forecasting based upon continuous samples proved more efficient than daily forecasting.

The unequal effect of information on financial time series' volatility was studied by Black (1976), which led to further research into the effect of positive and negative information on volatility. Ross (1989) studied this effect, concluding that variance in price changes was proportional to the type of information, which inspired the study by Conrad, Gultekin and Kaul (1991). They suggested integrating the effect of asymmetry for the prediction of conditional variances after studying differential asymmetric predictability of volatility.

Nonlinear GARCH models were particularly sensitive to extreme observations for in-sample tests, as suggested by Franses and Van Dijk (1996). Another variation, the QGARCH model, was observed as superior to the random walk, GJR-GARCH and GARCH for exclusion of extreme observations of the 1987 stock market crash. This was particularly true for forecasting the return volatility of subsamples from five European countries, although the GJR-GARCH model was deemed inappropriate for forecasting purposes. This view was challenged by Engle and Ng (1993), who argued for the superiority of the GJR-GARCH as the most suitable parametric model for providing accurate volatility forecasts and low conditional variance.

For rolling and recursive samples under RMSE and MAE criteria, the superiority of the linear GARCH model over its nonlinear versions was not necessarily true, as suggested by Lee (1991). The author studied GARCH models in the context of their out-of-sample forecasting ability to predict the volatility. A fixed period, 1973–1989, was selected to examine the forecasting power of linear and nonlinear GARCH models to predict the volatility of exchange rates for the US dollar against the Canadian dollar, French franc, British pound, German mark and Japanese yen. Both RMSE and MAE were utilised for this study since the performance of exchange rates depends on the measuring criteria.

Both rolling and recursive methods were employed for comparison purposes in studying the forecasting strength of linear GARCH models (regular GARCH and IGARCH including trend) and nonlinear GARCH models (ARMA GARCH index, non-parametric kernel models and EGARCH with trend). Two criteria were specified, and a mix of results was obtained. It was observed that kernel models performed better when subjected to the MAE with recursive forecast, while rolling forecasting was preferred for RMSE. The high volatility was better explained with the aid of the GARCH (p, q) model than with the non-parametric kernel model (RMSE criterion).

February 1988–December 1996 was the period selected for seven emerging countries (Taiwan, Philippines, Mexico, Malaysia, Colombia, Brazil and Argentine) and their stock market monthly returns by Gokcan (2000). With the exception of Argentina, leptokurtic results were obtained for all countries and the GARCH (p, q) yielded lower AIC in in-sample testing, performing significantly better than EGARCH for all countries. Excluding Brazil, the GARCH (p, q) for one-month-ahead forecasting provided less forecasting error for all countries. As such, the GARCH model better explained the dynamic volatility of returns. It was also observed to have improved the forecasting ability regarding all emerging countries, compared with the nonlinear EGARCH.

The predictability of conditional variance of return was explained by Conrad et al. (1991) for companies of various capitalisation sizes. The authors considered 1962–1988 in combining daily returns of US stock exchanges, in accordance with company sizes, into three value-weighted portfolios. The aim was to study the effect of asymmetry on returns, for which they considered the end of the year effect and the cross correlations (asymmetric, lagged) for the univariate and multivariate GARCH (*p, q*) and ARMA (*p, q*) models. Results indicated considerable asymmetry in the ability to predict volatilities of larger companies, which made it more rational to account for the effect of asymmetry on both mean and variance when modelling time-dependent returns and volatilities.

The asymmetric information effect on volatility was extended from US and UK stock markets (French, Schwert & Stambaugh 1987; Sentana 1993) all the way to the Japanese market (TOPIX index) (Engle & Ng 1993) for the 1 January 1980–31 December 1988. A combination of a non-parametric model and diagnostic tests was employed by Engle and Ng (1993), who discovered that negative information had a more severe effect in increasing volatility than did positive news. Additionally, the testing accuracy of various models for the impact of news on volatility was measured using seven variations of the GARCH model: EGARCH, AGARCH, VGARCH (1,1), nonlinear NGARCH, standard GARCH, partially non-parametric model (PNP) and GJR models. The GJR stood out as the clear winner among parametric models, since it allowed for the most accurate parametric volatility forecasting with low conditional variance. The PNP model was also useful in simulating the news impact curve.

To that end, the present study seeks to estimate conditional volatility and assess the persistence in variance and leverage effect simultaneously. To compute the asymmetry effect and the persistence when considering regime shifts in volatility, it was concluded that persistence in variance decreases for the models. Considering the half-lives of shock to volatility also reduced considerably. Additionally, using these two models demonstrated that persistence is reduced to a greater extent by employing the GJR-GARCH, considering daily returns in oil and currencies from 2012 to the end of 2018.

This study fills the gap in the previous literature by implying the half-life approach obtained from the univariate analysis. This enables understanding of the dynamic behaviour of study variables individually before estimating volatility spillover between oil and currencies in the next chapter. Further, the half-1ife approach has been used in limited studies in stock markets but not in currency exchange markets. Thus, univariate GARCH and half-life have not been used together in the forex markets.

3.3 Time Series Properties and Unit Root Tests

This section analyses the general methodology of this study. Various methods are used to describe the data and analyse the dynamic behaviour of variables. This research focuses mainly on crude oil prices and exchange rate, with emphasis in this chapter upon volatility using mean and variance analysis approaches. This section will review the general methodology that will be used to investigate the dynamic behaviour of oil and exchange rate in mean and variance.

3.3.1 Diagnostic tests

Before selecting the models for this chapter, it is essential to conduct preliminary diagnostic tests that can improve the selected models' reliability.

3.3.1.1 Skewness

The property of skewness is a standardised third moment test symmetry that measures the mean of a time series. It is established that normal distribution has no skewness, but the opposite is not necessarily true; having zero skewness does not mean the distribution must be normal or symmetric. That is, a likelihood-symmetric distribution is certain to have a zero-skewness value, and further, a series displaying skewness is certainly not normally distributed. Instead, it is asymmetrically distributed. When skewness is present, it is characterised as follows: the stretched tail-end towards the left side indicates negative skewness from mean and this means most observations lie here, and vice versa. Since most time series fail to show normal distribution, it is necessary to include skewness and conduct normality tests (Brooks 2008).

3.3.1.2 Kurtosis

'Kurtosis' refers to a specific ratio between the conditional fourth moment and square of conditional variance for a time series that displays normal distribution; it aims to test its peakedness. To simplify measurement, the statistic is modified to become $(\omega - 3)$. Regarding the context of normal distribution, kurtosis has a value of 0, which is referred to as a mesokurtic case. When the kurtosis is greater than 0, such a time series is termed leptokurtic; for such cases, the tail is broader and has a larger greatest value on either side of the mean than does normal distribution. A time series with kurtosis lower than 0 is called a platykurtic time series and it shows lower and wider peaks with thinner tails.

It has been observed that higher kurtosis means there are more extreme values in the time series; extreme deviations in variance are rarer and vice versa. Difference between conditional and unconditional distribution becomes more prominent with the increase in kurtosis, as suggested by Gourieroux (1997). For example, Student's t-test distribution is leptokurtic, as is the Laplace distribution and they both have fat rear ends. Conversely, uniform and Bernoulli distributions display latykurtosis.

It has been observed for many different scenarios that both the financial and economic time series display leptokurtic behaviour, where the tail is fatter than it is for normal distribution, especially for cases in which data has high frequency. This means that fitting an economic time series and its residuals may be done more readily using leptokurtic distribution. According to Lutkepolh and Krätzig (2004), Student's t-test results and generalised error distribution (GED) solidify the existence of conditional leptokurtosis. It has been observed (Brooks 2008; Enders 2009) that, statistically, Student's t-test distribution has a larger value for likelihood than does the normal one.

3.3.1.3 Normality test

The JB normality tests were introduced by Jarque–Bera (Bera & Jarque1981) and are widely employed, while the Bayesian test is often used as an alternative for many cases. Here, the null hypothesis is that the time series is mesokurtic and symmetrically distributed. This test statistic is asymptotic and follows a $\aleph^2$ distribution of second order. For a p-value greater than 5% for the JB test, normality series at a significance level of 5% cannot be rejected. Brooks (2008) suggested that a large sample is less likely to follow non-normal distribution, but such a non-normality scenario may be the result of certain extreme values or heteroskedasticity.

3.3.1.4 Lagrange multiplier

Initially suggested by Engle (1982), the LM tests for the existence of ARCH given that there is conditional normality. Often, the test is used to search fresh return data, where the null hypothesis assumes there is no ARCH effect. For the ARCH and GARCH models, a specific criterion is given. The null hypothesis states that the q lags' coefficients for squared residuals may be close to 0 (Brooks 2002). Meanwhile small TR^2 values assert that the null hypothesis cannot be rejected, and large TR^2 values claim that the ARCH effect is present. It can also be utilised for scenarios in which there is non-Gaussian residual distribution (Gourieroux 1997). Another viewpoint holds that the LM test checks how accurate the MGARCH specification is (Bauwens et al. 2006). Alternatives for running residual-based diagnostics on conditional heteroskedasticity models are the Wald and portmanteau tests of type Box–Pierce–Ljung. Where residuals are different from a normal distribution (Ding & Engle 2001).

3.3.1.5 Autocorrelation test

The Ljung–Box test has been suggested as a Q test, by Ljung and Box (1978) who modified the general condition (Box & Pierce 1970) to test the adequacy of the fit. This test examines the serial correlation and has a null hypothesis stating the condition of no correlation

Such an approach is believed to be a neater fit for given data (Box & Jenkins 1970). Nevertheless, when a_t displays a different distribution than normal, the Q statistic is less dependent on deviant observations from the normal distribution.

3.3.1.6 Modelling criteria

Two measures that articulate the relationship among the lags and their quantities are the autocorrelation function (ACF) and partial autocorrelation function (PACF). The ACF and PACF coefficients may be different from 0 up to a specific lag order. ACF is equal to PACF for the first lag, but PACF formulae become more complex for the second and larger lags (Gujrati 2003). When a series cannot be represented by simplistic graphs, ACF and PACF fail to encapsulate the characteristics of given data. To interpret odd series, the alternative AIC (Akaike 1974) and BIC information criteria (Schwarz 1978) methods are used because they eliminate subjective unexplainable factors. AIC and BIC may have values less than 0. Given a specific set of parameters, the regression gives minimal information. For predictions, AIC and BIC may be useful because they can test for the aptness of the order p and q. Large p and q will result in less conditional variance, although this means that individual error is large as a result of the estimation, so in effect, it gives a larger error of the mean squared error as suggested by Brockwell and Davis (2002).

Overall, the addition of a regressor would give higher values for AIC and BIC, which are termed as a penalty. When the model is improved, these two can be close to negative infinity. Information criteria are observed to decrease when the sample size for the above formulae decreases, although it cannot be done since a reduction of usable observations would yield smaller values for AIC and BIC (Enders 2009). For short regression, information criteria have a small value compared with long regression, and both of these may be utilised for in-sample and out-of-sample regressions. Further, AIC is regularly utilised to test nested and non-nested regression models, while BIC gives a specific row of the lags, distributed asymptotically. They have a stricter and regular penalty when compared with AIC, yet the latter is perceived as swifter, in that it returns order for moderate size, large size and even infinitely large data (Gujrati 2003; Brooks 2008).

3.3.2 Stationary tests

This section examines econometric tools used for investigating interactions among oil price and several exchange rates. Much literature has shown that a unit root may exist in time series exchange rates. Thus, if non-stationary data results are approximated through the OLS method, this often gives a 'spurious regression' that contrasts with the case for stationary independent variables; for the former, regression analysis would yield an insignificant t value for the slope coefficient, and a low R^2 value. For non-stationary variables that trend over time, regression analysis may give a good fit given that it is done under standard measures of significance, although it is possible that the variables are unrelated. For this reason, mean-variance analysis must examine the longstanding relationship between oil and exchange rate markets through their non-stationary data. Before examining mean-variance for oil and exchange markets, empirical evidence is obtained to test each series for a unit root in levels.

According to Al-Khazali et al. (2006), it is essential to use multiple tests to make the results more robust. This is done by using the ADF (1979), the PP (1988) and KPSS (1992) tests. All three tests vary in their treatment of 'nuisance' serial correlations (Chen et al. 2002). Gilmore and McManus (2002) suggested a procedure to use the least restrictive models containing a constant term and trend term, which will be utilised here.

3.3.2.1 Unit toot tests

From the literature, it is observed that financial time series may prove non-stationary, and oil prices and exchange rates can be too. Researchers such as Cheung and Lai (2001), Gil-Alana (2000), Gil-Alana (2002), Henry and Olekans (2002) and Serletis and Gogas (2000) have shown that unit root exists in exchange rate series. Liu et al. (1997), Huber (1996), Narayan and Smyth (2004, 2005), Narayan (2005, 2006), Qian et al. (2008) and Ozdemir (2008) demonstrated similar findings for unit root tests concerning stock prices as an example of financial series. These studies have shown how unit root, used as an efficient tool in exchange rate series data, is stationary.

3.3.2.2 ADF test

Testing for the unit root means that one of the abovementioned conditions must be violated. Suppose there is a series x_t:

$$x_t = a + bx_{t-1} + \epsilon_t \tag{3.1}$$

Here, a is constant, b is the parameter under observation and ϵ_t is white noise. If $|b| = 1$, x_t has a unit root since variance is increasing with time. If $|b| < 1$, x_t is a stationary series.

Dickey and Fuller (1979) used three assumptions to observe if a root is present. First, they used a pure random-walk model with no intercept or trend and added an intercept. Lastly, they introduced both trend and intercept as such:

$$\Delta x_t = bx_{t-1} + \epsilon_t \tag{3.2}$$

$$\Delta x_t = a + bx_{t-1} + \epsilon_t \tag{3.3}$$

$$\Delta x_t = a + \beta t + bx_{t-1} + \epsilon_t \tag{3.4}$$

Error term in each equation is assumed to be uncorrelated, and b is the parameter of interest. OLS can be applied to estimate b with its associated standard error. To detect whether a unit root is present, it is essential to test for $H_o: b = 0$ (unit root) and alternative hypothesis $H_1: b < 0$. Critical values for this test are dependent on the deterministic and sample size. It is essential to select appropriate models to test the unit root's existence.

Excluding intercept or deterministic time trends is not appropriate and would cause bias in estimation for b, meaning that the unit root test would be inaccurate.

However, including intercept or trend term would reduce the unit root test's power. The Dickey and Fuller (DF) test has been criticised for its poor statistical power, and its lack of consideration of values for parameters other than simply 0. Also, if error term is autocorrelated, it does not follow a white noise process and the test will be oversized for rejecting the null. Thus, Dickey and Fuller (1979) proceeded with an augmented version of the DF: the ADF. This was different in that it had lagged dependent variables within regressors to make the error term serially independent. ADF is given as:

$$\Delta x_t = bx_{t-1} + \sum_{i=1}^{k} \tau_i \Delta x_{t-1} + \epsilon_t \qquad (3.5)$$

$$\Delta x_t = a + bx_{t-1} + \sum_{i=1}^{k} \tau_i \Delta x_{t-1} + \epsilon_t \qquad (3.6)$$

$$\Delta x_t = a + \beta t + bx_{t-1} + \sum_{i=1}^{k} \tau_i \Delta x_{t-1} + \epsilon_t \qquad (3.7)$$

Here, a is constant, β is coefficient of time trend, k is lag truncation parameter order of AR process and b is coefficient of lagged dependent variables. This follows a non-standard limiting distribution similar to DF statistic and the same hypotheses ($H_o\colon b = 0$) and alternative hypothesis ($H_1\colon b < 0$). The idea that Yt contains a root cannot be accepted. If the null hypothesis is true for the level series, ADF is applied to the first difference. If the null hypothesis cannot be accepted for the case of the first difference, it is said that the series is a first-order integral, I(1).

It is necessary to first determine how many lagged first-difference terms exist for the dependent variable before undertaking the ADF, since it will capture the autocorrelated variables that were omitted and would give the error term by default. Brooks (2008) suggested that the ADF test is valid only when an i.i.d. process is assumed. When applied, it may allow for certain correlations among error terms.

3.3.2.3 PP test

This test, suggested by Phillips and Perron (1988), is used where the disturbance term may be statistically independent, having constant and uncorrelated variance, based on a DF generalisation. Here, the assumption was relaxed by considering other possible scenarios, such as no requirement for homogeneity and independence. This was done by utilising the non-parametric w.r.t nuisance parameters approach. A z-statistic is used here to account for serial correlation. Like the DF, the PP also tests for whether b is statistically zero. It can be done by including or neglecting intercept and trend:

$$\Delta x_t = bx_{t-1} + \epsilon_t \tag{3.8}$$

Here, the null hypothesis is that H_o = 0 is still the unit root having alternative stationarity $H_1: b < 0$. Since the PP test uses non-parametric with z-statistic, it is not necessary to consider lags that would correct for high-order serial correlation, as is the case for ADF. This test is robust compared with unspecified autocorrelation and heteroskedasticity for the test equation. If the z-statistic is larger than its critical value, the null hypothesis is rejected in favour of the unit root. In contrast with the ADF test, the PP test does not rely on assuming an i.i.d. process. It also allows for error terms to be correlated. In this way, it can operate in the presence of heteroskedasticity. It may be given as:

$$\Delta Y_t = \beta_1 + \beta_2 t + \delta Y_{t-1} + \vartheta \Delta Y_{t-1} + \epsilon_t \tag{3.9}$$

For such tests, the null hypothesis is that the series must be non-stationary; consequently, rejection would state that the series is stationary. Critical values for these tests may be derived from MacKinnon (1996).

3.3.2.4 KPSS test

The test was proposed by Kwiatkowski et al. (1992) for the null hypothesis; it is not the same as common unit root tests. The null hypothesis for KPSS is that the series is stationary with respect to a deterministic trend. As such, the series is expressed as the sum of deterministic trend, random walk and stationary error. It incorporates the LM statistic to assess if the hypothesis for random walk had zero variance. Regression of the KPSS model including time tend is written as:

$$\Delta x_t = a + \beta t + m \sum_{i=1}^{k} + \epsilon_t \tag{3.10}$$

$$S_t = \sum_{i=1}^{k} \widehat{\epsilon_t} \tag{3.11}$$

Here, ϵ_t is stationary, independent and identically distributed and S_t is sum of residuals. This equation makes it clear that for m = 0, the process is trend stationary and for $m \neq 0$, it is integrated. The null hypothesis here, unlike the previous tests, assumes that stationarity of the series to test is m = 0. KPSS test statistic is presented as:

$$KPSS_T = \frac{\sum_{i=1}^{m} S_i^2}{m^2 \widehat{w_T^2}} \tag{3.12}$$

$$\widehat{w_T^2} = \widehat{\sigma_\epsilon^2} + 2\sum_{i=0}^{m}\left(1 - \frac{\tau}{t-1}\right)\widehat{\vartheta_t} \tag{3.13}$$

$$\widehat{\vartheta_t} = \frac{1}{m}\sum_{i=1}^{m}\widehat{\epsilon_t}\widehat{\epsilon_{t-\tau}} \tag{3.14}$$

Here, $\widehat{\sigma_\epsilon^2}$ estimates variance of error term in the trend model regression ϵ_t and $\widehat{\vartheta_t}$ estimates the covariance.

3.3.3 Time series forecasting using univariate GARCH models

After applying the unit root tests, several models have been suggested recently for prediction of time series. Predictions of time series are conducted to uncover its future movements, as suggested by past data, given that the past data can provide sufficient relevant information. The assumption here is that past behaviour should dictate future behaviour of the series. Price forecasting, return and volatility are valuable for making successful decisions (Gourieroux 1997). It may not be deemed feasible to uncover why and how the future time series behaves in a certain way because volatilities of several time series (e.g., financial time series) largely depend on the economy, policy, war and global events. If the forecast aims to predict a future numerical value without delving into the reasons for it, it is more appropriate to apply the quantitative forecast, as suggested by Makridakis et al. (1998).

3.3.3.1 GARCH (p, q) model

GARCH models are most frequently utilised to model various financial markets, although the interrelationship between said markets may also be modelled differently depending on the user's preference. Initially proposed by Bollerslev (1986), the GARCH model stood to overcome obstacles present in the modified ARCH model, which was developed by Engle (1982). The GARCH model is particularly useful in answering questions raised over the possibility of market volatility resulting from local events or other markets.

Having considered the usefulness of the GARCH model, it is essential to note that it exists in two key forms: univariate and multivariate GARCH. Univariate GARCH will be explained in this section, and multivariate GARCH will be applied in Chapter 4.

The GARCH, proposed by Bollerslev (1986), is a popular model used to describe the dynamics of conditional volatility; it follows the work of Engle (1982). A general description of the volatility present in exchange rates can be given by the GARCH (p, q) model as:

$$x_t = c_0 + \sum_l^m c_m x_{t-m} + \epsilon_t \tag{3.15}$$

$$\epsilon_t | I_{t-1} \sim N(0, \sigma_t^2) \tag{3.16}$$

$$\sigma_t^2 = b_0 + \sum_l^p \alpha_p \epsilon_{t-p}^2 + \sum_l^q \beta_q \epsilon_{t-q}^2 \tag{3.17}$$

where $\sigma > 0, \beta_i \geq 0, \alpha_i \geq 0$; $\sum_l^p \alpha_p + \sum_l^q \beta_p < 1$ and x_t shows differences between the logarithmic values of exchange rates at a given time, ϵ_t is innovation that can change exchange rates for the information set I_{t-1} and time t-1. It is assumed that market efficiency exists, so changes in the daily exchange rates are distributed with 0 mean. Then, the error ϵ_t has a normal distribution with a mean of 0 and variant conditional variance σ_t^2. The variables p and q represent lags, where p is autoregressive and q is the moving average.

For the case of $\beta_i = 0$, this model becomes the ARCH (q) model, as proposed by Engle (1982). The absolute positive condition remains valid, such that variance must also be positive and the sum condition on β_i and α_i is required to fulfil wide sense stationarity.

3.3.3.2 GJR-GARCH model

This model was suggested by Glosten, Jagannathan and Runkle (1993) to capture the asymmetry effect. To account for leverage effects of positive and negative information on conditional variance, this model added a squared residual term with a dummy variable. GJR (p, q) may be given as:

$$\sigma_t^2 = c + \sum_{i=1}^q (a_i + \gamma_i I_{t-i}) u_{t-i}^2 + \sum_{j=1}^p b_j \sigma_{t-j}^2 \tag{3.18}$$

Here, the dummy variable is I_{t-i} and it takes the value of 1 when the last residual is negative and 0 elsewhere. In times of bad news, the negative information may have the potential ARCH effect of $(a_i + \gamma_i)u_{t-i}^2$. For positive information, the effect is $a_i u_{t-i}^2$. To obtain positive values for the conditional variance, the terms a_i, b_j, γ_i and $a_i + \gamma_i$ must also be positive, as suggested by Glosten et al. (1993). Bollerslev (2008) found that the asymmetry had no leverage effect.

The GJR model is very similar to the threshold GARCH (TGARCH) model suggested by Zakoian (1994). For both models, the squared residual term was considered for asymmetric news impact. By rearranging both models' equations, it can be observed that they are equivalent to each other; this enabled them to be termed the GJR-GARCH model (Zakoian 1994). Based on current available literature, a wholesome standardised formula for GJR-GARCH (1, 1).

3.3.3.3 Estimation of Half-life

When volatility shocks exist, measuring the persistence using the half-life method is important to find the mean period necessary for the volatility to return to its long-term mean value. Volatility may be predicted using volatility shock on a moving-average basis (Banerjee & Sarkar 2006). A form of covariance stationary time series with an infinite moving order, as suggested as the mean-reversion rate, with $\alpha_1 + \beta_1$ having a value of–1. If the term $\alpha_1 + \beta_1$ is close to 1, the half-life to volatility shocks will be greater. If $\alpha_1 + \beta_1 \geq 1$, the GARCH model becomes non-stationary, and volatility proceeds towards infinity (Banerjee & Sarkar 2006). The scale of the numerical value for $\alpha_1 + \beta_1$ dictates the pace of mean reversion. It can then be stated that for the half-life of volatility shocks:

$$I_{half} = \frac{\ln(\frac{1}{2})}{\ln(\alpha_1 + \beta_1)} \quad (3.19)$$

The estimation of average mean time renders it necessary to be reduced by half.

The present chapter demonstrates the pace of mean reversion for major, commodity and emerging currencies through the half-life method. This method is particularly useful for policymakers, investors and financial experts, who can use it to determine the pace of price reversion back to its mean value. Such a method aids them in selecting strategies and planning their entry and exit to the stock market.

3.4 Empirical Analysis

3.4.1 Data analysis and descriptive statistics

The availability of sufficient data, including daily exchange rates and oil price obtained from the DataStream International database, made it possible to conduct the study using data from July 2012–December 2018 divided into two periods: overall period and oil decline period. The oil decline period is from 6 April 2014–29 February 2016. As shown in Tables:3.1–3.4 the prices of WTI oil and 13 currency pairs were selected for this study. The major currency pairs include USDEUR, USDGPB, USDCHF and USDJPY. Meanwhile the commodity currency group incorporated USDAUD, USDNZD and USDCAD. Finally, the emerging countries currency pairs include USDBRL, USDKWR, USDMXN, USDPLN, USDSEK and USDZAR. All data were analysed in local currencies to be used in the hedge estimation in Chapter 4. Returns for each time series were computed as:

$$S_{tm} = \ln(Q_{tm}) - \ln(Q_{tm-1}) \tag{3.20}$$

Here, S_{im} represents the return, time series is denoted as t, day is denoted as m, Q_{tm} denotes price level for the present day and Q_{tm-1} represents price level for the previous day. The natural logarithm of price levels is given by ln.

Oil prices sometimes affect currency fluctuations and economic decisions made by countries. This section interprets oil prices and currency movements between 2012 and 2018. Figure 3.1 indicates significant fluctuations in oil prices. In 2013, the cost of a barrel was about $110 and this represented the highest price. A slump in prices was experienced in the middle of 2014 and again in 2015, with barrel prices of about $30. These notable price fluctuations were caused by increased oil supply in the US and a decline in global demand (Hou et al. 2015). When operating in a perfectly competitive market, product prices are influenced by demand and supply. For instance, when demand is high and supply is low, prices increase. The reverse is also true. Therefore, to revamp the oil prices, the OPEC intervened by reducing oil production to ensure demand and supply were equal (Parnes 2019). As a result, oil prices began to increase again after 2016, as shown in Figure 3.2.

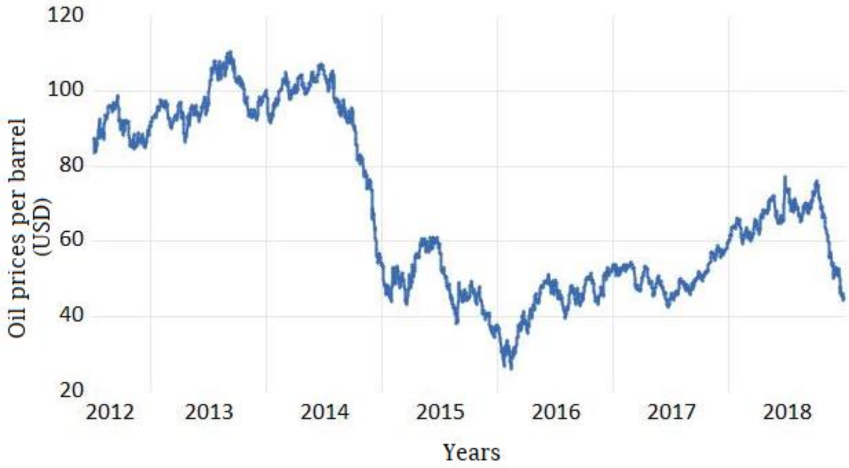


Figure 3.1: Oil prices between 2012 and 2018

Source: DataStream International database

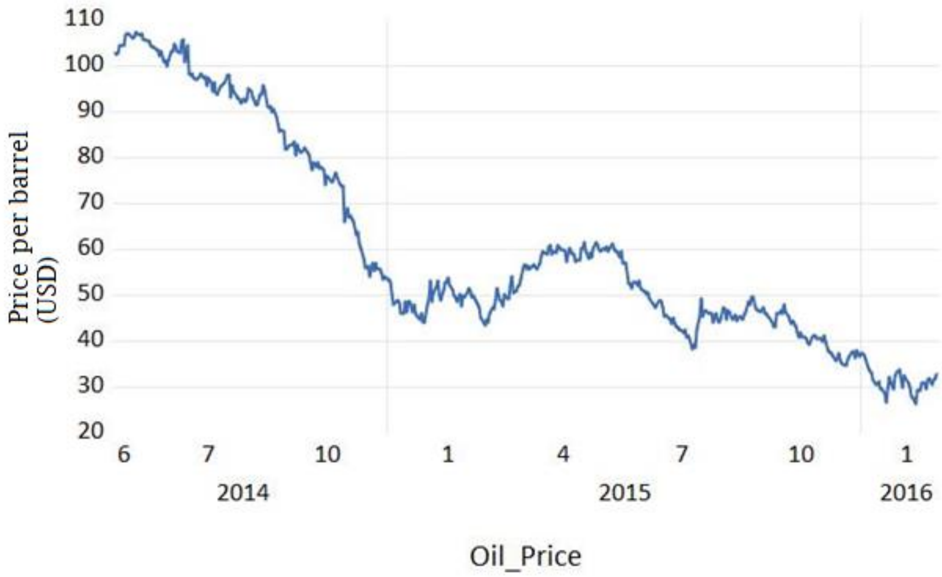


Figure 3.2: Oil price decline between 2014 and 2016

Source: DataStream International database

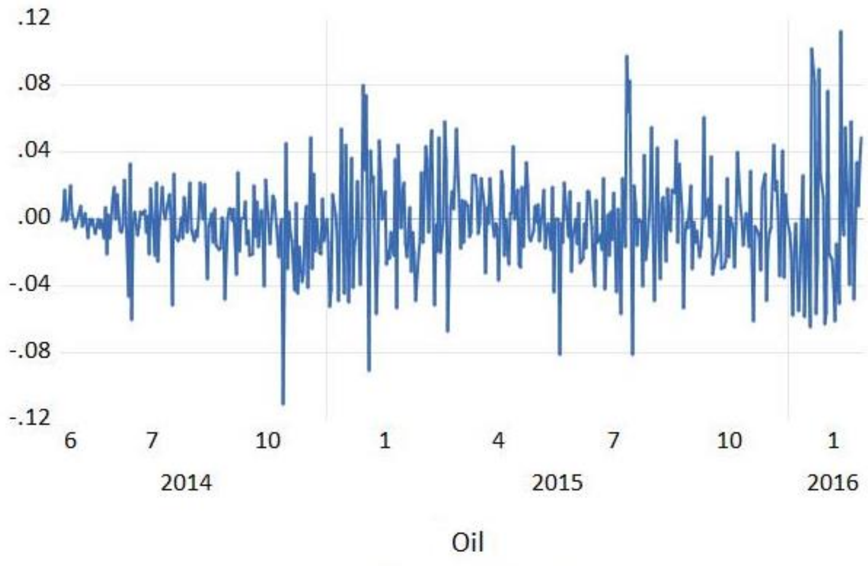


Figure 3.3: Volatility of oil prices

Source: DataStream International database

Figure 3.3 illustrates the volatility of oil prices between 2014 and 2016. Several factors can be cited as having caused the 2014 decline in oil prices. Increased supply and decreased demand were identified as causing the reduction in oil prices between 2014 and 2016 (Rogoff 2016). China, one of the world's most populated countries and now a leading economy, had a significant influence on the global drop of oil prices because it had low demand for oil during this period. Russia, India and Brazil also witnessed rapid expansion in the first decade of the twenty-first century. This came to a halt because of low demand for oil, similar to China, further pushing oil prices down in 2014. The high oil prices experienced in 2012 prompted leading economies such as the US and Canada to extract their own oil instead of importing from oil-rich nations. The decrease in oil importation by major economies in favour of local production exerted pressure on oil-rich countries, further pushing global oil prices down in 2014 (Baffes et al. 2015).

Production decisions implemented by large oil-producing countries in the Middle East, such as Saudi Arabia, also contributed to falling oil prices in 2014. During this time, Saudi Arabia was deciding whether to lower its oil prices to reflect market prices or minimise oil production to manage price fluctuations. After consulting with relevant agencies, Saudi Arabia chose to maintain its oil production and reduce prices, since this option offered long-term benefits as opposed to giving up market share (Vătavu et al. 2018). Moreover, oil production is cheaper in Saudi Arabia than it is in other countries like the

US and Canada. This enabled Saudi Arabia to embrace low oil prices in the hope that the US and Canada would be forced to abandon local production because of unsustainable costs.

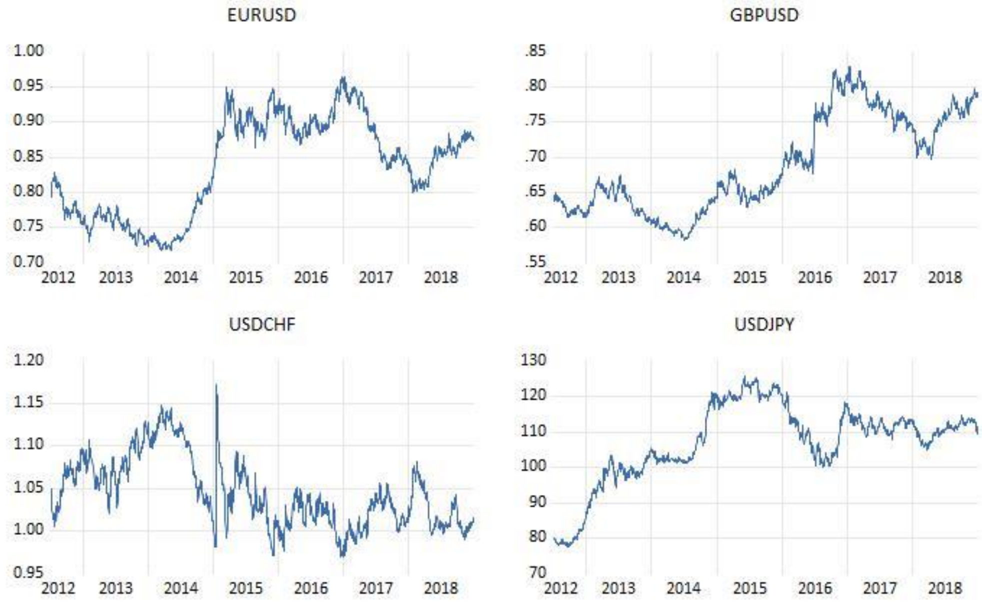


Figure 3.4: Major currencies against the US dollar

Source: DataStream International database

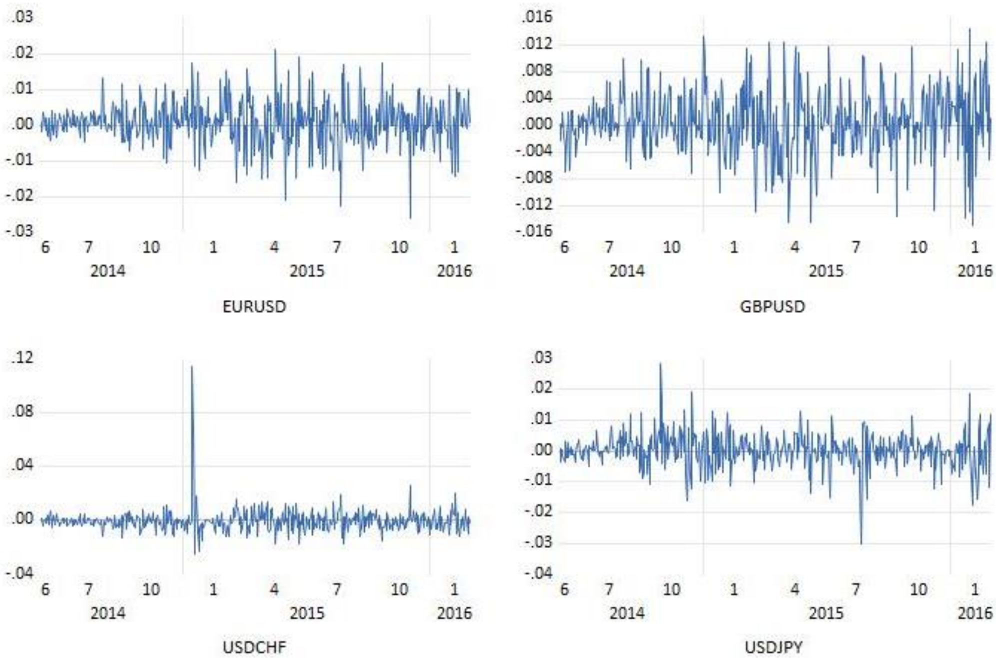


Figure 3.5: Major currency pairs return

Source: DataStream International database

The world’s oil is traded in US dollars. Therefore, a rise or fall in the value of the US dollar affects oil prices. For example, the value of the US dollar, as shown in Figures 3.4 and 3.5 from 2012 to 2014 respectively, increased the value of oil (see Figure 3.1) in the same period (McLeod & Haughton 2018). From 2014 to 2016, the value of the US dollar causing the price of oil to drop significantly. In 2015, the Switzerland Central Bank decided to abandon the cap on the Swiss franc, which caused a sharp spike in the market (see Figure 3.5). Further, following the Brexit referendum in June 2016, the GPB strengthened against the dollar, as shown in Figure 3.5. This led to a slight drop in the price of oil (Lorusso & Pieroni 2018).

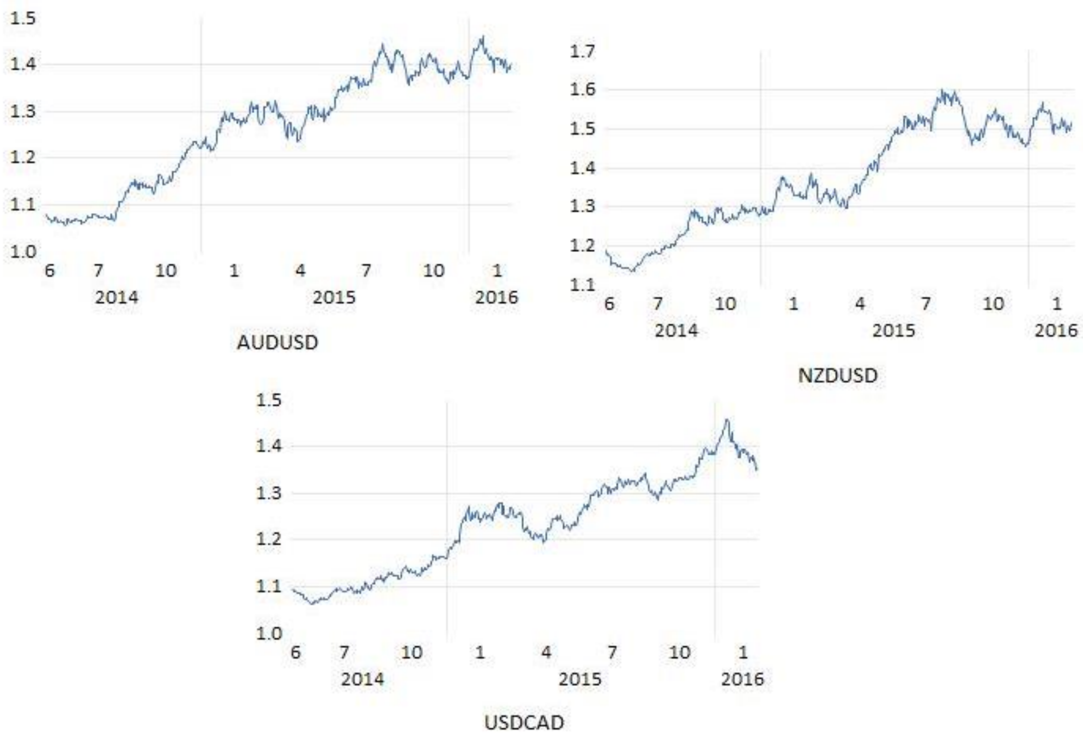


Figure 3.6: Commodity currencies

Source: DataStream International database

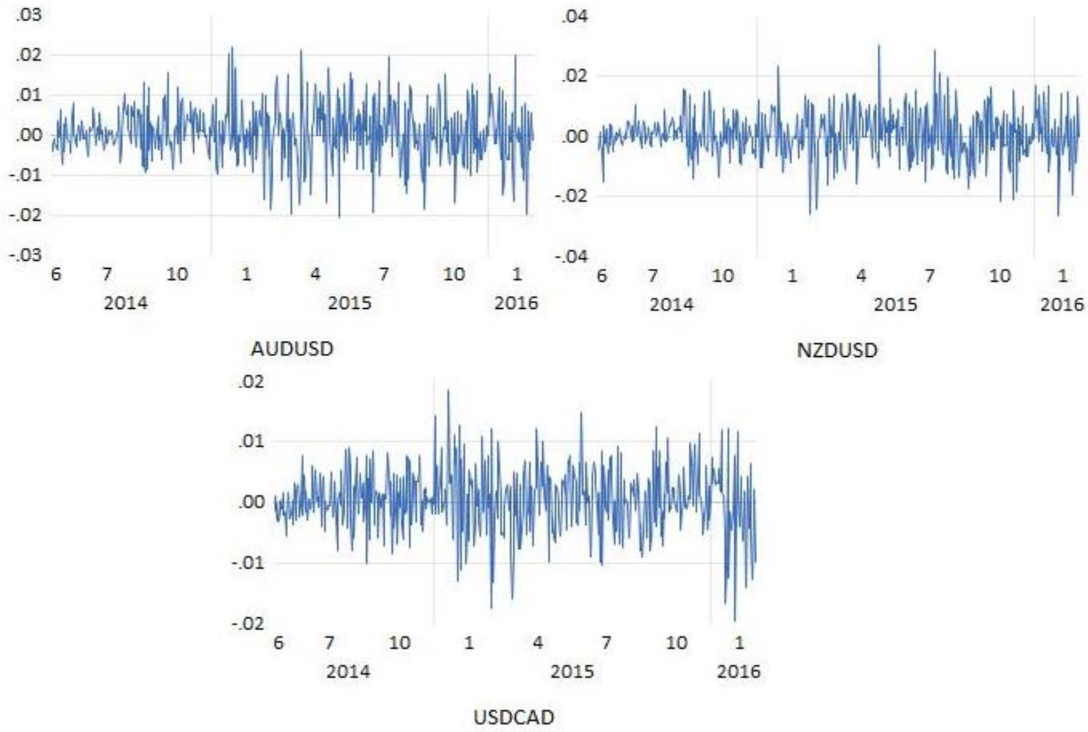


Figure 3.7: Commodity currency pairs return

Source: DataStream International database.

As the value of commodity currencies such as the Australian dollar (AUD), New Zealand dollar (NZD), and Canadian dollar (CAD) depreciated, the price of oil dropped and caused the US dollar to strengthen against these currencies. This trend caused oil prices to reduce further (Alam, Shahzad & Ferrer 2019). Figure 3.7 shows that these currencies' pair returns were quite volatile because of changes in the value of the US dollar (McLeod & Haughton 2018).

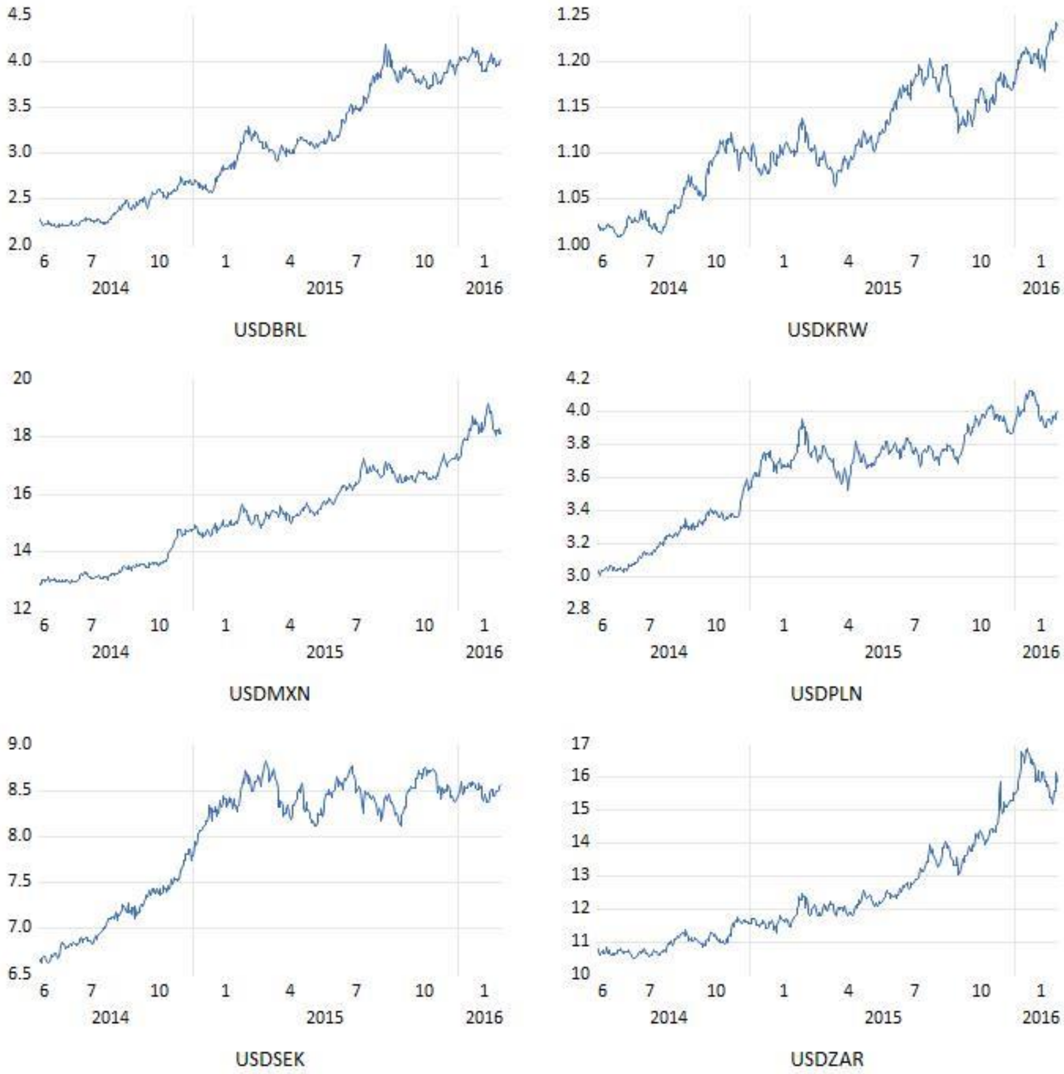


Figure 3.8: Emerging market pairs

Source: DataStream International database.

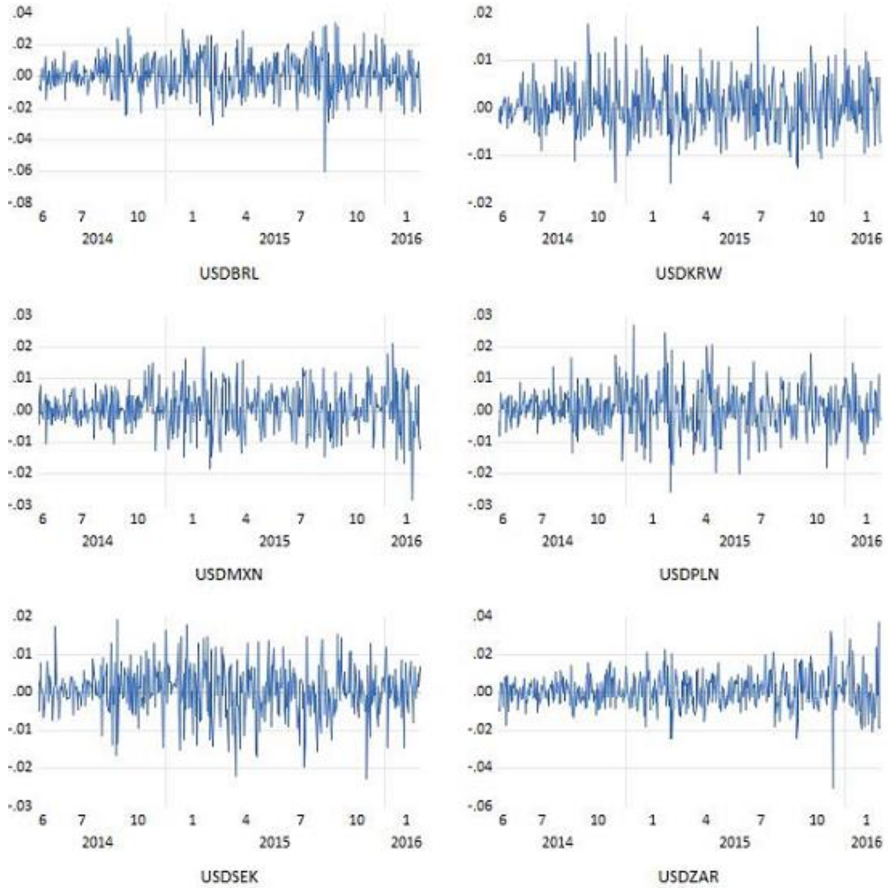


Figure 3.9: Emerging currency pair returns

Source: DataStream International database.

According to Li, Zhang and Yuan (2019), when the US dollar strengthens against the currencies of emerging economies such as Brazil, South Korea, Mexico, Poland, South Africa and Sweden, the value of oil drops. The currencies of emerging economies experienced an upwards trend in 2014–2016, but oil prices had a downwards trend during the same period. This happens when the value of the US dollar rises because lesser units of these currencies will be converted into dollars to purchase a barrel of oil (Kilian 2014).

Descriptive statistics for ‘overall’ and ‘oil decline’ periods, such as the mean, standard deviation, maximum, minimum and number of observations (the observation of overall period is 1,694 for each series, and 454 observations for each series of oil price decline period) were calculated for all series mentioned above. Additionally, parameters of skewness and kurtosis were computed to test for normal distribution, alongside the Jarque–Bera (JB) statistic. Each statistic helped investigate the shape of distribution for the data.

Results for this analysis were based on a long period and must not be mistakenly related to a specific economic climate. As depicted in Table:3.2, in the overall period, USDBRL and USDCHF showed the highest and lowest return at 0.000396 and –0.000019, respectively. Overall, the mean did not deviate drastically between the time series. While during the oil decline period (see Table:3.4), for the mean statistic, the best return was achieved by the USDBRL at a value of 0.001248, while USDCHF performed the worst with a mean of –0.000229.

Regarding the standard deviation statistic, volatility was observed in the oil and exchange rate market, with all standard deviations below 2.5 during the overall period, except for oil and USDJPY, the safest currency pair being USDCHF at 0.04. Oil and USDJPY were the most volatile markets at 22.977 and 11.03 standard deviation, respectively. Analysis of these values shows that they are in line with preset expectations. Chapter 2 discussed the risky economic and political situations caused by oil high volatility, which are reflected in exchange rate statistics. The standard deviation during the oil price decline period showed that oil and USDJPY also have the highest risk with 22.898 and 7.421, respectively. The lowest risk observed on the USDGPB currency pair had a value of 0.03.

The volatility of these time series is further exemplified through maximum and minimum statistics, with USDCHF showing the broadest range of maximum value at 0.114, and USDCAD showing a narrower range of maximum value at 0.019. USDPLN and USDNZD fell between these two, at 0.045 and 0.040, respectively. Meanwhile the lowest minimum of oil was –0.111, and USDCAD showed a minimum of –0.019. The USDCHF and oil indicated they were particularly volatile during the oil decline period, with the maximum value over 0.114 and the latter decreasing below 0.112. The narrower range of maximum was by USDGPB with a value of 0.014. USDPLN and USDAUD were in the middle value of maximum at 0.026 and 0.021, respectively. During this period, the USDGPB showed the lowest minimum value of –0.015 while USDGPB showed the largest minimum value of –0.111.

Correlations among oil and major commodities, and emerging countries' currencies under investigation in this thesis were from the overall period 1 July 2012–30 December 2018 and the oil price decline period 3 June 2014–29 February 2016. A visual inspection of these tables reveals that correlations among the variables were very high. In general, all currencies showed strong correlations between oil returns and currency exchange markets. The major currencies in the overall period showed a strong negative correlation in USDEUR at the value of –0.917, while USDGBP and USDJPY showed a negatively correlated relationship with oil at –0.675 and –0.631, respectively, However, the USDCHF was positively correlated with oil at a value of 0.710. During the oil price decline period, a similar pattern was observed, but with higher correlation, as EURUSD represented the higher value at –0.913. USDGBP and USDJPY correlations were stronger during this period, with values of –0.915 and –0.840, respectively. However, the USDCHF correlation changed, with only minor differences in the strength of the associations detected during this period with a value of 0.719.

A second striking feature is the correlation between oil and commodity currencies returns. This is especially the case for UADAUD, USDNZD and USDCAD, which all had correlations of more than 0.80 with oil in the two periods. Only the USDAUD showed a negative correlation with oil during the overall period, with a value of –0.838, while USDNZD and USDCAD showed positive correlations, with values of 0.849 and 0.884, respectively. In addition, the changes in correlation during the oil price decline period showed a negative sign for UASAUD (–0.943) and UADNZD (–0.858), while the value of –0.932 applied to UASCAD. These findings suggest that all commodity currencies have relatively commodity economies that are influenced by changes in oil activity.

A third finding is that the correlations among oil and different emerging countries varied. During the overall period, all emerging currencies positively correlated to oil—the highest correlation was with the USDPLN at a value of 0.912, while the lowest correlation was with USDKRW at a value of 0.669. The rest of the emerging countries' currencies had high positive correlation values: 0.848 for USDBRL, 0.822 for USDMXN, 0.883 for USDSEK and 0.812 for USDZAR.

Correlations between the emerging countries' currencies and oil during the oil price decline period were also high (but negatively so). USDPLN had the highest negative correlation with oil at a value of –0.961 while the lowest value was USDZAR at –0.801. USDBRL, USDKRW, USDMXN and USDSEK showed values of –0.870, –0.898, –0.911 and –0.934, respectively. Analysis for data distribution showed that during the overall period, most time series revealed negative skewness and excess kurtosis. However, oil, USDGPB, USDCHF, USDKRW and USDMXN were positively skewed with low values below the coefficient of 0.55; this was not significant at the 5% level. The JB statistics indicate the normality hypothesis was rejected for oil and all currency pairs in both levels and first difference at 1%.

All series were found to have fat tails (leptokurtic), which necessitated examination of the series for the presence of the ARCH effect because this was done when employing the ARCH test. Therefore, the Q statistic of Ljung–Box (1978) and ARCH-LM statistics indicated the null hypothesis for no autocorrelation and homoskedasticity was rejected at a 1% significance level. As a result, we find evidence for the ARCH effect in all series, while the result of ARCH-LM statistic for both periods indicate that the ARCH effect was observed. This suggests that conditional heteroskedasticity has been largely captured and the GARCH model can be used in these time series. As result, it was decided the GARCH model must be used to estimate the results because the aforementioned time series exhibited characteristics of the ARCH effect. This will be discussed in detail in the following sections.

3.4.2 Unit root tests

It is important to check the stationarity of the financial time series by using unit root tests before the estimation; this will ensure there are no spurious regression problems (Granger & Newbold 1974). Before estimating GARCH models, each time series will be tested for the unit root to indicate at which level the data are non-stationary. Thus, we used multiple unit root tests to ensure that all series were integrated in the same order. Three unit root tests were used to increase confidence in the robustness of results (Al-Khazali et al. 2006). Further, to examine the stationarity of the oil and currency pairs prices, ADF, PP and KPSS tests were used to detect the presence of the unit root.[5] The results of unit root tests are presented in Tables 3.5 and 3.6 and indicate that all series are not stationary at level[6] despite the fact they are stationary in first log difference—that is, all series are integrated with order 1 (I[1]).

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[5] The null hypothesis for ADF and PP is there is a unit root, while the null hypothesis for KPSS is there is no unit root.

[6] The null hypothesis of no-stationarity for ADF and PP unit root tests is rejected if the ADF and PP tests statistics are less than the critical values: –2.56, –1.94 and –1.61 at 1%; 5% and 10%, respectively. The null hypothesis of stationarity for the KPSS unit root test is rejected if the KPSS test statistic is greater than the critical values that equal 0.739; 0.463 and 0.347 at 1%; 5% and 10%, respectively.

Table 3.1: Descriptive statistics in level (overall period)

	Return	Mean	Std.Dev	Skewness	Kurtosis	Jarque-Bera	LBQ(4)	ARCH-LM(4)	correlation oil/currencies
	oil	68.289	22.977	0.292	-1.405	163.486	6759.207	593739.595	-
Major currencies	USDEUR	0.836	0.069	-0.163	-1.317	129.999	6733.918	376610.011	-0.917
	USDGBD	0.689	0.068	0.32	-1.286	145.835	6744.167	469478.896	-0.675
	USDCHF	1.045	0.04	0.549	-0.525	104.602	6355.006	68496.963	0.710
	USDJPY	107.060	11.03	-0.907	0.625	260.194	6747.384	469407.6	-0.631
Commodities Currencies	USDAUD	1.222	0.148	-0.534	-1.128	170.412 6	760.313 5	75768.477	-0.838
	USDNZD	1.348	0.119	-0.061	-1.251	111.577 6	709.714 2	68258.36	0.849
	USDCAD	1.204	0.129	-0.411	-1.341	174.600 6	767.805 7	25785.532	0.884
Emerging Currencies	USDBRL	2.953	0.653	-0.041	-1.311	121.833	6767.194	518456.741	0.848
	USDKRW	1.111	0.045	0.046	-0.21	3.712	6544.012	100042.984	0.669
	USDMXN	16.200	2.813	0.011	-1.55	169.774	6766.57	620675.126	0.822
	USDPLN	3.543	0.337	-0.046	-1.245	109.999	6720.403	321671.799	0.912
	USDSEK	7.839	0.967	-0.338	-1.5	191.214	6762.595	609741.906	0.883
	USDZAR	12.117	2.07	-0.161	-0.912	66.049	6736.826	345881.86	0.812

Note: * Indicate rejection of null hypothesis at 1% significance level. Jarque-Bera is the statistic for normality test. LBQ is Ljung-Box test for serial correlation. LM referred to Lagrange Multiplier statistics for ARCH test.

Table 3.2: Descriptive statistics in first difference (overall period)

	Return Index	Mean	Std.Dev	Skewness	Kurtosis	Jarque-Bera	LBQ(4)	LBQ_S(4)	ARCH-LM(4)
	Roil	-0.00036	0.021	0.067	3.255	749.644	10.864	108.117	111.58
Major currencies	RUSDEUR	0.000057	0.005	-0.065	2.025	290.894	1.312	92.426	17.388
	RUSDGBD	0.000123	0.006	1.946	30.582	67122.35	9.532	143.82	52.878
	RUSDCHF	-1.9E-05	0.006	4.753	83.961	504245.6	20.853	120.260	148.829
	RUSDJPY	0.000189	0.006	-0.278	4.225	1282.395	1.296	709.237	23.177
Commodities Currencies	RUSDAUD	0.000221	0.006	0.164	1.941	273.808	2.148	103.847	3.425
	RUSDNZD	0.000106	0.007	0.137	2.305	380.43	4.312	73.214	0.623
	RUSDCAD	0.000173	0.005	-0.094	1.082	85.235	1.718	150.423	43.93
Emerging Currencies	RUSDBRL	0.000396	0.01	0.079	3.834	1040.119	15.525	106.921	44.561
	RUSDKRW	-1.5E-05	0.005	0.167	1.61	190.961	3.582	95.939	17.431
	RUSDMXN	0.000229	0.007	0.846	8.926	5828.897	16.108	91.631	59.298
	RUSDPLN	0.000065	0.007	0.179	2.028	299.531	3.552	68.491	14.718
	RUSDSEK	0.000145	0.006	0.069	1.506	161.521	7.235	14.560	9.06
	RUSDZAR	0.000334	0.01	0.185	1.377	143.6	2.315	119.300	36.757

Note: * Indicate rejection of null hypothesis at 1% significance level. Jarque-Bera is the statistic for normality test. LBQ is Ljung-Box test for serial correlation. LBQ_S is Ljung-Box test for serial correlation of squares residual. LM referred to Lagrange Multiplier statistics for ARCH test.

Table 3.3: Descriptive statistics in level (oil decline period)

	Return	Mean	Std.Dev	Skewness	Kurtosis	Jarque-Bera	LBQ(4)	ARCH-LM(4)	correlation oil/currencies
	oil	60.273	22.898	0.745	-0.725	52.085*	826.238*	21974.107*	-
Major currencies	USDEUR	0.859	0.067	-0.662	-1.042	53.821*	1809.571*	55364.901*	-0.913
	USDGBD	0.644	0.030	-0.220	-0.164	4.187*	1786.752*	37472.757*	-0.915
	USDCHF	1.047	0.040	0.385	-0.456	15.162*	1572.650*	8197.227*	0.719
	USDJPY	116.348	7.241	-1.005	-0.419	79.991*	1804.452*	52409.094*	-0.840
Commodities Currencies	USDAUD	1.268	0.122	-0.379	-1.180	37.305*	1819.403*	72233.324*	-0.943
	USDNZD	1.372	0.134	-0.071	-1.269	30.918*	1816.464*	58696.002*	-0.858
	USDCAD	1.233	0.104	0.003	-1.110	23.359*	1822.982*	98519.544*	-0.932
Emerging Currencies	USDBRL	3.080	0.626	0.171	-1.358	37.193*	1826.883*	91555.494*	-0.870
	USDKRW	1.112	0.059	0.018	-0.921	16.115*	1798.611*	43603.073*	-0.898
	USDMXN	15.280	1.627	0.207	-0.873	17.709*	1822.492*	96823.214*	-0.911
	USDPLN	3.613	0.302	-0.525	-0.857	34.815*	1808.778*	54344.484*	-0.961
	USDSEK	8.000	0.669	-0.779	-0.951	63.157*	1816.054*	62733.639*	-0.934
	USDZAR	12.470	1.649	0.978	0.015	72.576*	1816.437*	72328.172*	-0.801

Note: * Indicate rejection of null hypothesis at 1% significance level. Jarque-Bera is the statistic for normality test. LBQ is Ljung-Box test for serial correlation. LM referred to Lagrange Multiplier statistics for ARCH test.

Table 3.4: Descriptive statistics in first difference (oil decline period)

	Return Index	Mean	Std.Dev	Skewness	Kurtosis	Jarque-Bera	LBQ(4)	LBQ_S(4)	ARCH-LM(4)
	Roil	-2.507e-3	0.029	0.323	1.844	72.336*	8.645	129.775*	29.571*
Major currencies	RUSDEUR	4.95e-4	0.006	-0.192	1.474	43.956*	6.919	30.220*	5.109
	RUSDGBD	4.05e-4	0.005	-0.133	0.838	14.666*	14.265*	38.786*	1.523
	RUSDCHF	-2.29e-4	0.009	5.901	72.144	101313.17*	15.755*	38.062*	39.471*
	RUSDJPY	2.11e-4	0.005	-0.171	4.006	306.511*	3.462	30.381*	9.349
Commodities Currencies	RUSDAUD	5.69e-4	0.007	-0.088	0.782	12.19*	6.364	23.035*	1.231
	RUSDNZD	5.52e-4	0.008	-0.004	1.153	25.218*	14.967*	15.002*	0.005
	RUSDCAD	4.77e-4	0.005	-0.205	0.886	18.087*	2.586	59.279*	17.127*
Emerging Currencies	RUSDBRL	1.248e-3	0.012	-0.186	1.381	38.762*	11.838*	52.710*	7.248
	RUSDKRW	4.16e-4	0.005	0.225	0.231	4.868	5.129	12.640*	1.666
	RUSDMXN	7.46e-4	0.007	-0.176	0.81	14.774*	1.693	63.081*	7.193
	RUSDPLN	5.98e-4	0.007	-0.042	1.075	22.027*	7.94	45.869*	2.952
	RUSDSEK	5.41e-4	0.007	-0.28	0.848	19.551*	4.793	9.999*	3.062
	RUSDZAR	8.7e-4	0.009	-0.034	2.718	140.174*	5.48	92.427*	31.632*

Note: * Indicate rejection of null hypothesis at 1% significance level. Jarque-Bera is the statistic for normality test. LBQ is Ljung-Box test for serial correlation. LBQ_S is Ljung-Box test for serial correlation of squares residual. LM referred to Lagrange Multiplier statistics for ARCH test.

The values for consolidated statistics are given in percentages, with the number of rolling subsamples in which the overall and oil price decline periods rejected the non-stationarity hypothesis for the 5% significance level. This rolling window technique was applied in harmony with the three unit root tests in to detect any anomalies. For both periods, the non-stationarity hypothesis was accepted for all variables in both periods, while the hypothesis was rejected at the first order.

Table 3.5: Unit root tests results (overall period)

		Level			First Difference		
	series	**ADF**	**PP**	**KPSS**	**ADF**	**PP**	**KPSS**
	Oil	-0.915	-0.905	49.066	-30.839	-44.165	0.111
Major currencies	RUSDEUR	0.343	-1.668	43.952	-29.157	-41.742	0.109
	RUSDGBD	0.763	-1.261	64.992	-30.164	-39.377	0.081
	RUSDCHF	-0.259	-1.171	38.973	-29.009	-37.118	0.019
	RUSDJPY	0.892	-1.846	37.23	-28.65	-40.984	0.436
Commodities Currencies	RUSDAUD	1.342	-1.259	64.395	-29.034	-42.277	0.095
	RUSDNZD	0.576	-1.413	54.258	-29.743	-43.329	0.054
	RUSDCAD	1.365	-1.081	67.806	-29.057	-41.809	0.098
Emerging Currencies	USDBRL	1.326	-1.004	63.655	-31.625	-45.089	0.1
	USDKRW	-0.188	-0.642	14.697	-30.367	-42.696	0.05
	USDMXN	1.032	-0.827	77.668	-29.912	-42.345	0.08
	USDPLN	0.3	-1.422	47.217	-28.637	-42.492	0.087
	USDSEK	0.898	-0.95	67.842	-30.217	-43.393	0.097
	USDZAR	0.85	-1.767	59.816	-29.263	-40.811	0.124

Note: The null hypothesis for ADF and PP is there unit root while the null hypothesis for KPSS is there is no unit root. The null hypothesis of no stationarity for ADF and PP unit root tests is rejected if the ADF and PP tests statistics are less than the critical values which equal to -2.56; -1.94 and -1.61 at 1%; 5% and 10%, respectively. The null hypothesis of stationarity for KPSS unit root test is rejected if the KPSS test statistics is greater than the critical values that equal to 0.739; 0.463 and 0.347 at 1%; 5% and 10%, respectively.

Table 3.6: Unit root test results (oil price decline period)

	series	Level			First Difference		
		ADF	PP	KPSS	ADF	PP	KPSS
	Oil	-1.444	-1.41	18.521	-16.632	-24.197	0.063
Major currencies	RUSDEUR	1.473	-1.633	18.131	-14.227	-22.303	0.188
	RUSDGBD	1.739	-0.364	14.797	-13.387	-20.831	0.112
	RUSDCHF	-0.596	-2.822	10.835	-14.797	-17.94	0.022
	RUSDJPY	0.58	-1.873	14.313	-15.031	-20.174	0.586
Commodities Currencies	RUSDAUD	1.73	-1.145	21.508	-15.215	-23.709	0.098
	RUSDNZD	1.52	-1.084	20.963	-16.191	-24.401	0.082
	RUSDCAD	1.826	-0.873	21.344	-14.754	-22.595	0.08
Emerging Currencies	USDBRL	2.211	-0.386	22.252	-16.511	-23.697	0.054
	USDKRW	1.785	-0.47	19.718	-14.942	-22.792	0.049
	USDMXN	2.299	-0.327	21.755	-14.736	-21.971	0.028
	USDPLN	1.717	-1.416	19.751	-14.086	-23.07	0.097
	USDSEK	1.63	-1.771	18.037	-16.379	-23.572	0.264
	USDZAR	1.98	0.191	19.862	-14.283	-22.056	0.119

Note: The null hypothesis for ADF and PP is there unit root while the null hypothesis for KPSS is there is no unit root. The null hypothesis of no stationarity for ADF and PP unit root tests is rejected if the ADF and PP tests statistics are less than the critical values which equal to -2.56; -1.94 and -1.61 at 1%; 5% and 10%, respectively. The null hypothesis of stationarity for KPSS unit root test is rejected if the KPSS test statistics is greater than the critical values that equal to 0.739; 0.463 and 0.347 at 1%; 5% and 10%, respectively.

3.4.3 Univariate GARCH tests

In this part of the empirical analysis, the study presents the interpretation of univariate GARCH approaches. Here, the objective is to understand dynamic behaviour by applying these approaches for the overall and oil price decline periods to select the best currency pair based on the mean-variance approach.

3.4.3.1 Overall period

3.4.3.1.1 Univariate GARCH (*p*, *q*)

Table 3.7 summarises the oil and currencies' volatility forecasts for the overall period based on the univariate GARCH method. All coefficients are statistically significant except the *a* for USDBRL, USDMXN and USDPLN in the overall period. Based on univariate GARCH estimation, oil returns were affected by their own shocks and volatility at the 1% significance level. GARCH results show a variety of responses to the major currency pairs' shocks and volatility. USDEUR and USDJPY returns were affected by their own shocks and volatilities at the 1% significance level, while the USDGBP was affected by its own shock at the 10% significance level and for 1% of its own volatility. The USDCHF showed a degree of persistence at the 10% level for its own shocks and 1% for volatility. The commodity currency returns displayed a high degree of persistence because of the high correlation between their economies and commodity markets. All commodity currencies returns were affected by their own shocks and volatilities at the 1% significance level.

The emerging country currency pairs show similar dynamic behaviours. Both USDKRW and USDZAR were affected by their shocks and volatilities at the 1% significance level, while USDBRL, USDMXN and USDPLN were not affected by their own shocks. However, volatilities were observed at the 1% significance level. The USDSEK was affected by its shock at the 5% and 1% significance levels.

Table 3.8 illustrates the asymmetrical effect of bad and good news on oil and currencies. Using the GJR-GARCH model, the *d* coefficient is significantly negative for the USDEUR (–0.025), and positive for the USDCHF at 1%. However, the coefficients of USDGBP and the USDJPY were statistically insignificant. Only the USDNZD had a negative asymmetrical effect as a commodity currency (–0.060). Except USDKRW and USDZAR, which were negatively significant at coefficient values of –0.042 and –0.046 respectively, all emerging currencies were statistically insignificant.

3.4.3.1.2 Half-life

During the overall period, oil showed a high volatility persistence at 0.997, which represents the highest half-life—237 days to recover from shocks. The half-life results indicate that the USDJPY was the safest asset, with 6 days to recover after shocks; however, the USDEUR showed the most volatile behaviour, with persistence lasting for 191 days. The USDGBP half-life was 69 days while the USDCHF's was 9 days. All commodity currency pairs revealed a high half-life—139 days for USDNZD, 111 days for USDAUD and 104 days for USDCAD. The half-life results confirm that the highest degree of volatility persistence was USDKRW (133 days), while USDSEK showed the lowest half-life decay (14 days). The half-life decay rates for USDBRL, USDMXN, USDBLN and USDZAR were 69, 57, 62 and 57 days, respectively.

3.4.3.2 Oil price decline period

Table 3.8 summarises oil and currencies volatility forecasts for the oil price decline period based on the univariate GARCH method. All coefficients were statistically significant except the coefficient *a* for the USDSEK during the oil price decline period. All major currency pairs were affected by their shocks and volatilities in different ways at the 1% significance level. In terms of the impact of past shocks and volatilities, all commodity currencies were affected by their own past shock and volatility at the 1% significance level. Past shocks and volatilities were observed for USDBRL, USDMXN and USDPLN at the 1% level of significance. However, the USDKWR and USDSEK shocks did not affect the currency pairs, but their volatilities did at the 1% significance level. Further, USDZAR shocks and volatilities affected the currency pair at the 10% and 1% significance levels, respectively.

Moving to the asymmetric effect, coefficient *d* is the effect of the oil price decline on conditional volatility. The GJR-GARCH results indicate that all major currencies were significant at 1%, except USDEUR. Similar to the overall period results, only USDNZD was statistically significant among the commodity currencies with a coefficient value of –0.97. Coefficients values of emerging currencies were responsive to news at a 1% significance level except USDKWR, which was insignificant. Coefficient values for emerging currencies were –0.117 for USDBRL, –0.171 for USDMXN, –0.079 for USDPLN, 0.242 for USDSEK and –0.166 for USDZAR.

For half-life, the degree of volatility persistence calculated by the summation of shock (ARCH) and volatility (GARCH) indicates that the value of persistence in oil is close to 1. This highlights the importance of measuring the half-life of a time series, which captures the persistence of volatility. During the oil decline period, oil will be affected for 13 days before it can recover from shocks and volatilities. The half-life of USDEUR had the highest value of major currencies, with volatility impact lasting 216 days. This indicates that investors must consider this behaviour in their decisions when investing in this currency pair. However, USDCHF had the lowest half-life value of 1 day; this is one reason USDCHF is the safest haven in terms of hedging currency. The USDJPY was the second-lowest currency pair, with volatility persisting for 12 days. Finally, USDGBP had an observed half-life of 70 days. Moreover, USDAUD and USDNZD experienced high half-lives values of 997 and 144, respectively, while USDCAD half-life was 78 days because of the high correlation with oil, which had a half-life of 70 days since Canada is a major oil-exporting country. The half-life of USDBRL was 47 days, USDKRW was 42 days and USDMXN was 78 days. USDPLN had the highest half-life (95 days), while USDSEK was 49 days. Finally, USDZAR had the lowest half-life: 9 days. It was observed that the dynamics behaviour of all emerging markets had moderated half-life values. This is considered a sign of advantage in terms of adding these currency pairs to the SAMA portfolio when hedging is needed.

Table 3.7: Univariate GARCH (overall period)

	Return Series	c	α	β	d	LogL	Persistence degree	Half-Life
	Oil	2.125e-06* (3.626e-07)	0.056* (1.540e-03)	0.940* (1.286e-03)	0.061* (2.587e-03)	4374.214	0.997	236.703
Major currencies	EURUSD	8.815e-08 (6.915e-08)	0.026* (0.005)	0.970* (0.005)	-0.025* (8.097e-03)	6609.211	0.996	190.673
	GBPUSD	4.280e-07*** (2.606e-07)	0.079** (0.036)	0.9101* (0.031)	0.026 (0.0407)	6550.833	0.990	69.221
	USDCHF	8.231e-08 (1.798e-07)	0.0763*** (0.0456)	0.902* (0.026)	0.0603** (0.0252)	6424.717	0.928	9.370
	USDJPY	2.816e-07* (1.267e-07)	0.060* (0.015)	0.934* (0.013)	0.099 (0.0742)	6440.298	0.896	6.345
Commodities Currencies	USDAUD	2.209e-07 (8.927e-08)	0.035* (0.008)	0.957* (0.008)	-0.020 (0.0157)	6367.481	0.993	111.431
	USDNZD	2.131e-07 (1.547e-07)	0.025* (7.431e-03)	0.969* (8.134e-03)	-0.028* (9.795e-03)	6167.065	0.995	139.309
	USDCAD	1.4315e-07*** (8.5842e-08)	0.028* (5.693e-03)	0.965* (7.5478e-03)	-0.013 (9.540e-03)	6748.105	0.993	103.92
Emerging Currencies	USDBRL	1.747e-06 (1.839e-06)	0.106 (0.065)	0.883* (0.070)	-0.089 (0.0563)	5562.449	0.990	69.009
	USDKRW	1.532e-07 (9.518e-08)	0.042* (7.820e-03)	0.952* (8.632e-03)	-0.042* (0.0147)	6651.248	0.994	132.780
	USDMXN	9.503e-07 (2.011e-06)	0.098 (0.093)	0.888* (0.119)	-0.034 (0.0305)	6014.795	0.987	56.744
	USDPLN	9.087e-07 (1.892e-06)	0.097 (0.089)	0.891* (0.113)	-0.021 (0.0191)	6011.924	0.988	62.117
	USDSEK	4.006e-5* (7.542e-6)	0.079** (0.042)	0.872* (0.200)	0.080 (0.073)	6256.578	0.952	14.25
	USDZAR	1.159e-06 (7.559e-07)	0.049* (0.017)	0.938* (0.022)	-0.046* (0.0135)	5504.567	0.988	59.151

Note: *;**;*** indicates the significance of 1%; 5%; 10% significance level, respectively. The selected optimal lags of the GARCH model are obtained using AIC criteria. (.) is the standard deviation of the estimated coefficient. LogL is the maximum likelihood value.

Table 3.8: Univariate GARCH (oil decline period)

	Return Series	c	α	β	d	LogL	Persistence degree	Half-Life
	Oil	4.488e-05* (3.605e-06)	0.1182* (0.0108)	0.829* (7.060e-03)	0.063* (0.0182)	1009.373	0.947	12.932
Major currencies	EURUSD	2.912e-07 (3.251e-07)	0.0505** (0.022)	0.946* (0.0264)	-0.025 (0.0361)	1678.991	0.996	216.408
	GBPUSD	3e-7 (2.35e-7)	0.011* (4.739)	0.015* (58.5951)	-0.116* (0.0048)	1803.784	0.990	70.367
	USDCHF	2.958e-5 (2.814e-5)	0.040** (2.005e-2)	0.529*** (0.293)	-0.252* (2.506e-04)	1533.772	0.570	1.234
	USDJPY	2.154e-6 (1.842e-6)	0.156** (0.076)	0.787* (0.110)	-0.319* (0.0852)	1747.490	0.944	12.070
Commodities Currencies	USDAUD	3.324e-07 (3.386e-07)	0.0753* (0.022)	0.9240* (0.020)	1.235e-04 (0.0387)	1634.066	0.999	997.469
	USDNZD	5.891e-07 (6.095e-07)	0.066* (0.0252)	0.9289* (0.024)	-0.097* (0.033)	1582.894	0.995	144.184
	USDCAD	2.038e-05* (5.947e-6)	0.093* (0.028)	0.897* (0.218)	-1.264e-03 (0.0776)	1738.848	0.990	78.054
Emerging Currencies	USDBRL	2.489e-06 (2.072e-06)	0.091* (0.029)	0.894* (0.033)	-0.1172* (0.0429)	1401.529	0.985	47.073
	USDKRW	5.789e-07 * (2.148e-10)	0.075* (0.019)	0.915* (0.017)	0.157** (0.0799)	1664.309	0.991	79.291
	USDMXN	5.8002e-07 (5.053e-07)	0.074* (0.019)	0.916* (0.022)	-0.171* 3.283e-03	1668.155	0.991	78.054
	USDPLN	5.150e-07* (1.92e-10)	0.072* (5.785e-03)	0.920* (4.973e-03)	-0.079* (0.0246)	1665.242	0.992	95.429
	USDSEK	6.254e-07 (6.31e-07)	0.033 (0.022)	0.952* (0.030)	0.242* (0.0464)	1652.560	0.986	49.393
	USDZAR	6.115e-06 (8.078e-06)	0.175*** (0.103)	0.755* (0.199)	-0.166* (0.000005)	1527.410	0.930	9.693

Note: *;**;*** indicates the significance of 1%; 5%; 10% significance level, respectively. The selected optimal lags of the GARCH model are obtained using AIC criteria. (.) is the standard deviation of the estimated coefficient. LogL is the maximum likelihood value.

3.5 Conclusion Remarks

This chapter investigated the selected currencies for portfolios based on the mean-variance approach using univariate analysis to rank the preferred currency composition of Saudi Arabia's foreign reserves. SAMA needs to understand the dynamic behaviour of financial assets so its portfolios can be clearly allocated and rebalanced as financial markets shift. SAMA tends to measure its overall asset portfolio on this basis instead of understanding the opportunity for global diversification to enable significant growth in SFCR. SAMA must allocate large portions of the country's foreign currency reserves to include foreign currencies that can form a type of self-insurance to shield against the risks associated with falls in oil prices. This chapter suggests that SAMA may be more susceptible to cumulative shocks that can be hedged through holding foreign assets.

The riskiness of each asset is expected to change as new information is processed in the market. For this reason, SAMA is likely to prefer considering the dynamic behaviour of oil and currency exchange rates by applying univariate analysis individually for each time series. Thus, univariate analysis will help SAMA use an effective currency-selection strategy to diversify the increasing risk of depletion of foreign currency reserves. It can do this by investing in foreign exchange markets. Therefore, the results reported in this chapter will help SAMA portfolio managers with strategic portfolio management, the development of dynamic optimal portfolio allocations and hedging efficacy, which can have significant implications for calculating the dynamic behaviour of oil and currencies.

In the distributions of oil and currency returns, the asymmetric GARCH and half-life approaches were used. Estimations of the parameters of the GJR-GARCH univariate equation showed that most coefficients were statistically significant. Moreover, the univariate GARCH results produced evidence for the importance of long-term volatility persistence on all time series because the b coefficients were higher than a.

Factor a calculated the effect on market fluctuations of the lagged square error factor in the mean equation, which refers to the influence of the previous period's price changes. Evidence was found for the significant effects of ARCH and GARCH on the conditional volatility of oil and currency pairs. The results captured higher a coefficients during the oil price decline period than in the overall period. This suggests the recent news had a greater impact on current conditional volatility in 8 of the 14 time series, including oil.

Among the major currencies, up-to-date news influenced USDEUR and USDJPY more than did old news, while USDCHF and USDGBP were affected more by old news. All commodity currencies were influenced by recent news more than they were by than old news. Further, all emerging currencies, except USDKRW and USDZAR, were influenced more by old news.

Coefficient *b* captured the impact of conditional volatility on current volatility, showing how old news influenced current conditional volatility. The oil and all currency pairs in major and commodity currencies were influenced more by old conditional volatility than by current volatility. Meanwhile all emerging currencies except USDKRW and USDZAR were influenced by new conditional volatility on current volatility than the previous day. Further, for the overall period, the asymmetric coefficient is not significant for 8 of the 13 currencies. There was evidence of response to bad news in the previous period for oil. It is important to note that the coefficients were considerably positive for USDCHF, yet significantly negative in the oil decline period. This means that the USDCHF asymmetric effect may be influenced by oil. Again, this effect does not tend to last longer because the asymmetric coefficient is positive when the overall sampling duration is extended.

When the coefficient *d* for the asymmetric effect is not significant, it becomes negatively significant, as observed for the British pound and Japanese yen in major currencies and for USDBRL, USDPLN and USDSEK in emerging countries' currencies. This demonstrates that currencies' conditional volatility increased in response to bad news in the previous period. Coefficient *d* reflected the effect of the existence of an oil decline event on conditional volatility. This term was negative and statistically significant, implying that following the oil price decline, the conditional volatility of currencies fell. This means that the emerging countries' currencies are less volatile (or risky) and more efficient after a decline in oil price. Investors are eager to optimise their portfolio wealth, so they tend to rely on diversification strategies depending upon their risk appetite. A rise or fall in investor inclination to risk would swiftly increase or decrease their vulnerability to risky assets, so the rise and fall in asset values occurs concurrently, as suggested by Dimitrious, Kenourgios and Simos (2013).

The half-life approach results indicate that SAMA could employ this method to significantly improve SFCR composition. It has been hypothesised that this strategy would lead to an ideal currency structure, allowing Saudi Arabia greater room for international currency diversification and a lower risk of volatility persistence. We found evidence of different time horizons in terms of responding to shocks (half-life) in normal and oil decline periods. It is important to note that most half-life periods for emerging countries' currencies responded to shocks during the oil price decline period more strongly than they did in the overall period.

Chapter 4: Selecting Currency Composition for Saudi Arabian Monetary Authority Foreign Currency Reserve Portfolio

4.1 Introduction

Global financial markets have become integrated and are now largely free of government influence. Scholars and policymakers are focusing on the co-movement of different financial assets. This integration of global financial markets has provided better risk sharing and risk reduction. Moreover, it has attracted a large number of traders and investors. The efficiency of global financial markets has increased in the post-financial crisis era. However, there is a drawback for these integrated financial markets in that financial crises spread quickly because of interconnections between them. It is important to conduct a detailed literature review and understand study findings, their methodologies and sample sizes and types. This chapter identifies the relationship between oil and currency returns and considers volatility spillover. In this chapter, important concepts are explained to fully understand the research concepts used in this study.

First, the concept of interdependence is crucial to understand because directly relates to exchange markets' integration. Moreover, the spillover effect in the interrelated market is important. The relationship between mean and variance is associated with the concept of interdependence, while the relationship between variances is examined for the spillover effect. This shows that causality and GARCH constitute the interdependence concept as part of the overall analysis.

According to Roger (1993), there are two main methods for understanding the compositions of currencies in a country's foreign reserve (i.e., transactions approach and mean-variance approach). According to the transaction approach, central banks should efficiently manage the currency composition of net foreign exchange reserves. This can be achieved by manipulating net assets and liabilities of foreign financial assets (Dooley 1986). According to this method, it is possible to optimise foreign assets through manipulation of assets or liabilities; however, this approach prefers optimisation based on liabilities. The focus of this approach is foreign assets transactions cost and foreign liabilities' mean-variance (Dooley et al. 1989). Dooley et al. (1989) also pointed out the use of currencies in both financial transactions and international trades, in which the exchange rate regime is used, and the country is as large as the major determinants of the transaction considerations. Conversely, the second approach (i.e., mean-variance) assumes that the role of a country's central bank is to work as an investor concerned with reducing investment risk and increasing return on investment. Therefore, foreign reserves should be used for investment that can provide higher returns at the lowest possible risk.

The transaction approach provides a practical solution for foreign reserve management because it focuses on the optimisation of financial assets and liabilities. However, this approach has many inherent problems for researchers because it requires access to central banks' data and decisions, which is practically impossible because of the confidential nature of such information. However, scholars can conduct analyses on basis of mean-variance using the publicly available data (Ben-Bassat 1980; Rikkonen 1989; Dellas & Yoo 1991; Murray et al. 1991; Pétursson 1995; Levy & Levy 1998; Papaioannou et al. 2006).

According to Krugman (1983), the significant oil price decline in the 1970s triggered multilateral responses from the global financial system. Oil price volatility was studied for its effect on foreign exchange rates, especially in the context of the US dollar, German mark and Japanese yen. This involved selecting two oil-importing countries—Germany and Japan—and oil-exporting countries (OPEC). The effect of asymmetries was studied. The author developed a three-region model to analyse the impact of oil shocks on foreign exchange rates of oil-importing and exporting countries. The first model assumed that OPEC spends oil export revenues; the model found that exchange rate movement is regulated by asymmetries. In the second model, developed by Krugman (1983), capital flow is discussed in the context of OPEC, which can adjust its expenditure according to fluctuation in oil prices. Conversely, rational speculations are introduced in the third model. It is important to note that the first model is based on real factors, while the second is based on financial factors in the short term. The third model concentrates on the relationship between financial factors and real factors on the basis of speculation. However, policy guidelines are limited in this study since these models only provide suggestions and are highly simplified in terms of how real financial markets work (Krugman 1983).

4.2 Related Literature

This section seeks to identify knowledge gaps in previous studies and ways to solve this problem. Information will be provided for designing the proposed central banks' foreign reserves asset allocation framework.

4.2.1 Central bank foreign reserve allocation

In reserve management literature, strategic asset allocation is comparatively less well documented than is currency composition. Several authors published work on different aspects of foreign reserve management, with a specific focus on strategic allocation of central bank portfolio assets (e.g., Bernadell et al. 2004; Bakker and van Herpt 2007; Berkelaar, Coche & Nyholm 2010; Joia & Coche 2010). A management framework for strategic asset allocation of central bank portfolios was suggested by Cardon and Coche (2004). They proposed that asset allocation decisions may be formed through a three-layer governance, comprising an oversight committee, investment committee and portfolio management. In relation to this, Fisher and Lie (2004) suggested a framework for strategic asset allocation of reserves with different assets classes considered, including government bonds, non-government bonds and currencies, to ensure sufficient liquidity for trade and intervention.

A behavioural finance application was suggested by Zhang, Chau and Xie (2012), with the Black–Litterman (BL) model for determining central banks' strategic asset allocation. This was used for the Chinese central bank's case for developing an optimal asset allocation, in which it was argued that the model was useful for reserve management allocation with different objectives. The BL model assumes that central banks consist of two subportfolios, and fits into behavioural variables that may affect attitudes of reserve managers on risk–return. One of these is a safety portfolio, monitored by precaution, with a lower expected return. It fulfils safety and liquidity objectives. The other is an investment subportfolio directed towards the return objective. An aggregate portfolio is formed by combining these two portfolios.

Zhang, Zhang and Zhang (2013) studied China's foreign reserves' strategic asset allocation. To examine the dynamic interdependence of risky assets, a regime-switching copula approach was implemented. It was discovered that central bank objectives focused on minimising portfolio risk, whereby reserve allocation encouraged a move towards safety. Alternatively, when higher risk levels were permissible for higher returns, the move towards safety was discouraged. The authors concluded that China's central bank must mitigate the move to safety after 2008, increasing investments in short-term bank deposits, euro bonds and long-term treasury bonds.

A more recent study by Bri'ere et al. (2015) found that the introduction of currencies with lower correlation to the US dollar considerably reduced portfolio risk. By expanding into equities, corporate bonds and mortgage-backed securities, the expected portfolio return could be improved. Overall, the literature argues that returns of foreign reserves are paramount for central banks' reserve management, particularly those who have reserves in excess amounts. For the same risk level, a less-intensive implementation of different constraints may obtain a better than expected portfolio return.

4.2.2 Currency composition of foreign reserves

The problem statement addressed in this chapter is the composition of optimal currency for SFCR. This chapter aims to identify the optimal composition of foreign currencies by central banks as investors to rebalance the SFCR. This chapter also provides background information and reviews the relevant literature for both the first and second models.

The optimal structure for foreign reserve management is the most important concern for researchers in the post-World War II scenario, although the optimal quantity problem of foreign reserve management is also important (Roger 1993). The end of the Bretton–Woods system led to challenges of the US dollar's dominance by other currencies. Moreover, after the end of Bretton–Woods, global capital flows have significantly increased, thereby increasing the foreign exchange reserves of many countries. Moreover, the Asian financial crisis of 1997–1998 led many countries' policymakers to believe that maintaining a strong level of foreign currency is important in avoiding the impacts of financial crises. Saudi Arabia has become the second-largest reserve holder in the world because of its huge oil exports. These developments have led scholars to search for an optimum quantity and structure of foreign reserves (Bird & Rajan 2003; Borio et al. 2008).

One of the foremost studies related to the first category was by Heller and Knight (1979), who stated that foreign exchange reserve composition has two main determinants: cost–

benefit characteristics and exchange rate arrangements. However, this research was limited, and the determinants were abstract; therefore, it allowed more scholars to study these determinants in detail. Dooley (1986) revealed that transaction and precaution needs are important factors that determine the composition of foreign exchange reserves. Dooley et al. (1989) developed a regression model and highlighted three more determinants: foreign debt, foreign trade volume and exchange rate regime. For this purpose, IMF data were used. The study was important; therefore, the same model was retested by Mathieson (2000) with the latest IMF data. It was found that reserve usage in financing activities and international trade determines foreign exchange reserve composition. Moreover, determinants of foreign currency reserve composition were identified by Chinn and Frankel (2008): inflation, GDP, fluctuation in currency and its extent and changes in volume. Mathieson (2000) used Dooley et al.'s (1989) model because it was based on the three-factor model for identifying optimal level and composition of foreign reserves. Moreover, the trading and financing activities of China were considered because Dooley et al. (1989) found them to be the core reason for safety and liquidity. Many factors influence currency composition according to Dooley et al (1989) (i.e., total number of transactions in a given currency, debt scale in terms of foreign debt and a country's currency exchange rate arrangement).

This chapter also reviews the literature related to the second category, including a critical discussion of the optimal currency structure for a central bank to maintain its foreign reserve. According to Ben-Bassat (1980), management of multiple currencies in a foreign exchange portfolio uses a floating exchange rate system. This system has the potential to gradually replace the Bretton–Woods system. Ben-Bassat (1980) reported that the mean-variance theory means that central bankers must develop an optimal allocation of foreign reserve assets to minimise portfolio risk in terms of a specific level of return and vice versa. They must seek a maximum return for specific reserve portfolio risk levels. The mean-variance theory assumes that returns are based on a normal distribution. It is essential for certain *ex ante* input parameters to apply the mean-variance portfolio decision models. For all assets within the investment world, it is essential for investors to establish approximations for expected returns and covariances. However, investors are often not knowledgeable enough of these values. Thus, they retrieve this information from the ex-post estimates of sample assets' past performance. There is an estimation risk problem associated with probability distribution of asset weights, in which ex-post estimates' optimal portfolios are unknown (Barry 1974, 1978; Klein & Bawa 1976, 1977; Klein et al. 1978; Bawa, Brown & Klein 1979; Dhingra 1980, 1983).

Other studies discuss the management of foreign currencies (see Willett 1969; Hagemann 1969; Steckler & Pickarz 1970; Makin 1971). However, they are limited to a two-currency choice (i.e., gold and the US dollar). Ben-Bassat (1980) was the first scholar to discuss this problem beyond the limits of the Bretton–Woods system.

Multiple currency management is popular among the world's central banks, so the simplicity of mean-variance analysis is considered suitable for managing foreign reserves held in multiple currencies. The importance of mean-variance analysis is highlighted by the fact that many central banks report this method on their websites (e.g., Canada [Murray et al. 1991], Finland [Rikkonen 1989], South Korea [Dellas & Yoo 1991] and Iceland [Pétursson 1995]). Moreover, according to Dellas and Yoo (1991), the significance of mean-variance analysis for South Korea's central bank is such that they compare their composition of currency with the results provided by mean-variance analysis. This highlights the importance of mean-variance analysis for central banks.

Papaioannou et al. (2006) amalgamated previous work into one paper and showed a simple treatment for the mean and variance methods. Their paper was based on four assumptions on the mean side and one on the variance side. For the latter, the paper used a DCC-GARCH model to analyse the currency risks on currency returns. Moreover, risk analysis analyses optimisation risk by capturing the dynamic risk of currencies. Overall, this paper's methodology is based on the estimation of variance-covariance matrix and currency return assumptions. The currency return assumption is based on foreign exchange market differences. Some authors have used these currency return assumptions in their studies (Rikkonen 1989; Dellas & Yoo 1991; Pétursson 1995). According to these authors, there are four assumptions: perfect foresight, uncovered interest parity, random walk and transaction costs assumption.

When Saudi Arabia and Russia increased oil production after 2014, oil prices fell significantly. Simultaneously, the US dollar increased in value. To study the link between these two variables, Chen et al. (2016) analysed the effect of oil price changes on the value of the US dollar against the currencies of 16 OECD countries. The true direction of the effect depended on whether the oil price shock was caused by a demand or supply factor. Overall, oil price shocks accounted for 10%–20% of the variation in the exchange rates, and the role of oil price shocks became stronger after the GFC erupted in 2008. To study this variation, a structural VAR model with time-varying parameters was employed. It is important to investigate the effect of volatility spillovers from oil to exchange rate markets because volatility plays a crucial role in asset allocation.

Chen, Choudhry and Wu (2013) studied extreme-value information to better comprehend the volatility and dependence structures in oil prices and US dollar exchange rates. The results favoured the inclusion of this extreme-value information since investors can benefit by its consideration. Therefore, Oana and Alexandra (2013) discussed portfolio diversification and investment in the currencies of emerging economies. A portfolio is considered efficient if it provides the highest expected return for a given level of risk. On the basis of secondary research, the US Federal Reserve system indicated that holding a clustered index of currencies is the best solution for an efficient portfolio. Emerging economies provide a fertile ground for investment and offer high returns. There are benefits in diversification because the yields offered are different from those of developed markets. To this end, Turhan, Sensoy and Hacihasanoglu (2014) investigated the co-movements of oil prices and the exchange rates of G20 member countries for 2000–2013. They used the corrected DCC model to conclude that the relationship between oil prices and exchange rates has strengthened in the last 10 years and become more negative. This strongly suggests that an increase in oil prices leads to stronger depreciation of the US dollar. These findings are helpful for investors and policymakers in terms of risk diversification and inflation targeting, respectively.

Chopra and Ziemba (1993) and Chopra (1993) showed that optimisation of the mean variance is particularly sensitive to inputs; they revealed that minute changes in input parameters may yield very different asset allocations of the optimal portfolio. To mitigate estimation errors, common techniques are discussed. The fact that foreign reserves data are not publicly accessible in most countries has hindered several empirical studies aimed at finding determinants of asset allocation and reserves' currency composition. In fact, the IMF Currency Composition of Official Foreign Exchange Reserves (COFER) includes data from less than 40% of emerging countries (Beck & Rahbari 2011).

Only five empirical studies seem to have been published regarding the mean-variance theory and currency composition. Ben-Bassat (1980) considered the period between 1972 and 1987 to show that for the Central Bank of Israel's foreign reserve currency composition and those of developing countries, risk and return consideration was important. Similarly, for South Korea's foreign reserve currency composition between 1980 and 1987, Dellas and Yoo (1991) discovered that risk and return were essential determining factors. A dynamic mean-variance framework was suggested by Papaioannou, Portes and Siourounis (2006). They suggested calculating the optimal level of world reserve portfolio by employing a variety of methods to estimate the mean returns and covariance matrices. To account for transaction considerations, the authors imposed various constraints, discovering that the reference currency is paramount; the optimal world reserve portfolio showed that the euro's share was less than that published in the COFER database.

Among the most recent studies regarding central banks' currency composition are Kim and Ryou (2011) and Beck and Rahbari (2011). The latter developed an optimal reserve portfolio within a minimum-variance framework and included a sudden stop in capital flows to produce several interesting results. It was observed that: (1) the US dollar, as a base currency, dominated optimal reserve portfolios; (2) the US dollar performed as a safe-haven currency during sudden stops, increasing its optimal portion in the reserve portfolios; (3) when debt-to-reserve ratio declines, US dollar shares should decline; and (4) the denomination of foreign currency debt did not hold particular importance for optimal reserve portfolios. Kim and Ryou (2011) also studied the efficiency of mean variance for foreign reserve portfolios, inspired by the ongoing debate concerning the need for central banks to diversify their reserves. To study the reserve portfolio efficiency of 18 countries, they implemented the likelihood-ratio procedure and found that the US dollar still dominated as an international reserve currency, even though it depreciated during the 2008–2009 GFC.

Following a decision on foreign currency reserve composition, a common step is a decision on allocation of the foreign reserve, or a decision on asset allocation or benchmark policy. In comparison with the relatively well-documented study of currency, literature on central banks' asset allocation is limited. According to León and Vela (2011), the foreign reserves' mainstream benchmark asset allocation relies on published data for the global bond market index, in which weights are proportional to market capitalisation or GDP figures. Nevertheless, Brennan, Kobor and Rustaman (2011) argued that, as per central bank practitioners, reserve management must move away from bond market indices because the benchmark allocation policies suggested by these indices outweigh more-indebted countries.

It is important to note that this study uses this mean-variance method in a more advanced manner than have previous studies. This research will apply multiple multivariate GARCH models to capture the volatility spillover between oil and currency pairs' returns and other factors significant in decision-making for foreign currency portfolios. Although several studies have examined the link between oil prices and US dollar values, little attention has been paid to oil and foreign exchange markets with respect to asset allocation. This topic deserves attention because any dramatic oil price change or pronounced movement between oil prices and US dollar values can have significant effects for policymakers and global investors. For instance, it can help effectively manage the fiscal policies of oil-exporting countries and market risks of both oil-importing and exporting countries, thereby mitigating oil price shocks. In addition to advanced multivariate GARCH models, the CCF model (one of the preferred models used by researchers applying two-step univariate GARCH) has been applied with multivariate analysis to understand the causality between oil and currencies in both directions using daily data. Thus, multivariate GARCH and CCF have not been used in exchange rate intensely, especially in foreign currency reserve, based on the researcher's knowledge.

4.2.3 History of dynamic asset allocation

Trippi and Harriff (1991) defined DAA as a group of investment strategies that respond to changes in portfolio value or external economic states by shifting the content of portfolios between asset groups on a continual basis. The desire to conduct DAA is explained by Hodges (1994) as the ability to exploit predictable market regularities and change the future distribution of fund returns to completely change its shape from the market index. These characteristics of DAA make it an attractive device to maximise investor profits by varying assets over time. As such, it is relevant to the portfolio choice problem, which has been the topic of considerable research over the last three decades. Conducted in static environments or discrete time settings, previous studies have been conducted on the optimal portfolio strategies for long-range investors. For example, in Latané and Tuttle (1967), Mossin (1968), Hakansson (1970) and Samuelson (1969), returns were often taken as i.i.d. The continuous-time technique was developed by Merton

(1969, 1971) as a powerful tool to analyse the portfolio choice problem in an intertemporal way. He also developed the theory that, for state-independent sets of future investment opportunity and preferences, intertemporal portfolio optimisation may be taken as a single-period utility function for the investor (Fama 1970). However, this is not necessarily true for a changing opportunity set. The portfolio self-insurance strategy emerged as a form of dynamic investment strategy in the late 1970s, becoming a subject of study for academics and practitioners. The strategy involves frequent trading in that it buys stocks with rising prices and sells stocks with falling prices, and its purchasing is a convex payoff function. Several authors, including Brennan (1979), Brennan and Schwartz (1976) and Brennan and Solanki (1981), studied the kind of insurance contract bought by investors as having certain utility function preferences and return-generating process beliefs.

Leland (1980) explored the topic of who should buy portfolio insurance and found that investors with average expectations and a risk tolerance that increased with increasing wealth, and investors with average risk tolerance and optimistic expectations of returns, would be most willing to buy portfolio insurance. The strategy became very popular from the mid-1980s onwards. Brennan and Schwartz (1988) developed a general model for time-independent portfolio insurance strategies, while Black and Perold (1992) formed the theory of constant proportion portfolio insurance. Both studies provided insights into the theoretical justifications for the portfolio insurance strategy, which still requires clarification despite its simplicity.

Portfolio insurance has been identified as the type of dynamic trading strategy likely to increase market volatility since the October 1987 crash. It also contributed to the market crash by increasing volatility and destabilising the market (Brady 1988). Thus, many researchers sought to uncover the effect of portfolio insurance on market equilibrium (Basak & Basak 1995; Donaldson & Uhlig 1993; Grossman & Zhou 1996). The original assumptions used by Merton (1973) in this work have been relaxed in recent years for the study of optimal portfolio choice. Wachter (1999) and Kim and Omberg (1996) assumed that interest rate is constant and equity premium behaves like an Ornstein Uhlenbeck process in seeking to solve a two-asset problem. Liv (1999) solved a spot-bond allocation bond, assuming the presence of an affine term structure. Brennan and Xia (2000) assumed a two-factor interest rate model in solving a three-asset problem.

4.2.4 Reserve management

Two types of studies have been conducted for reserve management—the optimum currency composition of foreign reserves and strategic asset allocation of foreign reserves. Studies pertaining to foreign reserves' currency composition can be split into two categories: empirical studies attempting to correlate central banks' reserve portfolios to observable country characteristics and theoretical studies using portfolio theory to achieve reserves' optimal currency composition.

Empirical studies to determine reserves' currency composition have been hindered by the fact that, in most countries, data on currency composition of reserves are confidential. Using classified data for reserves' currency composition, Heller and Knight (1978) studied 76 countries, finding that reserve currency composition significantly affects countries' trading patterns and exchange rate regimes. They concluded that transaction demands are particularly important as determinants of reserve currency composition.

These findings were affirmed by Dooley et al. (1989) and Eichengreen and Mathieson (2000); they formed analysed distinguishing factors for currency composition by using country-level COFER data. The latter suggested the inclusion of currency composition of external debt or financial flows to obtain information about transaction demands. Chinn and Frankel (2007, 2008) used combined COFER content to suggest that factors for currency composition should include the inflation rate of the reserve currency, size of the economy, exchange rate volatility and magnitude of the home financial market.

The aggregate COFER data were also utilised by Lim (2007) to assess the effect of previous changes in exchange rate on the aggregate currency shade of reserves; a stabilising diversification was found to be present. This means that central banks tend to buy US dollars when the currency declines, hoping to stabilise the market. Truman and Wong (2006) and Wong (2007) suggested that emerging markets tend to conduct passive (no actions taken when the US dollar declines) and stabilising diversification, but developing countries conduct active diversification (sell the dollar hoping to profit from its decline). Wooldridge (2006) confirmed that developing markets have indeed decreased their preference for the US dollar in recent times.

Empirical literature, then, reveals evidence of reserve currency composition being determined by transaction demands. Theoretical literature posits reserve currency composition as a solution to the Markowitz-type portfolio problem (the international version). Ben-Bassat (1980) suggested the application of mean-variance optimisation as a function of import currencies. Considering 1976–1980, the author compared the optimal and actual reserve portfolios to conclude that, for emerging markets, reserve currency composition was somewhat determined by portfolio objectives. This was not true for developed countries.

Considering a minimum-variance framework, Beck and Rahbari (2011) derived optimal portfolios for central banks with two assets and transaction demands caused by sudden stops in capital flows. They considered 23 emerging economies and their optimal euro and dollar shares to find that: (1) anchor currencies dominated optimal reserve portfolios; (2) during sudden stops, the dollar was a safe-haven currency with increased optimal share in central bank portfolios; (3) as the ratio of debt-to-reserve declines, dollar shares should decline; and (4) the size of foreign currency debt is insignificant for optimal reserve portfolios.

Contrary to the standard mean-variance optimal analysis for asset portfolios, Sheng (2011) adopted another approach to understand latent currency portfolios and less-obvious portfolio management strategies for 2000–2007. This was done for China's foreign reserves because China has not made its currency portfolio accessible to the IMF. Based on the budget constraint of China's reserve holding and a portfolio accounting identity, the study demonstrated that, in 2002, China drastically branched its reserves away from the US dollar but resorted to a portfolio-rebalancing strategy to conserve a steady currency composition after this period. It was estimated that China would hold approximately 2.5% in Japanese yen, 3.5% in British pounds, 4.7% in AUDs and 22% in euros by the end of 2007. On average, the rate of return stood at 3%.

There is a plethora of well-documented studies on strategic asset allocation of reserve management. Bernadell et al. (2004), Berkelaar et al. (2009) and Coche et al. (2010) edited three volumes related to the study of different aspects of foreign reserve management, in which some papers were dedicated to central banks' strategic asset allocation. According to Fisher and Lie (2004), a strategic asset allocation framework could be developed by considering assets (currency, equity, government bonds and non-government bonds) and ensuring liquidity for trade and intervention needs. They found that easing constraints could obtain a better return for same risk levels. A multi-objective, evolutionary optimisation algorithm was developed by De Cacella et al. (2010), who sought to obtain a group of viable portfolios by using a variable time horizon.

Caballero and Panageas (2007) developed a model to help determine the perfect size of foreign exchange reserves. Countries vulnerable to sudden shocks were used because such countries tend to invest in assets with fixed income or sophisticated payments and income that are more prone to unpredicted interruptions. The optimal protection strategy is at the centre of this concept, with assumptions that gains could be large. Other authors have agreed with these assumptions; similar results were obtained through mathematical and statistical computational models developed for the same purposes (e.g., Durdu et al. 2007; Caballero & Panageas 2007). Previously, other authors have developed different models. However, in practice, the defined relationship between foreign exchange reserves and import, short-term external debt and money supply coverage are not upheld.

4.2.5 Conventional approaches to optimal reserves

4.2.5.1 Early thinking

After World War II, there was a severe shortage of the US dollar. Regarding this, Triffin (1946) suggested that foreign reserves were a means of satisfying external obligation requirements. He established certain benchmarks for analysing whether a country is capable of meeting those obligations by considering a ratio of reserves to imports.

According to Frenkel and Jovanovic (1981), optimal reserves are ascertained based on the ability to stabilise macroeconomic adjustment costs incurred when reserves are absent, and the opportunity cost associated with holding reserves. They assumed a transaction-based rationale to forecast that the average reserves relied unfavourably on adjustment cost, exchange rate flexibility and reserves' opportunity cost and favourably for GDP and reserve volatility.

4.2.5.2 The precautionary motive

Greater integration of finance for developing economies has exposed them to greater short-term capital inflows, which may be affected by sudden stops and reversals (Edwards 2004). Several studies on optimal reserves have suggested that reserves may be regarded as self-insurance to decrease and mitigate unwanted output drops and crises caused by sudden stops and unfavourable shocks to economies. This is summarised as the precautionary motive.

Heller (1996) showed that the precautionary motive has a considerable effect upon monetary entities' decision to maintain global reserves. Ben-Bassat and Gottlieb (1992) produced a precautionary model in which reserves could be utilised by taking countries confronted automatically on outside debt. In terms of Asia's financial crisis, Aizenman and Marion (2003) suggested that in the following years, East-Asian countries started to store massive reserves based on the precautionary motive.

Aizenman and Lee (2007) showed that, for emerging countries, reserve allocation was dependent upon variables that considered the precautionary motive, in line with various emerging countries. An elaborate model was employed by García and Soto (2006), who showed that safeguarding against sudden stops was an essential factor in the worldwide stockpiling of reserves.

Several studies based on optimal reserves detailed emerging countries' precautionary motive using the consumption-based approach. As such, the framework developed by Jeanne (2007) was extended by Jeanne and Ranciere (2011) to enumerate optimum levels of reserves when considering expenditure smoothing and decreases in output resulting from fluctuations in the capital flow. Similarly, Durdu et al. (2009) focused on potential sudden stops that may affect foreign asset demand. Carroll and Jeanne (2009) developed a controllable framework for total foreign assets within a small open economy to enable estimation of the optimal precautionary wealth level against idiosyncratic risk.

Obstfeld, Shambaugh and Taylor (2010) provided insight into the working principles on reserve accumulation from the particular angle of financial stability and openness in international financial integration, also called macro-prudence. According to this model, it is necessary for central banks to allocate reserves and act as lenders (as a last resort for borrowers) to prevent excessive twofold losses for the economy: internal losses, such as runs on bank deposits and currencies, and external losses, shifts from foreign currency or banks.

Another small open economy model was formed by Hur and Kondo (2016), in which increases in foreign debt rollover risk are optimally managed by considerable reserve holdings held by emerging countries. This also allows for mitigation of difficulties caused by sudden stops. A statistical model was presented by Calvo, Izquierdo and Loo-Kung (2012) for viewing optimal reserves as a bargain between the potential price to be paid for sudden stops and opportunity cost of keeping reserves. It was concluded that holding reserves may be able to mitigate the likelihood of sudden stops and their associated costs.

4.2.5.3 The mercantilism motive

The mercantilism motive was explained by Dooley, Folkerts–Landau and Garber (2004). They stated that reserve collections could best be understood as directly resulting from East-Asian countries' export-oriented policies, specifically China, to achieve the objectives of enhanced job opportunities and economic output aided by greater exports. Conversely, Aizenman and Lee (2007) compared the precautionary motive (to safeguard for risk of sudden stops) and the mercantilism motive in terms of importance. They found that the variables related to the former were more statistically and economically important in understanding the accumulation of reserves. Variables for the mercantilism motive were statistically important, but not economically; this signals the superiority of the former in emerging countries' reserve demands. Aizenman and Lee (2008) suggested that the country's extensive accumulation of reserves occurs as a modification of the precautionary and mercantilism motives.

4.2.5.4 Loss aversion and narrow framing

A psychological approach was applied to agents' financial decision-making behaviours in the form of behavioural finance, which focuses on financial anomalies (Shefrin 2009). In particular, agents' preferences on loss aversion and narrow framing were considered. Loss aversion was the central proposition of Kahneman and Tversky's (1979) prospect theory. They suggested a value function specified for variations in wealth, instead of the final asset position, as done for standard economics. Outcomes were grouped based on gains and losses rather than a set base point; outcomes may be more sensitive to losses than to corresponding gains. Thus, greater weight is given to losses than to their equal counterparts.

Finance research is well versed in loss-aversion studies. To promote deeper knowledge of financial anomalies, behavioural financial studies have made important advancements. Shefrin and Statman (1985) considered the anomalies resulting from the disposition effect, which is relevant to loss aversion. The authors showed that, for situations explained well through the disposition effect, investors prefer to sell ‘winning’ stocks of higher value and retain ‘losing’ stocks with lower value compared with the set point of the stock’s purchase price. Odean (1998) showed that investors retained lesser-value stocks and sold higher-value stocks.

Different versions of the loss-aversion concept were used to justify reserve accumulation, according to Aizenman (1998). One such example is Gul’s (1991) disappointment aversion. Aizenman (1998) showed that the stabilisation fund increases in size when the disappointment-aversion principle is applied, compared with that of under-expected utility. Another intertemporal consumption model was developed by Aizenman and Marion (2003) in an effort to examine Asian emerging markets and their large reserve holdings.

Kahneman and Lovallo (1993) suggested that narrow framing is an important determining factor for individuals’ decision-making behaviours, whereby they observe risks within a narrow frame. This also suggests that people assess individual risks in isolation from other risks, as explained by Barberis and Huang (2007). Put simply, people behave is if certain advantages are derived directly from outcomes of particular risks, regardless of the fact that the risk may be isolated among a group of many risks.

A similar explanation was offered by Kahneman and Lovallo (1993) regarding organisational level. They considered the case of a decision-maker faced with multiple decisions. Their inclination to use a broad framework relies on how performance measurement and frequency. When performance is evaluated narrowly (such as while confronted with the possibility of risk if the performance is evaluated based on risk only), individuals choose to make decisions through narrow frames.

This is particularly effective when loss aversion and narrow framing are used in harmony. According to Read et al. (1999), loss aversion is particularly important for decisions that entail losses and gains. For this purpose, the aforementioned effect is projected to affect the decision-making abilities of those who assess particular risks using a broader frame to a narrow extent. A combination of loss aversion and narrow framing was suggested by Benartzi and Thaler (1995), who attributed the equity premium puzzle to myopic loss aversion.

Barberis, Huang and Santos (2001) formed a model that integrated behavioural factors, narrow framing and prominent loss aversion with the decision-making process. They provided reasoning for equity premium and claimed that investors would reap utility from consumption even in the face of volatile financial wealth and asset values. The existence of equity premium may be explained through the loss aversion of volatilities and narrow risk framing within the stock market. The behavioural model for optimal choice uncertainty was refined further by Barberis and Huang (2009).

Several theories related to the growth of foreign reserves and their optimal levels have recently been subject to growing challenges. The derivation of optimal reserves has yielded unsuccessful results, drawing focus to vast reserves hoarded by emerging economies, given that this derivation is dependent upon rational agents maximising expected utility. Considering this, the incorporation of behavioural factors, such as narrow framing and loss aversion, may present an optimistic pathway for greater understanding of countries' swiftly accumulating reserves.

4.2.6 Previous literature on the spillover effect

The international stock market crash of 1987 prompted researchers to examine the causes of the extensive damage to several of the world's largest stock markets; the US, the UK, Spain and Hong Kong suffered huge losses in the form of declining stock prices. It was discovered that volatility spillovers within these global markets could have affected each other, which prompted further research into the study of intermarket financial relationships in the global community. Further, it prompted research into intermarket volatility. These studies yielded valuable insights into factors that affect volatility spillovers and contagion, and hence, formed a critical chain of information that detailed the crossflow of investments over international borders. While they aimed to ameliorate these effects, a key concern is whether these empirical studies accurately captured the true nature of, for example, 'contagion', something that has been defined differently by many authors, contributing to its vagueness. The definition of contagion and what it constitutes has been hotly debated, as well as the best tools that can capture the effects of contagion channels. Forbes and Rigobon (2001, 2002) attempted to develop a sound definition for contagion. They proposed that co-movements and interdependencies in markets are separate and distinct, which may be because of high correlations between past and future periods, termed as the 'shift-contagion'.

This shift-contagion has been observed in markets in which there is excessive co-movement as a result of economic shock. Consequently, there is a need for extreme precaution when examining crisis transmissions, which are readily ignored by most authors; this renders their arguments as weak. For this study, the focus has been variance-covariance co-movements within oil and currency markets. The modelling framework used for this purpose is the GARCH and variations of multivariate GARCH that aim to capture volatility spillovers in these markets. These echo the meteor showers hypothesis proposed by Engle et al. (1990), in which the authors explained volatility clustering in the context of foreign market returns.

Experts have focused their research on volatility spillovers into two distinct groups, each with a specific focus. One group emphasised return series, their modelling and subsequent errors, and correlations of return series through different markets. Eun and Shim (1989) showed that the US stock market was the most influential and dominant, while an error of 26% of the return on stock was obtained because of elements of newness within markets. The second group of researchers also sought to study volatility spillovers and focused on issues of the series and modelling of volatility. In this regard, stochastic models may be particularly helpful, and are frequently utilised to find option pricing. Where the GARCH model utilises only one error term, this approach inserts a second error term into the conditional variance equation. Nevertheless, stochastic models have been perceived as relatively complex for modelling volatility; thus, they are unpopular compared with other models.

Increases in oil prices have been reported to cause exchange rate appreciation for oil-exporting countries. Similarly, increases in oil prices lead to exchange rate depreciation for oil-importing countries (Golub 1983; Krugman 1983). Krugman (1980) differentiated between the initial and long-term effects of oil price increases and stated that increases lead to exchange rate appreciation in the short term, while exchange rate depreciation ensues in the long term. He further expanded on his research in 1983, providing three models to explain his analysis. He concluded that oil price changes affect all countries, but that effects differ because of asymmetries between the economies concerned. In contrast, Golub (1983) used a stock/flow model to study the effect of oil price changes on exchange rate movements. He concluded that the effect depends on how the country reallocates wealth. Golub (1983) and Krugman (1983) highlighted how changes in oil prices determine exchange rate movements. When oil prices are high, wealth is transferred from oil-importing countries to oil-exporting nations. Therefore, oil-exporting countries experience exchange rate appreciation, while oil-importing nations experience exchange rate depreciation. These effects are achieved through changes in oil export revenues and raw material import bills (Krugman 1983; Golub 1983).

However, if an oil importer's exports are relatively large compared with their oil imports, the net transfer of wealth will be positive for the oil-importing country, leading to exchange rate appreciation (Corden 1984; De Grauwe 1996). Using cointegration analysis and an error-correction model (ECM) on monthly data from 1972–1995, Amano and Van Norden (1998) found that oil price shocks cause changes in the US dollar exchange rate; they identified a one-way causality between oil prices and exchange rates. However, the authors also reported evidence of how an increase in oil prices reduces the value of the yen but increases the value of the US dollar. Basher, Haug and Sadorsky (2016) also discussed the wealth effect channel and how it differs for oil exporters and importers; there is a transfer of wealth from oil-importing countries to oil-exporting nations, leading to exchange rate depreciation for the former and appreciation for the latter. Further, any global demand shock has substantial effects on all countries, but the exact effect differs depending on the global competitiveness of each country.

After the pioneering works by Krugman (1983) and Golub (1983), several researchers attempted to study the relationship between oil prices and the US dollar. A positive relationship between oil prices and the US dollar was hypothesised, but this was contested by several analyses. However, others aimed to prove a negative relationship between the variables. These studies used cointegration and causality analyses to study the relationship between oil prices and exchange rate values. Bénassy-Quéré, Mignon and Penot (2007) based their analysis on work by Krugman (1980). The US, EU, OPEC and China were the four regions considered; the exchange rate of the US dollar against the euro was considered. The study was conducted using the VECM on data on real oil prices and the US dollar from 1974–2004. They reported that a 10% increase in oil price led to a 4.3% appreciation in the US dollar. They also showed that causality ran from the oil price to the dollar value. However, from 2002 to the end of 2004, there was a sign of a new regime—a negative relationship between oil price and the US dollar.

In line with the findings of Amano and Van Norden (1998), Chen and Chen (2007) investigated the relationship between real oil prices and exchange rates for G7 countries using monthly panel data from 1972:1 to 2005:10. The researchers concluded that real oil prices caused exchange rate movements, and reported a cointegrating relationship between the two variables. Moreover, real oil prices were used to predict future exchange rate returns. Lizardo and Mollick (2010) reported a negative relationship between oil prices and the value of the US dollar. Cointegration tests showed that an oil price increase leads to a depreciation of the US dollar against the currencies of oil-exporting countries such as Canada and Mexico, and an appreciation against the currencies of oil-importing countries such as Japan. Buetzer, Habib and Stracca (2012) argued that oil-exporting countries peg their currencies or gather foreign exchange reserves when faced with oil price shocks, nullifying any changes in the exchange rate. Nonetheless, Fratzscher, Schneider and Van Robays (2014) found a negative correlation between the two variables using a structural VAR model that catered to heteroskedasticity in the data. The variance decomposition attributed the strength of the correlation to the economic shocks of 2008–2009. Using daily exchange rates of emerging countries from 2003:1 to 2010:6, Turhan, Hacihasanoglu and Soytas (2013) concluded that a rise in oil prices leads to an increase in the value of domestic currencies against the US dollar. The effect became more pronounced after the 2008 GFC. The most recent sample (since 2008) demonstrated that an increase in oil prices is followed by depreciation of domestic currencies against the US dollar. The reason proposed was that emerging economies are grounds for growth and attract foreign investment. There is also a 'recycling of petrodollars', whereby oil-exporting countries increasingly invest in emerging market economies.

Ferraro, Rogoff and Rossi (2015) stated that known oil price changes can be used to forecast exchange rate movements. Their empirical study showed that such predictions hold true at a daily frequency, but not at quarterly or monthly frequencies. The results were robust to the in-sample window size and independent of the sample period. Lagged commodity prices do not hold relevance. Their simple linear regression model showed no improvement when accounting for nonlinearity and cointegration.

According to Chaudhuri and Daniel (1998), there is a cointegration between real oil price and US dollar exchange rate in line with the Bretton–Woods agreement. This cointegration is true for most countries whose economies rely greatly on manufacturing and industry. The non-stationary factor in US dollar terms is caused by the non-stationary factor in crude oil price. Other scholars have confirmed these findings because over the long term, the non-stationary factor seems to be stationary. Moreover, it was also found that global acceptance of oil price volatility has increased, and countries have taken necessary remedial actions to counter the effects of sudden oil price changes. These findings were evident for Japan and Germany after 1986.

Some studies have found that the relationship between oil price fluctuations and currency exchange rates is significant during periods of higher volatility. Razgallah and Smimou (2011) reported that oil is not treated as an asset in most research on this topic. The relationship between oil price changes and exchange rates has not been properly investigated, meaning there is an endogenous relationship between oil price changes and exchange rates. However, an exogenous relationship cannot be established. Nonetheless, according to their study, the relationship is stronger during periods of higher volatility in oil prices.

Razgallah and Smimou (2011) identified a causal relationship between crude oil price and the US dollar in the long term and a possibility for reversal of causality in the short term. They analysed the oil price relationship with the dollar index in the long term, showing a causality from oil prices to the dollar over the study period. The findings were based upon crude oil being treated as an asset in its own class; this led to portfolio adjustment during the period of higher oil price fluctuations. In the short-term period, the traders trusted certain trends. Therefore, portfolio adjustments accelerated in a nonlinear fashion.

Gosh (2011) investigated the relationship between the currency exchange rate of India and oil price fluctuations. Daily data for this study were collected from July 2007 to November 2008; GARCH and EGARCH models were used to analyse the data and especially the influence of changes in oil prices on exchange rates. Oil price and exchange rate had a time-varying volatility relationship. The study showed that oil price increases resulted in a decrease in the value of the Indian rupee against the US dollar. This was an important study because India is an oil-importing country, so increases or decreases in oil prices theoretically directly affect the Indian rupee. This study differed from others because a symmetric effect was found between oil price changes and the Indian rupee exchange rate. Changes in oil prices had same-size effects on the rupee.

Ayadi (2005) identified and analysed the relationship between oil price volatility and economic output. This study showed that real foreign exchange rates are affected by oil price volatility. When oil price increases, oil-exporting countries benefit in form of higher export revenues (Ayadi 2005).

The multivariate GARCH model was used in the trivariate analysis by Cifarelli and Paladino (2010), who examined the relationship between changes in oil prices, the US dollar and stocks. A negative relationship was observed between the exchange rate of the dollar and oil price fluctuations. The risk premium function of conditional crude oil price volatility was estimated using a univariate multivariate GARCH model. There is a strong relationship between changes in oil prices in stocks and share prices in time-varying and conditional moment interactions. The relationship affected the CAPM and trading components of the multivariate GARCH model. Their research discovered that oil price changes exerted a strong impact on inflation and growth at the global level. Thus, it is important for policymakers to effectively monitor the commodity market.

4.2.7 Multivariate GARCH

The GARCH-VECH approach was adopted initially by Engel and Rodrigues (1987), who studied the relationships between various international exchange rates. They utilised the international capital asset pricing (ICAPM) model and diagonal GARCH to overcome limitations presented by the sole use of CAPM. CAPM, used in isolation, assumes that asset returns are a function of several variables: demand, supply, variance and covariance. The model holds that variance of returns is a measure of the risk involved and returns show a normal distribution, with constant values for variance and covariance. Therefore, the inclusion of the diagonal GARCH model to CAPM allows for variations in variance and covariance, which must be considered for real cases.

A study comparing several GARCH approaches, including BEKK, was conducted by Karolyi (1995), who investigated the impact of stock-return innovations in a given market on conditional market return and the conditional market volatility of another given market. The study suggested that BEKK would be the most useful approach rather than other multivariate GARCH approaches. BEKK is particularly useful because it provides information on the relationship between conditional variance and covariance, which makes it possible to analyse the spillover and contagion relationship. BEKK also ensures that the variance-covariance matrix is positively defined. For these reasons, BEKK has proven the most popular of the multivariate GARCH approaches in the literature. Darbar and Deb (1997) studied the movements of equity returns in major international markets using BEKK. Kearney and Patton (2000) employed the multivariable BEKK to study different currencies in the European monetary system. Their results, however, varied since they employed BEKK models that were three, four and five multivariate. Therefore, it is essential to carefully specify the model before a proper estimation is conducted. Gannon and Au-Yeung (2004) implemented the BEKK model using a systematic approach that jointly examined structural break. A dummy variable was added to the variance equation for this purpose. This study was conducted on the Hong Kong market. By considering structural breaks in the BEKK model, they were able to identify a volatility spillover from the US market to the Hong Kong market.

Koulakiotis et al. (2009) studied the use of the BEKK-GARCH model. They observed three different European regions—France, Germany and Scandinavian countries—to examine how volatility and error were transmitted across cross-listed equities. This study revealed that the Finnish and Danish markets were more likely to export their volatilities to the Norwegian and Swedish markets. Swiss markets displayed similar behaviour, affecting equities in Germany. The Paris, Brussels and Amsterdam stock exchanges were major contributors to volatility in the Milan and Madrid markets. Studies by Brooks et al. (2000) and Isakov et al. (2001) sought to curtail the effect of asymmetry in the series by applying GJR in harmony with BEKK.

4.2.8 Portfolio weight and forecasting of optimal hedge ratio

This section will shed light on the possible advantage of obtaining forecasts on hedge ratios for various hedgers in particular oil and exchange rate markets, and potential negative influences that may arise. The optimal hedge ratio (OHR) is defined as the covariance ratio between oil and exchange rate returns and the variance of exchange rate returns within the mean-variance framework of Markowitz (1952). OHR is an effective way to capture the volatility between oil in currency prices to minimise the risk of a particular portfolio. An essential implication for this forecasting concerns planning investments and making appropriate decisions. Forecasting the OHR enables the hedger to select appropriate portfolios and adjust them for dynamic hedging. For a specific period, the most appropriate moment for hedging can be approximated. The timing of investment is crucial for the investor to yield successful results. If the selected moment for hedging is at the beginning of a specific period, this allows time to prepare capital for the investor, perhaps even prior to adopting the first position in sport market. When the selected moment is the very last one, an investor does not need to hastily allot funds prior to the hedge. This allows them time to manage and spread capital accordingly to allow for other investments before the hedge, as opposed to allocating all funds at the start of an investment. The prediction of hedge ratio allows greater flexibility for the capital.

Studies on the OHR have gained considerable attention from various scholars recently. This is because scholars agree on GARCH models' superiority in estimating OHR in financial markets (Baillie 1991; Kroner & Sultan 1993; Park & Switzer 1995; Lien 1996; Floros & Vougas 2004, 2006).

Assets cannot be classified as storable and perishable (Covey & Bessler 1995). As mentioned previously, MGARCH is particularly valid for obtaining forecasts for the OHR in financial markets including foreign exchange (forex) markets. As such, BEKK (1995), CCC (2000) and DCC (2002) MGARCH models were applied to capture the spillover effect and forecast the optimal weight and hedge ratio. It is necessary to discuss the accuracy of these models in forecasting oil and forex markets. Some researchers (Bollerslev 1986; Cecchetti, Cumby & Figlewski 1988; Baillie & Myers 1991; Kroner & Sultan 1993) have accepted the idea that hedge ratio is time dependent. A key theoretical problem in hedging is to obtain forecasts of time dependent OHR; this has received much attention from scholars and practitioners.

To prevent extreme asset allocations resulting from model inaccuracies or to meet investment mandates, institutional investors frequently employ portfolio weight limits of assets or groups of assets. Such practices were explained by Jagannathan and Ma (2003). They showed that imposing negative weight constraints was equal to reducing estimated security covariances. Here, upper bounds were comparable to the corresponding covariances. For instance, assets with high inter-covariances were likely to receive negative portfolio weights. Thus, negative weights reduced in magnitude when their covariances were reduced (similar to the impact of not imposing short-selling constraints). Similarly, assets with lower covariances with other assets were likely to become over-weighted. The impact of such overweight assets could be reduced by increasing the corresponding covariances.

The findings of Jagannathan and Ma (2003) were reassessed by Behr, Guettler and Miebs (2013), who utilised a minimum-variance portfolio strategy with flexible weight constraints. If input parameters are error-free, it was shown that including portfolio weight constraints was favourable for optimisation. Weight constraints ensured that portfolio weights were not directed according to sampling errors inherent in the historical data parameter estimates. This led to a concentrated portfolio (see Green & Hollifield 1992; Chopra & Ziemba 1993; Chopra 1993). Conversely, in their approach, the weight constraints reduced sampling error and potential loss of sample data for portfolio optimisations.

Roncalli (2010) analysed the work of Jagannathan and Ma (2003) for a more specific setting, reporting that imposing portfolio weight constraints on global minimum-variance portfolios was like using a shrinking estimate of the covariance matrix. However, the impact on mean-variance and tangency portfolio is less well known. In particular, for the risk minimisation of mean-variance portfolio for specific expected returns, the impact of portfolio weight constraints on the mean-variance portfolio is largely unknown.

4.2.9 Hedge ratio estimation

The existence of cointegration in currency markets was discovered by Brenner and Kroner (1995), Lien (1996) and Kroner and Sultan (1993). A GARCH-based correction model was employed by Kroner and Sultan (1993), who discovered that the longstanding cointegration association among assets' dynamic distribution and financial assets was not a negligible factor when estimating OHR accurately. However, the cointegration relationship led to smaller hedge ratios, as reported by Ghosh (1993), Kroner and Sultan (1993) and Lien (1996). It was also observed that estimation and forecasting of OHR did improve. Further, a bivariate error-correction model with conditional hedge (called the ECM) was suggested by Kroner and Sultan (1993), whereby a GARCH-based error structure was necessary to find the risk-minimising hedge ratio for currencies such as Britain's pound, Japan's yen, France's franc, Canada's dollar and Germany's mark. This model accounted for the dynamic distribution of assets and the long-term cointegration relationship between financial assets.

Among several methods for approximating OHR is conventional OLS, developed by Ederington (1979). The proposed strategy hinges on the regression of spot prices on future prices (Ederington 1979; Witt, Schroeder & Hayenga 1987). Strategies consisting of regression of percentage price variation (Brown 1985) and actual price change were also developed (Myers & Thompson 1989). However, OLS is not preferred because of its negligence of heteroskedasticity of the variance of residual term and its inability to use current information to construct conditional covariance. A dynamic OHR for treasury bonds was suggested by Cecchetti et al. (1988), who based it on the ARCH model devised by Engle (1982). This was done to depict time variation of OHR based on available information.

This was also studied by Myers (1991), who compared the time-dependent generalised GARCH hedge ratio and the traditional constant hedge ratio regarding the commodity futures market. The OLS method was applied to commodity markets and led to the conclusion that the GARCH-based OHR was superior to the constant hedge ratio. It was considerably adaptable to the relationship between previous and present volatilities. The time dependence of OHR for treasury bonds was demonstrated by Cecchetti et al. (1988) for the future of the t-bond between October 1977 and May 1986. Observations were taken because the treasury bonds to be held short for a month. Between October 1977 and May 1986, spot returns for treasury bonds were retrieved based on the Salomon brothers analytical record of yield and yield spreads. Interactive Data Corporation was the source for the concurring futures prices.

The hedging effectiveness and hedge ratio in the Greek stock indices future market was studied by Floros and Vougas (2004, 2006). It was realised that the multivariate GARCH model provided a more exact time-dependent hedge ratio and increased risk reduction compared with OLS, ECM and VECM models for the FTSE/ASE Mid 40 and FTSE/ASE-20 index. This outcome was confirmed by Choudhry (2004). A model integrating OLS with cointegration (CI) was developed by Park and Switzer (1995) for the US and Canadian stock index futures. This was compared with the bivariate GARCH, 1-to-1 naïve and OLS models to estimate the OHR. The GARCH was the best of all three models.

The GARCH-based hedge was most effective in reducing the variance of GARCH over naïve hedge, OLD, OLS-CI and unhedged positions by 3.762%, 8.870%, 5.840% and 97.916% for S&P 500, respectively. Further, the GARCH model outperformed in the case of the mean-variance approximated utility maximisation, especially in instances in which transaction costs were accounted for. These conclusions by Choudhry (2003, 2009) complemented the study by Kroner and Sultan (1993), which showed the greater usability associated with M-GARCH models to explain time dependence and estimate varying hedge ratios. Choudhry (2009) stressed that the improved hedging efficiency produced by cointegration depended on the market and frequency of the data under consideration.

Time series dependent on first-order mean and second-order variance are well simulated and forecasted through the modelling techniques of GARCH. GARCH-family models are often taken for granted for their ability to measure hedge ratio, which stems from their efficiency in fitting oil and currency exchange price accurately and detailing the relationship between them (Baillie 1991). Park and Switzer (1995) used bivariate GARCH models to estimate the OHR of both the US and Canadian stock indices using one-period-ahead rolling forecasting. They discovered that, among the 1-to-1 naïve, OLS-CI and OLS models, bivariate GARCH was superior in forecasting hedging effectiveness.

OHRs were studied by Brooks and Henry (2002), who focused specifically on the UK stock market by accounting for the cointegration association of prices, including the error correcting term in the equation for the mean. They implemented an asymmetric BEKK-GARCH model to study the effects of information on the variance-covariance matrix and the return volatility. The values of BEKK-GARCH and OHR depended on the naïve hedge model; they were compared numerically through the FTSE 100 stock index and FTSE stock futures index between 1 January 1985–9 April 1999. The unhedged position produced greater returns than the hedged position; asymmetric models allowed the greatest reduction in variance for in-sample and out-of-sample testing. Similar to Hsieh's (1993) measurement, hedging effectiveness was calculated using the minimum capital risk requirements (MCRRs) for 1-day, 10-day, 1-month, 3-month and 6-month investments. Measurement of MCRRs was the minimum capital amount necessary for absorbing all fixed percentages of potential losses (Brooks & Henry 2002).

For investments shorter than one month, the time-dependent BEKK-GARCH model best fit the data compared with other models, allowing for reduction of portfolio risk and improvement of hedge ratio forecast accuracy. The model was not particularly effective for long-term hedging. Out-of-sample forecasting for long-term hedging was perceived to increase risk rather than mitigate it. Brooks and Henry (2002) concluded that the

BEKK-GARCH may be useful in short-term investment-based forecasting of hedge ratio for investments of under one-month duration.

ECM-GARCH-X was another model suggested by Kroner and Sultan (1993) for studying the longstanding interrelationship among the assets and dynamic distributions for various currencies: British pound, Canadian dollar, German mark, Japanese yen and Swiss franc. To estimate and forecast the OHR, the ECM-GARCH model was reported to outperform conventional and error-correction models (CI).

From the literature above, it is clear that forecasting of hedge ratio using models in line with volatility estimation models is often generalised to all time series. Comparatively fewer scholars have studied hedge ratio prediction compared with the plethora of studies on volatility forecasting. This explains why the present study contributes to the literature on volatility forecasting—it draws analogies by considering oil and currency prices as SFCR portfolio assets. The optimal weight will be determined following Kroner and Ng (1998), and the hedge ratio will be considered following Kroner and Sultan (1993). We assume that using the above approaches will optimise profits, accounting for both risk and expected returns. The GARCH model approximates the OHRs, relying the aforementioned approaches. This allowed for consideration of time-dependent conditional variance and covariance.

4.3 Econometric Models

In this chapter, analyses using multiple GARCH models to capture volatility spillover is suggested. This allows for better study of interrelation among oil and currency pairs. This enables better risk management and greater portfolio diversification decisions. Moreover, it allows forecasting of the optimal weight and hedge ratio. Data used in this study were obtained from the DataStream International database, and all currencies were taken in local currencies.

4.3.1 Spillover models

Literature sources frequently utilise three approaches in modelling volatility spillovers. As discussed in Chapter 3, one of these approaches is the ARCH/GARCH model, which estimates a univariate conditional variance, exemplified by the following GARCH (1,1) model:

$$x_t = \mu + a x_{t-1} + \epsilon_t \quad (4.1)$$

$$\epsilon_t = z h_t \quad (4.2)$$

$$h_t^2 = \omega + \alpha h_{t-1}^2 + \beta \epsilon_{t-1}^2 \quad (4.3)$$

Here, μ is a constant, h_t^2 is the conditional variance, and ϵ_t is the error term and z as offset term. Applying these equations to several financial series provides information on the relationships between volatilities, as represented by their variables. The conditional variance, h_t^2, can also be integrated within an equation similar to Equation (4.1). Testing for volatility spillovers of x_t to y_t, the causality test can be used for the coefficient of the lagging conditional variance.

This example utilises the simplest form of the univariate GARCH. There are, of course, examples of more complicated methods that follow the same basic methodology. Although the multivariate GARCH can usefully explore volatility spillover relationships, the large number of variables that must be considered will cause a lack of convergence or efficiency concerns in estimations.

Proposed by Cheung and Ng (1996), the CCF is another method that can investigate volatility spillovers. Based on the univariate GARCH, it tests for causality in variance. The basic approach is as follows. First, a multivariate GARCH is used to estimate volatility spillovers. Then, CCF is applied to yield causality in the variance to confirm the MGARCH results. CCF is advantageous because it does not require many parameters to be estimated, as is the case with multivariate GARCH. The ambiguity associated with possible interrelations between variables in GARCH is eliminated when CCF is utilised. Further, CCF has a well-defined, asymptotic distribution that is robust to distributional assumption. However, it does have certain drawbacks. When small samples are chosen, application of CCF makes it likely that causalities at high lags will be neglected, which increases the degree of freedom and reduces the usefulness of the test. Further, it does not specify causation. However, this study uses large samples, which make the CCF an ideal model for this research. In this thesis, multivariate GARCH and CCF models will be implemented to provide useful information about variance and covariance, which have been explored in the extant literature.

4.3.2 The multivariate approach

4.3.2.1 VAR-GARCH model

For the present bivariate VAR-GARCH (1, 1) model, the BEKK version suggested by Engle and Kroner (1995) was employed to model the processes that govern daily changes in oil prices and exchange rates for two periods. July 2012–December 2018 and the oil price decline period, June 2014–February 2016. This allows the examination of correlation between the first and second moments of oil returns and changes in exchange rates in a shifting framework. Additionally, the framework consists of certain exogenous variables that can capture the impact of global shocks on oil prices.

This suggests a particular specification of the conditional mean equation with $R_t = [R_{1,t}, R_{2,t}]$, a normally distributed innovation vector of $\varepsilon_t|\Omega_{t-1} \sim N(0, H_t)$ that follows normal distribution where H_t is the relevant variance-covariance matrix, and Ω_{t-1} is the available information set previously. The terms $\Psi_{11}^{(t)}$ and $\Psi_{22}^{(t)}$ represent the response of oil and exchange rate returns to their lags, respectively. The terms $\Psi_{12}^{(t)}$ and $\Psi_{21}^{(t)}$ represent causality from exchange rate changes to causality from oil and vice versa, respectively. The term i represents the lagged period. Certain exogenous variables have been incorporated into the model, such as $R_{ex,t}$ (the daily exchange rate) and $p_{oil,t}$ (logarithmic value of global oil price).

As an economic interpretation, investors' reactions to the oil and exchange rate volatilities explain the inclusion of exchange rate volatility lags in their strategies. As such, the conditional mean equation is as:

$$y_t = \mu + \sum_{i=1}^{p} \Psi_i y_{t-i} + \sum_{i=0}^{p} \eta_i h_{t-i} + \varepsilon_t \tag{4.4}$$

$$\mu = \begin{bmatrix} \mu_1 \\ \mu_2 \end{bmatrix}; \Psi_i = \begin{bmatrix} \Psi_{11}^{(t)} & \Psi_{12}^{(t)} \\ \Psi_{21}^{(t)} & \Psi_{22}^{(t)} \end{bmatrix}; \eta_i = \begin{bmatrix} \eta_{11}^{(t)} & \eta_{12}^{(t)} \\ \eta_{21}^{(t)} & \eta_{22}^{(t)} \end{bmatrix}; \varepsilon_t = \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}$$

Here, y indicates the oil and exchange rate changes, respectively. The terms $h_t = [h_{11,t}, h_{22,t}]$, $h_{11,t}$ and $h_{22,t}$ show the conditional variances of oil return and exchange rate changes, respectively. The terms $\Psi_{11}^{(t)}$ and $\Psi_{22}^{(t)}$ account for the response of oil and exchange rate changes to their lags, while $\Psi_{12}^{(t)}$ and $\Psi_{21}^{(t)}$ show the Granger causality to oil from exchange rate. The term *i* shows the lagged period. If the term $\Psi_{12}^{(t)}$ is not similar to 0, this means that oil is a function of exchange rate uncertainty (where the lag length is $I = 0, 1, \ldots$, p where 0 shows the contemporaneous effect). It is assumed that the innovations vector follows a normal distribution, with the corresponding variance-covariance matrix given as H_i, Ω_t with the information set at t-1.

After specifying the conditional mean equation, it is necessary to estimate the BEKK representation of the multivariate GARCH model. In contrast with other multivariate GARCH models, like the VEC-GARCH, the BEKK specification has certain obvious advantages because of its quadratic forms, which ensures positive definiteness of the conditional covariance matrices within the system. Contrary to the DCC model suggested by Engle (2002), which was used to estimate the time-varying correlations straight, the BEKK variant makes room for time-dependent correlations and interactions among variances in a lead-lag framework. Also, the issue of dimensionality presented by Caporin and McAleer (2012) does not remain a significant problem in the case considered, with only two variables. Compared with the two-step CCF presented by Cheung and Ng (1996), the causality-in-variance tests inclusive of the multivariate GARCH-BEKK are superior (Hafner & Hewartz 2008).

4.3.2.2 VECH and BEKK approaches

Several GARCH models have been developed and readily modified in the literature, the earliest of which remains a complex GARCH model: the VECH model devised by Bollerslev, Engle and Wooldridge (1988). This model was a modification of the basic model originally developed by Engle and Bollerslev (1986) and utilised the simultaneous equation form of the basic GARCH model.

VECH was proposed by Bollerslev, Engle and Wooldridge (1988) and is considered one of the earliest complex GARCH models and may be used to estimate multivariables. It may be written as:

$$vech(H_t) = C + \sum_{j=1}^{q} A_j vech(\epsilon_t \epsilon_{t-j}) + \sum_{j=1}^{p} B_j vech(H_{t-1}) \qquad (4.5)$$

where *vech* is an operator placing the elements present in the lower triangle of a symmetric matrix into columns, C is a vector-sized N(N + 1)/2 with N variables, A_j and

B_j are the parameters matrix-sized N(N + 1)/2 x N(N + 1)/2. Applied to two series, VECH is given as:

$$\begin{bmatrix} h_{11,t} \\ h_{12,t} \\ h_{22,t} \end{bmatrix} = \begin{bmatrix} c_{11} \\ c_{12} \\ c_{22} \end{bmatrix} + \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & b_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} \epsilon_{1,t-1}^2 \\ \epsilon_{1,t-1}\epsilon_{2,t-1} \\ \epsilon_{2,t-1}^2 \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} & b_{13} \\ b_{21} & b_{22} & b_{23} \\ b_{31} & b_{32} & b_{33} \end{bmatrix} + \begin{bmatrix} h_{11,t-1} \\ h_{12,t-1} \\ h_{22,t-1} \end{bmatrix} \quad (4.6)$$

This is a representation of the bivariate model on VECH and yielded 21 parameters. Conditional variances of the first and second series are $h_{11,t}$ and $h_{22,t}$, respectively, while $h_{12,t}$ represents the conditional covariance between the two variables to be estimated. This VECH model is relatively complex and involves the handling of many variables and parameters that must be estimated, pointing to a small degree of freedom within the system and making the problem difficult to solve.

The BEKK became the most popular model among the multivariate GARCH models used in studies because it can capture the interrelation between conditional variance and covariance between variables. That means the BEKK makes it possible to analyse the spillover between variables (Marçal & Pereira 2008). The GARCH-BEKK model is an extension that has the additional property of positive definite conditional covariance matrices. On the basis of the variance equation, the BEKK representation for a multivariate GARCH (1,1) model is usually written as:

$$\sigma_t^2 = \mu + \alpha_1 \varepsilon_{t-1} + \beta \sigma_{t-1}^2 \quad (4.7)$$

$$H_t = C_0' C_0 + A' \varepsilon_{t-1}' \varepsilon_{t-1} A + B' H_{t-1} B \quad (4.8)$$

The value of the conditional variance depends on the long-term variance given by matrix C; the actual variance of the considered period, matrix A; and the predicted variance for the considered period, matrix B. The respective variances are given by matrices A and B and have the following values:

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \quad B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \quad (4.9)$$

Thus, the bivariate form of the BEKK model is:

$$H_t = C_0' C_0 + \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix}' \begin{bmatrix} \varepsilon_{1,t-1}^2 & \varepsilon_{1,t-1}\varepsilon_{2,t-1}' \\ \varepsilon_{2,t-1}\varepsilon_{1,t-1}' & \varepsilon_{2,t-1}^2 \end{bmatrix} \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} + \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}' H_{t-1} \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix} \quad (4.10)$$

C_0 is a (2 × 2) lower triangular matrix of constants. The constant term is decomposed into a product of a lower triangular matrix and an upper triangular matrix to ensure the positive definiteness of H_t. A is a (2 × 2) matrix that displays the correlation of the conditional variance with the past squared errors, and its elements can measure the effects of shocks or unanticipated events on the conditional variances. B is also a (2 × 2) square matrix of parameters that show the volatility levels of conditional variances among variables. The H_t matrix components rely on themselves and the past value of $\varepsilon_{t-1}'\varepsilon_{t-1}$.

The equation for the BEKK model includes the lagged squared error terms and squared variance to obtain positive values for the conditional variance/covariance matrix. Matrices A and B show how the conditional variances depend on their own lagged values and lagged return shocks by capturing the ARCH and GARCH effects; however, the conditional covariances are functions of the lagged covariances and the lagged cross-products of the return shocks (Chang et al. 2013). The off-diagonal parameters $(a_{12}, a_{21}, b_{12}, b_{21})$ reveal the cross-market effect of the variance shocks in $(a_{12}\ and\ a_{21})$ and the volatility spillover of (b_{12}, b_{21}). For the bivariate case, the multivariate BEKK approach gives fewer parameters (only 11) than VECH.

Finally, to overcome these issues, Engle and Kroner (1995) introduced the BEKK model. The BEKK model conducts parametrisation of the initial system of equations in a quadratic form, which satisfies the conditional of definite positiveness for the variance-covariance matrix, without modifying the content of the equation extensively. Thus, although it is useful to apply multivariate GARCH-BEKK, since the BEKK model uses fewer variables than VECH, it will be unrealistic to include a large number of markets in this model. Thus, a bivariate BEKK-GARCH should be applied. In this regard, this study will test the following hypothesis:

Hypothesis H_{B1}: There is a volatility spillover from oil prices to exchange rates in major currencies, including the US dollar.

Hypothesis H_{B2}: There is a volatility spillover from oil prices to some other currencies (such as emerging markets currencies).

4.3.2.3 CCC approach

A MGARCH-CCC model was introduced by Bollerslev (1990). The conditional correlations were not a function of time and the conditional variances were proportional to the product of the conditional standard deviations. By employing this constraint, the number of unknown variables is reduced, and the estimation is simplified. It may be given as:

$$H_t = D_t R D_t = (\rho_{ij}\sqrt{h_{ii,t}h_{jj,t}}) \tag{4.11}$$

Here, $R = (\rho_{ij} = E(\eta_t\eta_t))$ is a symmetric positive matrix of size $k \times k$ and consists of the correlation $\rho_{ij}(\rho_{ij} = 1\forall i), \varepsilon_t = D_t\eta_t$ and η_t is a i.i.d. random vector. The term $D_t = diag(h_{11t}^{\frac{1}{2}} \dots h_{kkt}^{\frac{1}{2}})$. The model assumes that the conditional variance h_{iit} is dependent on the univariate GARCH.

$$h_{iit} = w_i + \sum_{j=1}^{q} \alpha_{ij}\varepsilon_{i,t-j}^2 + \sum_{j=1}^{p} \beta_{ij}h_{ii,t-j} \qquad i = 1, \dots, k \tag{4.12}$$

4.3.2.4 DCC approach

Many empirical studies have showed that the assumption of random shocks having time-independent conditional covariance is not necessarily true. To construct the time-independent conditional correlation matrix, Engle and Sheppard (2001), Engle (2002) and Tse and Tsui (2002) suggested generalising the CCC model. In particular, Tse and Tsui (2002) proposed a varying correlation GARCH model with conditional correlations as a function of the previous period's conditional correlations. As suggested by Tse and Tsui (2002), the DCC is given as:

$$H_t = D_t R D_t \tag{4.13}$$

$$R_t = (1 - \theta_1 - \theta_2)R + \theta_1\Psi_{t-1} + \theta_2 R_{t-1} \tag{4.14}$$

Here, D_t has been previously defined, R is a $k \times k$ symmetric positive definite parameter matrix having diagonal unit elements, and Ψ_{t-1} is the $k \times k$ correlation matrix for the previous P standardised residual $(\widehat{\varepsilon_{t-1}}, \dots, \widehat{\varepsilon_{t-p}})$. To ensure that Ψ_{t-1} remains positive, the condition is that $P \geq k, \theta_1$ and θ_2 are positive scalar parameters such that $\theta_1 + \theta_2 <$ 1. Additionally, according to Engle (2002), there are several variations of DCC models, and the covariance matrix may be decomposed as:

$$H_t = D_t R_t D_t R_t = diag(q_{11t}^{\frac{1}{2}}, \dots, q_{kkt}^{\frac{1}{2}}) Q_t diag(q_{11t}^{\frac{1}{2}}, \dots, q_{kkt}^{\frac{1}{2}}) \tag{4.15}$$

Here, Q_t is a $k \times k$ symmetric positive definite matrix that consists of the conditional covariance of the standardised residuals, as:

$$Q_t = (1 - \theta_1 - \theta_2) Q_0 + \theta_1 \eta_{t-1} \eta_{t-1} + \theta_2 Q_{t-1} \tag{4.16}$$

Here, Q_0 is the unconditional covariance matrix for the η_t, θ_1 and θ_2 are positive scalar parameters such that $\theta_1 + \theta_2 < 1$, θ_1 shows the impact of last shocks on a current conditional correlation and θ_2 captures the impact of past correlation. If the values of θ_1 and θ_2 are statistically significant, the conditional correlations may not remain constant. The likelihood function is given as (Engle 2002):

$$L(\theta) = -\frac{1}{2} \sum_{t=1}^{T} (log 2\pi + 2 log|D_t| + log|R_t| \eta'_t R_t^{-1} \eta_t \tag{4.17}$$

The estimation of the DCC model is a two-step, consistent process. Q_t is used to find the DCC:

$$\rho_{ij,t} = q_{ij} (q_{ii,t} q_{jj,t})^{1/2} \tag{4.18}$$

Next, the term $\rho_{ij,t}$ may be used to estimate the conditional covariance:

$$h_{ij,t} = \rho_{ij} (h_{ii,t} h_{jj,t})^{1/2} \tag{4.19}$$

Here, the terms $h_{ii,t}$, $h_{jj,t}$ and $h_{ij,t}$ represent the conditional variance and conditional covariance produced by employing univariate GARCH models.

4.3.3 Causality in the variance approach

For this section, the CCF is another model that uses univariate GARCH model in two steps. It was applied in this study to confirm the results of multivariate GARCH for more robust results. The CCF model was first used by Cheung and Ng (1996) to examine the causality in variance between variables. In the first step, the univariate EGARCH model estimates the conditional mean and variance, and in the second step, it is used to generate the squared residual required to test the null hypothesis of no-variance causality.

4.3.3.1 EGARCH model (the univariate step)

It is essential to note that, for traditional GARCH models, past values and their sign (positive or negative) produce a symmetric effect on conditional variance. However, in reality, many data series yield an intense asymmetric impact on conditional variance. For many equity markets, it has been observed that returns and volatility may be negatively correlated. This suggests that negative returns may be associated deeply with higher volatility compared with positive returns. This asymmetry was addressed by Christie (1982) and Black (1976), who referred to a 'leverage effect'. This leverage effect states that, as the price of an asset falls, the volatility in its returns increases.

For this reason, this study uses the exponential GARCH (EGARCH) model developed by Nelson (1991). The EGARCH is a popular model frequently utilised to observe the leverage effect. As such, it allows conditional variance to be a function of both the magnitude and sign of the error term, which implies that the variance of exchange rates may be a function of past error terms as well. In this vein, it can be said that positive and negative error terms would have different effects on the expectational errors. One great advantage associated with this model is, unlike other models, the condition of absolute positivity for the coefficients need not hold true to yield a positive variance. This can be given for the EGARCH (p, q) model as:

$$log(\sigma_t^2) = \omega + \sum_{i=1}^{q} \alpha_i g(z_{t-i}) + \sum_{j=1}^{p} \emptyset_j log\left(\sigma_{t-j}^2\right) \tag{4.20}$$

$$g(z_t) = \theta(z_t) + (|z_t| - E|z_t|), \quad z_t = \frac{v_t}{\sigma_t} \tag{4.21}$$

The differences between Equation (4.20) and the basic GARCH model can be observed, where the log of conditional variance is given on the left side. The use of log implies that the leverage effect is exponential for this case, rather than quadratic, as was observed previously, and the exponential nature of the conditional variance ascertains its positivity. As stated previously, leverage effect can occur only when a given asset's price declines as its returns become volatile. Such behaviours have been observed for the EGARCH model, where $\theta < 0$. Thus, to test for the presence of leverage effect, the hypothesis can be tested as $\theta < 0$ with an asymmetric impact for the case $\theta \neq 0$.

Specifications for the EGRACH (1, 1) model's conditional variance are:

$$log(\sigma_t^2) = a_0 + a_1(|z_{t-1}| - E|z_{t-1}|) + \emptyset log(\sigma_{t-1}^2), \qquad z_t = \frac{v_t}{\sigma_t} \qquad (4.22)$$

The term $(|z_{t-1}| - E|z_{t-1}|)$ shows the effect of size and change in magnitude of past error and its effect on current volatility of oil and exchange rates. The term z_{t-1} shows the effect of the sign of lagged residuals. Since the sign can be both positive and negative, both possibilities must be considered. If the sign is negative, the negative error increases volatility more so than does the positive error. If the sign is positive, again, this implies that the positive error enhances volatility more than the negative error does. These can be termed as exchange rates' appreciations and depreciations. The last term in Equation (4.22) is the logarithmic value of the conditional variance for the previous period. Also, the extent of prevalent volatility hinges on the size of $\emptyset$, so for values of $\emptyset = 1$, unconditional variance is said to be non-existent; this is termed a 'random walk' (i.e., the conditional variance must be integrated and have a degree of 1). For values of $\emptyset < 1$, it can be said that unconditional variance does exist as a mean-reverting process.

The existing parameters in Equation (4.22) can be easily obtained by taking the maximum value of the log-likelihood function. Many empirical studies have sought to achieve this by utilising the normal density even as the standardised residuals yielded by ARCH models stay leptokurtic since they assume normality. Nelson (1991) suggested that the errors obtained here can be assumed as displaying a GED, which is advantageous because it occurs with a low probability. For example, it can happen during speculative attacks and is unlikely to incur deviations.

4.3.3.2 CCF

The CCF measures causality in variance between variables as a two-step process. As a first step, the univariate EGARCH model is estimated, akin to the univariate model, which allows for time variations. The second step involves testing for the null hypothesis (that there is no causality in variance) by obtaining squared residuals from the univariate model. These steps have been highlighted by Cheung and Ng (1996), Hamori (2003) and Hong (2001) as follows.

Given two stationary time series, X_t and Y_t, and information sets $I_{1t} = \{X_{t-j}; j \geq 0\}$, $I_{2t} = \{Y_{t-j}; j \geq 0\}$, where $I_{3t} = \{X_{t-j}Y_{t-j}; j \geq 0\}$, it can be stated that Y_t causes variance in X_{t-j} given that:

$$E\{(X_{t+1} - \mu_{x,t+1})^2 \big| I_{1t}\} \neq E\{(Y_{t+1} - \mu_{y,t+1})^2 \big| I_{3t} \tag{4.23}$$

Here, $\mu_{x,t+1}$ is the mean of X_{t+1} that depends on I_{1t}. Similarly, it can be stated that X_t causes variance in Y_{t-j} given that:

$$E\{(Y_{t+1} - \mu_{y,t+1})^2 \big| I_{2t}\} \neq E\{(\mathrm{X}_{t+1} - \mu_{x,t+1})^2 \big| I_{3t}\} \tag{4.24}$$

Here, again, $\mu_{y,t+1}$ is the mean of Y_{t+1} that depends on I_{2t}. Feedback will exist in variance for:

$$E\{(X_{t+1} - \mu_{x,t+1})^2 \big| I_{3t}\} \neq E\{(X_{t+1} - \mu_{y,t+1})^2 \big| I_{3t} + Y_{t+1} \quad\} \tag{4.25}$$

The expressions given in Equations (4.23), (4.24) and (4.25) mean that the causality is too vague for use in empirical methods. This is why X_t and Y_t are also presented as:

$$X_t = \mu_x + h_{x,t}^{0.5}\epsilon_t \tag{4.26}$$

$$Y_t = \mu_y + h_{y,t}^{0.5}\xi_t \tag{4.27}$$

Here, ϵ_t and ξ_t are independent white noise processes whose variance is 1 and mean is 0. The standardised squared terms of these are written as:

$$U_t = (\tfrac{X_t - \mu_{x,t}}{h_{x,t}})^2 = \epsilon_t^2 \tag{4.28}$$

$$V_t = (\tfrac{Y_t - \mu_{y,t}}{h_{y,t}})^2 = \xi_t^2 \tag{4.29}$$

In Equations (4.28) and (4.29), $h_{x,t}^{0.5}$ and $h_{y,t}^{0.5}$ are conditional variances for X_t and Y_t, which can be presented in EGARCH forms as:

$$l_{M,t} = \emptyset_{f,0} + \sum_{i=1}^{\infty} \emptyset_{f,i}(\theta_{f,\mu})\{(M_{t-i} - \mu_{M,t-i})^2 - \emptyset_{M,0}\} \tag{4.30}$$

$$\mu_{M,t} = \sum_{i=1}^{\infty} \emptyset_{f,i}(\theta_{M,\mu})M_{t-i} \tag{4.31}$$

where M may be X or Y, $\theta_{M,\mu}$ is a parameter serving as a vector of dimensions $p_{M,\mu}$ x 1, such that $G = \mu, l; \emptyset_{f,i}(\theta_{f,\mu})$ and $(\theta_{f,l})$ are functions of $(\theta_{f,\mu})$ and $(\theta_{f,l})$. Given that $r_{u,v}$ is the cross-correlation for the sample at a lag of p:

$$r_{u,v}(p) = w_{v,u}(p)\sqrt{w_{v,v}(0)w_{u,u}(0)} \qquad (4.32)$$

Here, $w_{v,v}(0)$ and $w_{u,u}(0)$ are sample variances for U_t and V_t respectively. $w_{v,u}(p)$ is the p[th] lag for sample cross-covariance, for a sample size of T, given as:

$$w_{u,v}(p) = \begin{cases} T^{-1}\sum_t (U_{t-p} - \bar{U})(V_t - \bar{V}), & p \geq 0 \\ T^{-1}\sum_t (U_{t+p} - \bar{U})(V_t - \bar{V}), & p < 0 \end{cases} \qquad (4.33)$$

The terms U_t and V_t are standardised squares and are independent of each other. Consequently, their variance indicates a test statistic whose distribution is asymptotic and given as:

$$\sqrt{T}r_{u,v}(\text{p}) \sim N(0,1) \qquad (4.34)$$

Thus, the abovementioned equation may be utilised to test the null hypothesis (that there is no causality in variance) with the alternative hypothesis. When the former is true (that there is no causality in variance), it indicates that the two standardised residuals do not have any correlation. For example, when $r_{u,v}(p)$ has a value other than 0 for some p that is also greater than 0, there has been evidence that U_t is Granger, and this causes U_t in variance. The likes of these have also been observed in other studies, such as Inagaki (2007) and McMillan and Speight (2003).

4.3.4 Portfolio weights and hedge ratios

To achieve portfolio diversification and risk management, time-dependent conditional variance and covariance must be accurately measured. As an example, suppose SAMA is an investor in oil and wants to hedge its position against negative price movements, and does this by investing in foreign exchange markets. Realistically, the objective of the investor is to minimise risks for the oil portfolio while keeping expected returns unchanged. For this purpose, the analyses of Kroner and Sultan (1993) and Kroner and Ng (1998) may be utilised by estimating portfolio weights and hedge ratios using variances and covariances derived from VAR (1)-MGRACH-BEKK (1,1) model. Optimal portfolio weight for the oil is given as:

$$w_t^{12} = \frac{h_t^2 - h_t^{12}}{h_t^1 - 2h_t^{12} + h_t^2} \tag{4.35}$$

Constraints of the following type are imposed on the optimal weight for oil on mean-variance portfolio optimisation if short selling is not permitted:

$$w_t^{12} = \begin{cases} 0 \; if \; w_t^{12} < 0 \\ w_t^{12} \; if \; 0 \leq w_t^{12} \leq 1 \\ 1 \; if \; w_t^{12} > 1 \end{cases} \tag{4.36}$$

Here, w_t^{12} is the oil weight in \$1 of two assets (forex markets and oil) at time t. h_t^{12} shows conditional covariance for foreign exchange markets and oil. Optimal weight of foreign currencies for the holding of portfolio may be given as 1 – w_t^{12}.

In this regard, this study will test the following hypothesis for selecting the optimal weight and determining hedging strategy:

Hypothesis H_C: There is an optimal weights and hedge ratio to mitigate the oil risk for the SFCR.

Since the objective of SAMA is to optimally hedge any risks associated with investment in the oil market, the following is imperative: a proper position of forex markets must be obtained to minimise risks associated with the hedged position. Hedge ratios represent the short position that should be adopted by an investor to reduce the risk of a portfolio holding just oil. This is, the forex markets portfolio can be used to hedge against oil return volatility. To minimise portfolio risk, a long/short position (i.e., buying/selling) of \$1 in the oil market may be guarded by the short/long position (selling/buying) of \$$\alpha_t$, shown in foreign exchange markets.

Selling in the foreign exchange market is adequate because SAMA already owns oil as an asset and seeks to sell it in the future. This is because as market price increases, a short hedge diminishes risk through gains in the oil market becoming offset by loss realised in the foreign exchange market. Conversely, as market price decreases, a short hedge diminishes the risk that comes with oil losses, which are offset by gains in foreign exchange markets. Hedge ratio between foreign exchange markets and oil is given as:

$$\alpha_t^{12} = \frac{h_t^{12}}{h_t^2} \quad (4.37)$$

Here, α_t^{12} shows OHRs of portfolio. It is observed that OHR seeks to decrease variance of the position's value. To improve existing literature, time-dependent optimal portfolio weights and hedge ratios have been estimated to identify the effect of varying market conditions (Olson et al. 2014).

4.4 Empirical Analysis

4.4.1 Full sample and unit root test

Equation (3.20) computed daily returns for oil and 13 currency pairs, using daily data for first difference of the series' logarithmic value. Observations were from July 2012–December 2018. It was essential to account for potential volatilities present because of oil price decline events of June 2014. This was done by dividing the period into oil price decline and an overall period. Detailed analysis of the data can be found in Chapter 3.

To summarise the descriptive analysis, 1,694 observations were considered for each series for July 2012–December 2018 and daily data were used. It has previously been noted and suggested by several empirical analyses (Arouri & Nguyen 2010) that weekly data may be superior to daily data in some cases. However, this was neglected for the present analysis of the oil exchange market relationships. This was because of the greater convenience of daily data in effectively capturing changes in volatilities that arise from avoidance of time aggregation, and compensation effects of other data frequencies. As done previously, returns for the currency exchange market and oil were calculated using logarithmic ratios of two successive prices. Calculations and their results were displayed against the US dollar since the primary focus of the analysis was Saudi Arabia, which pegged its currency to the US dollar. Thus, oil returns relationships were priced in terms of the US dollar, which has rarely been studied with reference to exchange markets. Results for the logarithmic return series showed that higher returns were obtained for the USDBRL than for the currency pairs. Specifically, the emerging currency pairs had the highest returns at 0.000396, while the major currencies had the lowest returns at –0.000019.

The mean statistic employed for return series showed minimal values compared with standard deviation statistic. The negative kurtosis coefficient was observed. This was also exemplified by the negative skewness of the return series, which made it more likely to observe large negative returns than would be in the case of normal distribution. Further, the JB statistic for testing showed that non-normal distribution was present for the return series; the null hypothesis was employed at the 1% significance level and was rejected as such. The Q statistic of Ljung–Box (1978) indicated that serial autocorrelations were present for all return series considered. This test was conducted as the ARCH test (Engle 1982) for squared return series and showed that heteroskedasticity was present at the 1% significance level. This strengthens the case for employing the GARCH model to study the dynamic behaviours of oil and all currency pairs.

Unit root tests were conducted for prices and logarithmic values of return series for crude oil and the exchange rate. The ADF, PP and KPSS testing methods were employed for levels and logarithmic differences. The price series under evaluation all followed unit root processes, with stationary first differences. The null hypothesis stated that there was a unit root for the 1% significance level, and this was not accepted, as shown by the large negative values obtained.

4.4.2 Multivariate analysis

This section examines the conditional volatility in returns to capture the volatility spillover across oil and currency pairs in the overall and oil price decline periods using MGARCH-BEKK results. Moreover, MGARCH-CCC and MGARCH-DCC will help determine the dynamics of conditional correlations in returns across oil prices and currencies. To do that, we began with the estimation results for the MGARCH-BEKK model, MGARCH-CCC and MGARCH-DCC (see Tables 4.1 to 4.6).

For oil and currency pairs' transmission, the covariance and DCC (see Figures 4.1–4.6) yielded by the BEKK model using t distribution provided estimates for the conditional variance, covariance and other correlations. There were clear signs of volatility clustering, with the highest conditional variance for currencies, and the smallest for oil during the 2014 oil decline period. According to Kaufmann (2001), volatility increases are the consequence of unexpected increases in speculative behaviour of crude oil and currency markets. This causes markets to become disconnected. Conditional correlations among currencies and oil led to declines in volatility.

The conditional covariances between oil and currencies had a range of values. This implied that the conditional interrelations among oil and currencies had the greatest volatility and lowest value. For June 2014–February 2016, the conditional variance, covariance and correlations experienced the greatest volatility. This was a result of the 2014 oil decline period, when extreme rises and falls in oil prices occurred. Further, volatility transmission was largely persistent throughout the markets, suggesting they would be consistent across time. Thus, recent observations must be accounted for in predicting future trends in volatility. Such volatility transmissions may be more essential for the BEKK, CCC and DCC used to conduct the analysis.

4.4.2.1 Own shock and volatility effect

The own shock and volatility effect results documented in the MGARCH-BEKK model for oil and major currency pairs were obtained from ARCH (*a*) and GARCH (*b*) effects (see Tables 4.1–4.6). (a_{ii}), which measures short-term persistence representing the parameters and (a_{jj}) explains the past shock effect of oil or currency pairs on the current volatility (i.e. the dependence of volatility on its own lagging innovations in one market). Meanwhile, the GARCH effects for the parameters (b_{ii}) and (b_{jj})—which measure the past long-term persistence of oil or currency pairs—explain conditional volatility in each series. The results based on the MGARCH-BEKK model for oil and major currency pairs show that the oil own shock (ARCH) effect (a_{ii}) was observed in each portfolio and estimated values less than the oil volatility (GARCH) effect. This indicates that its own volatility in oil and currencies (GARCH) is larger than its own shocks (ARCH).

The empirical results based on the BEKK model reveal that the oil own shock (ARCH) effect (a_{ii}) was observed in all major currency pairs at the 1% significance level for the overall period. However, USDCHF during the oil price decline period was statistically insignificant. The oil volatility (GARCH) effect (b_{ii}) was observed on USDGBP, USDCHF and USDJPY at the 1% significance level and there was no effect on USDEUR during the overall period. However, all major currency pairs had a significant effect at the 1% level. In terms of currency pairs' own effect (a_{jj}), their own shocks were captured at the 1% significance level for all series in both periods. Simultaneously, all major currency pairs were affected by their volatilities (b_{jj}) at the 1% significance level, except USDCHF during the oil price decline period.

The commodity currencies' portfolios shared the same results in terms of oil and currencies' own shocks and volatilities, which were significant at the 1% level. In contrast, during the oil price decline phase, all commodity currencies were unaffected by the currency shocks, but were all significant at the 1% level according to the currencies' volatilities. In both periods, the emerging countries' currency pairs also shared the same results in terms of oil and currency pairs' own shocks and volatilities (ARCH) and (GARCH) at the 1% significance level.

4.4.2.2 Spillover effect

The spillover effect observed on the MGARCH-BEKK model as emanating from oil shocks to currency pairs was the most significant. For shock spillover, there was evidence of spillovers between oil and major currency pairs (a_{12}). This is because the (a_{12}) coefficient captures the cross-market effect from the oil error term to the currencies' conditional variance. The estimated coefficients during the overall period were positive and significant at the 1% level in USDEUR and USDJPY, with values of (0.010) and (0.016), respectively. However, it was negative and significant for USGGBP at–0.021 and USDCHF at –0.169. In contrast, the parameter (b_{12}) tests the cross-market effect from oil conditional variance to currencies' conditional variance, which was positive for USDGBP but negative for USDEUR and USDJPY; the latter two both have a coefficient of –0.004. The USDCHF was statistically insignificant. During the oil price decline period, the spillover effect was observed from oil shocks to all major currencies (a_{12}) at the 1% level of significance, except for USDGBP. Further, volatility spillover was negatively transmitted from oil to USDEUR and USDGBP at the 1% significance level, but not for USDCHF and USDJPY. The oil volatility spillover (b_{12}) was observed positively and respectively for USDEUR and USDGBP at coefficient values of 4.392e-3 and 0.013.

During the overall period, (a_{21}) which captured the cross-market effect in the opposite direction of the 'the currency shock spillover' was observed for USDEUR and USDJPY but was not statistically insignificant for USDGBP and USDCHF. The currency volatility spillover was observed for USDCHF and USDJPY but did not appear for USDEUR and

USDGBP. During the oil decline period, the currency shock spillover a_{21} from the euro and Japanese yen on oil was observed at the 1% significance level, and from the British pound to oil at the 10% significance level. However, there was no spillover effect on oil volatility as far as the Swiss franc was concerned. In terms of currency volatility spillover, there was a volatility spillover effect from the euro at a coefficient value of –0.146 and the British pound at –0.440. There was no spillover effect from the Swiss franc or Japanese yen.

For the commodity currencies, during the overall period, BEKK results showed that they shared the same characteristic (i.e., there was no spillover effect from oil and currency shock and volatility on the Canadian dollar), while the spillover cross-effect between oil and currencies shocks' and volatilities was observed for USDAUD and USDNZD at the 1% significance level. It is important to note that oil shock and volatility spillovers were negatively transmitted to USDAUD and USDNZD, while the currency shock and volatility spillovers were positive. During the oil price decline period, the result suggests a spillover effect transmitted from oil to the NZD and Canadian dollar at the 1% significance level, while the AUD was statistically insignificant. The values of the coefficients of UASNZD and USDCAD were 0.046 and –0.063, respectively. The oil volatility transmitted from oil to all commodity currencies was negative at the 1% significance level. In terms of oil volatility spillover, all commodity currencies were significant at the 1% level, with coefficient values of –0.019 for USDAUD, –0.061 for USDNZD and –0.185 for USDCAD. The currency volatility spillover was transmitted to oil from the NZD but not from the Australian or Canadian dollar.

For the emerging currency pairs, the oil shocks spillover appeared in half the emerging countries, including USDBRL, USDPLN and USDZAR, at the 1% significance level, while USDSEK and USDKRW reported a significance level at 5%. However, the oil shocks spillover to USDMXN was not statistically significant. The oil volatility spillover was captured for USDKRW, USDPLN, USDSEK and USDZAR at the 1% significance level, while USDBRL was at the 5% level. However, USDMXN was not affected by oil's volatility. In terms of the currency volatility spillover effect, the results captured the volatility transmission from oil to USDKRW, USDPLN, USDSEK and USDZAR at the 1% significance level. The USDBRL captured a spillover at the 5% significance level. There was no volatility transmission from oil to the USDMXN. Moreover, the spillover effect from currencies to oil was observed only for USDKRW at the 1% significance level, while the rest were not statistically significant.

For the emerging currency pairs during the oil price decline period, the spillover appeared only from oil shocks to USDBRL and USDMXN and was not observed for USDKRW, USDPLN, USDSEK and USDZAR. In terms of volatility spillover effect, the results captured the volatility transmission from oil volatility to USDBRL, USDMXN, USDPLN and USDZAR, while there was no impact on USDKRW and USDSEK. The currency shocks spillover only leaked to oil from USDMXN and USDZAR. Moreover, the spillover effect from currencies to oil was observed from USDBRL, USDKRW and USDMXN; however; there was no effect from USDPLN, USDSEK and USDZAR to oil. Based on the finding for GARCH-BEKK, we can accept the null hypothesis, which asserts there was a volatility spillover from oil prices to currencies, since most coefficients are significant. Therefore, in the wake of the oil price decline, emerging currencies and oil establish closer links.

Table 4.1: Estimate results of multivariate GARCH model: BEKK, CCC and DCC models for oil and major currency pairs (4 July 2012–31 December 2018)

Coefficients	USDEUR	USDGBD	USDCHF	USDJPY
Results of the MGARCH-BEKK(1.1) Model				
a11	0.259* (0.005)	0.246* (0.003)	0.115* (0.033)	0.239* (0.003)
b11	0.964* (0.001)	0.967* (0.001)	0.977* (0.011)	0.969* (0.001)
a22	0.131* (0.006)	0.178* (0.010)	0.197* (0.036)	0.222* (0.003)
b22	0.988* (0.001)	0.978* (0.003)	0.211** (0.088)	0.970* (0.001)
a12	0.010* (0.002)	-0.021* 0.002)	-0.169* (0.039)	0.016* (0.001)
a21	0.125*** (0.073)	-0.003 (0.057)	0.033 (0.065)	0.098* (0.014)
b12	-0.004* (0.001)	0.006* (2.562e-4)	0.014 (0.012)	-0.004* (0.000)
b21	0.004 (0.015)	0.005 (0.021)	-0.624* (0.232)	-0.026* (0.003)
Estimates of Constant Conditional Correlation				
R21	-0.089* (0.019)	-0.142* (0.022)	0.028 (0.019)	0.0433** (0.021)
Estimates of Dynamic Conditional Correlation				
θ1	0.0307* (0.0119)	0.0192* (1.566e-03)	0.074* (0.021)	0.104 (0.024)
θ2	0.920* (0.0235)	3.426e-14* (0.6271)	0.679* (0.080)	0.480 (0.307)
LogL	10940.056	10830.672	10622.987	10745.838
LBQ_O	1.698	1.765	8.998	2.184
LBQ_C	1.964	9.230	5.8815	1.241

Notes: a and b capture shock and volatility effects, respectively. *;** and *** indicates reject of null hypothesis at 1%, 5% and 10% significance levels, respectively. LogL is the Maximum Likelihood statistics. LBQ_O & LBQ_C are the statistic of Ljung-Box test for serial correlation with order 4 of squared residuals of oil and currency pair, respectively.

Table 4.2: Estimate results of multivariate GARCH model: BEKK, CCC and DCC models for oil and commodity currency pairs (4 July 2012–31 December 2018)

Coefficients	USDAUD	USDNZD	USDCAD
Results of the MGARCH-BEKK(1.1) Model			
a11	0.242* (0.012)	0.235* (0.004)	0.214* (0.032)
b11	0.967* (0.006)	0.969* (0.001)	0.970* (0.009)
a22	0.155* (0.012)	0.125* (0.005)	0.131* (0.035)
b22	0.976* (0.004)	0.980* (0.001)	0.973* (0.013)
a12	0.019* (0.004)	0.026* (0.002)	0.009 (0.008)
a21	-0.242* (0.072)	-0.208* (0.019)	-0.211 (0.142)
b12	-0.009* (0.001)	-0.012* (4.418e-4)	-0.005 (0.004)
b21	0.096* (0.027)	0.093* (0.004)	0.001 (0.041)
Estimates of Constant Conditional Correlation			
R21	-0.185* (0.021)	-0.118* (0.022)	-0.3872* (0.018)
Estimates of Dynamic Conditional Correlation			
θ1	0.022 (0.019)	4.961e-11* (0.016)	0.0208 (0.013)
θ2	0.685 * (0.047)	0.0546 (0.288)	5.991e-16 (0.385)
LogL	10707.973	10428.321	11149.932
LBQ_O	1.817	2.072	3.628
LBQ_C	1.704	7.030	11.441

Notes: a and b capture shock and volatility effects, respectively. *;** and *** indicates reject of null hypothesis at 1%, 5% and 10% significance levels, respectively. LogL is the Maximum Likelihood statistics. LBQ_O & LBQ_C are the statistic of Ljung-Box test for serial correlation with order 4 of squared residuals of oil and currency pair, respectively.

Table 4.3: Estimate results of multivariate GARCH model: BEKK, CCC and DCC models for oil and emerging countries currency pairs (4 July 2012–31 December 2018)

Coefficients	USDBRL	USDKRW	USDMXN	USDPLN	USDSEK	USDZAR
Results of the MGARCH-BEKK(1.1) Model						
a11	0.228* (0.029)	0.222* (0.022)	0.213* (0.044)	0.263* (0.015)	0.254* (0.023)	0.242* (0.018)
b11	0.972* (0.007)	0.973* (0.005)	0.976* (0.011)	0.964* (0.004)	0.967* (0.006)	0.970* (0.005)
a22	0.278* (0.064)	0.145* (0.015)	0.216 (0.146)	0.148* (0.019)	0.091* (0.018)	0.147* (0.013)
b22	0.952* (0.022)	0.984* (0.002)	0.973* (0.032)	0.978* (0.002)	0.990* (0.002)	0.984* (0.003)
a12	0.051* (0.019)	0.007** (0.003)	0.012 (0.011)	0.016* (0.002)	0.008** (0.004)	0.016* (0.006)
a21	-0.036 (0.052)	-0.232** (0.111)	-0.071 (0.050)	0.023 (0.050)	0.057 (0.082)	0.061** (0.029)
b12	-0.012** (0.005)	-0.003* (0.001)	-0.004 (0.004)	-0.007* (2.884e-4)	-0.003* (0.001)	-0.006* (0.002)
b21	0.004 (0.011)	0.059* (0.023)	0.022 (0.014)	0.013 (0.008)	0.023 (0.025)	-0.004 (0.003)
Estimates of Constant Conditional Correlation						
R21	-0.186* (0.020)	-0.1449* (0.023)	-0.236* (0.020)	-0.160* (0.023)	-0.153* (0.021)	-0.222* (0.022)
Estimates of Dynamic Conditional Correlation						
θ1	0.0585* (0.013)	3.470e-03 (0.023)	0.0459** (0.020)	0.037* (0.014)	0.042* (0.011)	0.015 (0.022)
θ2	0.5994* (0.075)	0.373 (0.437)	2.5643e-14* 0.190	0.894* (0.022)	0.867* (0.065)	0.981* (0.030)
LogL	9894.430	10976.583	10420.554	10525.994	10648.945	9904.915
LBQ_O	3.705	2.086	4.685	1.168	1.888	2.375
LBQ_C	3.336	5.336	1.639	7.216	7.002	2.001

Notes: a and b capture shock and volatility effects, respectively. *;** and *** indicates reject of null hypothesis at 1%, 5% and 10% significance levels, respectively. LogL is the Maximum Likelihood statistics. LBQ_O & LBQ_C are the statistic of Ljung-Box test for serial correlation with order 4 of squared residuals of oil and currency pair, respectively.

Table 4.4: Estimates results of multivariate GARCH model: BEKK, CCC and DCC models for oil and major currency pairs (oil decline period3 June 2014–29 February 2016)

Coefficients	USDEUR	USDGBD	USDCHF	USDJPY
Results of the MGARCH-BEKK(1.1) Model				
a11	0.262* (0.014)	0.443* (0.017)	0.070 (0.043)	0.215*** (0.112)
b11	0.939* (2.921e-3)	0.824* (6.552e-3)	0.852* (0.092)	0.965* (0.025)
a22	0.213* (8.171e-3)	-0.172* (0.011)	0.131* (0.181)	0.408* (0.101)
b22	0.971* (1.431e-3)	0.994* (1.948e-3)	-0.217* (0.048)	0.683* (0.135)
a12	-0.022* (2.663e-3)	-9.671e-4 (2.003e-3)	-0.217* (0.048)	0.056* (0.015)
a21	0.767* (0.066)	0.258*** (0.149)	-0.014 (0.241)	0.895* (0.302)
b12	4.392e-3* (8.622e-4)	0.013* (1.238e-3)	-0.029 (0.058)	-0.012 (0.010)
b21	-0.146* (0.016)	-0.440* (0.030)	-1.224* (0.389)	0.206 (0.267)
Estimates of Constant Conditional Correlation				
R21	-0.065 (0.045)	-0.187* (0.042)	1.364e-03 (0.044)	0.049 (0.041)
Estimates of Dynamic Conditional Correlation				
θ1	0.035** (0.014)	0.0190* (4.209e-03)	0.063* (0.022)	0.171* (0.048)
θ2	0.938* (0.027)	9.052e-03 (0.203)	0.880* (0.059)	0.204 (0.179)
LogL	2676.296	2792.076	2544.734	2745.891
LBQ_O	0.669	1.302	4.359	2.732
LBQ_C	1.208	1.028	0.449	0.694

Notes: a and b capture shock and volatility effects, respectively. *;** and *** indicates reject of null hypothesis at 1%, 5% and 10% significance levels, respectively. LogL is the Maximum Likelihood statistics. LBQ_O & LBQ_C are the statistic of Ljung-Box test for serial correlation with order 4 of squared residuals of oil and currency pair, respectively.

Table 4.5: Estimates results of multivariate GARCH model: BEKK, CCC and DCC models for oil and commodity currency pairs (oil decline period 3 June 2014–29 February 2016)

Coefficients	USDAUD	USDNZD	USDCAD
Results of the MGARCH-BEKK(1.1) Model			
a11	0.255* (0.031)	0.220* (0.039)	0.576* (0.052)
b11	0.934* (0.022)	0.939* (0.029)	0.862* (0.087)
a22	-6.578e-4 (0.110)	-0.005 (0.075)	-0.080 (0.089)
b22	0.969* (0.010)	0.906* (0.023)	-0.957* (0.097)
a12	0.013 (0.014)	0.046* (0.011)	-0.063* (0.014)
a21	-0.721* (0.227)	-0.967* (0.149)	2.327* (0.312)
b12	-0.019* (8.238e-4)	-0.061* (0.007)	-0.185* (0.021)
b21	0.086 (0.066)	0.592* (0.051)	0.063 (0.908)
Estimates of Constant Conditional Correlation			
R21	-0.234* (0.042)	-0.122* (0.045)	-0.511* (0.024)
Estimates of Dynamic Conditional Correlation			
θ1	0.062 (0.045)	3.937e-4 (8.776e-3)	0.016* (4.740e-03)
θ2	4.673e-15* (0.216)	0.000 (12.722)	0.187* (0.066)
LogL	2635.627	2569.883	2810.936
LBQ_O	0.489	0.431	4.006
LBQ_C	3.390	5.694	4.631

Notes: a and b capture shock and volatility effects, respectively. *;** and *** indicates reject of null hypothesis at 1%, 5% and 10% significance levels, respectively. LogL is the Maximum Likelihood statistics. LBQ_O & LBQ_C are the statistic of Ljung-Box test for serial correlation with order 4 of squared residuals of oil and currency pair, respectively.

Table 4.6: Estimates results of multivariate GARCH model: BEKK, CCC and DCC models for oil and emerging countries currency pairs (oil decline period 3 June 2012–29 February 2016)

Coefficients	USDBRL	USDKRW	USDMXN	USDPLN	USDSEK	USDZAR
Results of the MGARCH-BEKK(1.1) Model						
a11	0.352*	0.354*	0.118*	0.335*	0.323*	0.426*
	(0.013)	(0.050)	(0.019)	(0.031)	(0.055)	(0.109)
b11	0.902*	0.898*	0.921*	0.920*	0.941*	0.702*
	(0.003)	(0.036)	(0.002)	(0.015)	(0.046)	(0.194)
a22	0.155*	0.157**	0.132*	0.150*	0.184	0.414*
	(0.013)	(0.075)	(0.022)	(0.037)	(0.141)	(0.094)
b22	0.994*	0.983*	0.981*	0.971*	0.838*	0.644*
	(0.002)	(0.027)	(0.003)	(0.007)	(0.126)	(0.171)
a12	-0.028***	0.006	-0.062*	0.010	0.023	0.022
	(0.006)	(0.012)	(0.003)	(0.007)	(0.016)	(0.030)
a21	0.102*	0.790	-0.544*	0.014	-0.173	0.349***
	(0.063)	(0.921)	(0.069)	(0.216)	(0.544)	(0.187)
b12	0.032*	9.298e-4	0.033*	-0.011*	-0.019	-0.118*
	(0.002)	(0.008)	(0.001)	(0.003)	(0.015)	(0.021)
b21	-0.186*	-0.368**	-0.433*	0.011	0.587	-0.488
	(0.01)	(0.148)	(0.030)	(0.041)	(0.379)	(0.327)
Estimates of Constant Conditional Correlation						
R21	-0.212*	-0.204*	-0.315*	-0.145*	-0.132*	-0.288*
	(0.039)	(0.042)	(0.040)	(0.046)	(0.048)	(0.044)
Estimates of Dynamic Conditional Correlation						
θ1	0.013*	1.070e-12	0.004*	0.031	0.066	0.145**
	(0.003)	(0.051)	(0.029)	(0.023)	(0.047)	(0.074)
θ2	0.000	0.278*	0.000	0.935*	0.265	5.851e-15
	(3.492)	(0.800)	(8.128)	(0.065)	(0.534)	(0.337)
LogL	2391.153	2753.1	2671.779	2634.764	2656.321	2505.33
LBQ_O	1.238	1.368	4.343	0.946	0.694	2.162
LBQ_C	2.604	2.717	1.846068	0.474	1.640	1.191

Notes: a and b capture shock and volatility effects, respectively. *;** and *** indicates reject of null hypothesis at 1%, 5% and 10% significance levels, respectively. LogL is the Maximum Likelihood statistics. LBQ_O & LBQ_C are the statistic of Ljung-Box test for serial correlation with order 4 of squared residuals of oil and currency pair, respectively.

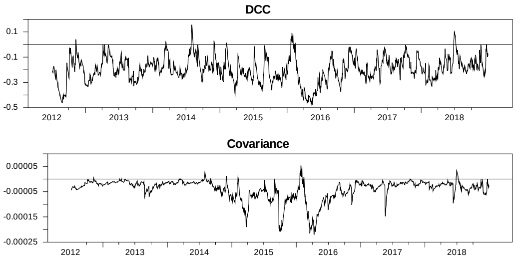
4.4.2.3 The Constant Conditional Correlation (CCC) results

The GARCH-CCC model showed a positive constant correlation between oil and all major currency pairs except USDCHF. The highest correlation is between oil and USDJPY at the coefficient value of 0.043. However, the GARCH-CCC model in the oil decline period showed no constant correlation between oil and all major currency pairs except USDGBP, which was negatively correlated at –0.187. The CCC model indicated that all commodity currencies were correlated constantly by a negative sign with oil at the 1% significance level. In both periods, the NZD had the highest value, while the Canadian dollar had the lowest value. The CCC model depicted that all emerging countries' currencies were constantly correlated with oil in both periods.

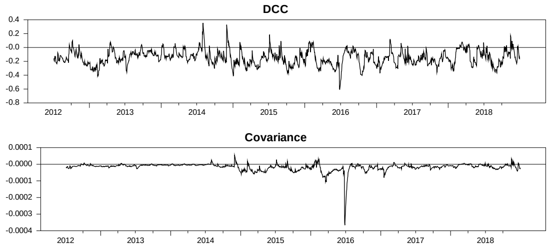
4.4.2.4 The Dynamic Conditional Correlation (DCC) results

Results for the MGARCH-DCC model are shown in Tables 4.1 to 4.6, while time-varying conditional correlations are shown in Figures 4.1 to 4.6. In the MGARCH-DCC model, the estimation of θ_1 refers to the impact of past shock on current conditional correlations, while the result of θ_2 measures the impact of past DCCs between oil and currency pairs. GARCH-DCC presents the dynamic correlation between oil and currency shocks and volatilities at the 1% significance level in both periods, except USDJPY in the overall period, which was statistically insignificant. The dynamic correlation on volatility during the oil decline price confirmed the insignificant results for USDCHF and USDJPY. The DCC graph also confirms that the DCC became negative at the start of the oil price's decline, while the DCC graph for USDGBP shows a negative correlation during overall and subperiods. The DCC graph for USDCHF and USDJPY shows a clear positive dynamic correlation, except for the oil decline price period.

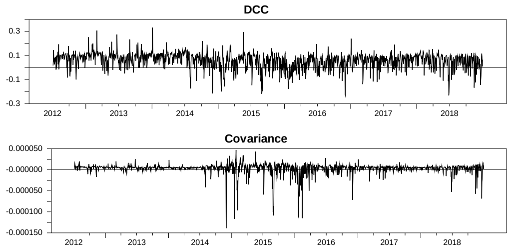
Oil–USDEUR



Oil–USDGBP



Oil–USDCHF



Oil–USDJPY

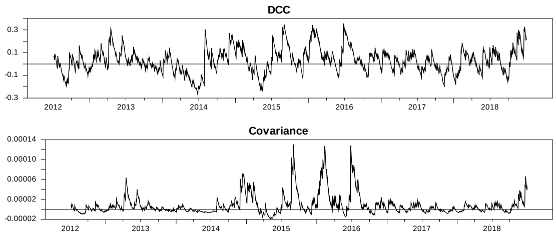
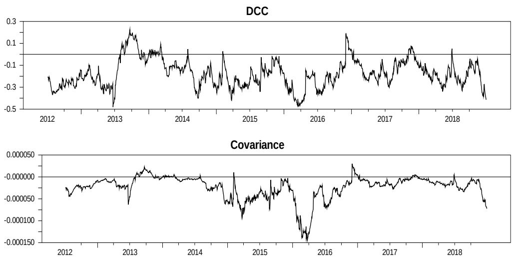
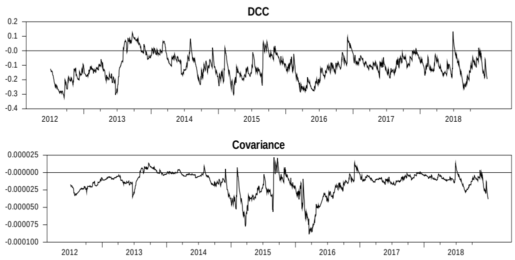


Figure 4.1: Covariance and DCC for oil–major currencies portfolios (overall period)

Oil–USDAUD



Oil–USDNZD



Oil–USDCAD

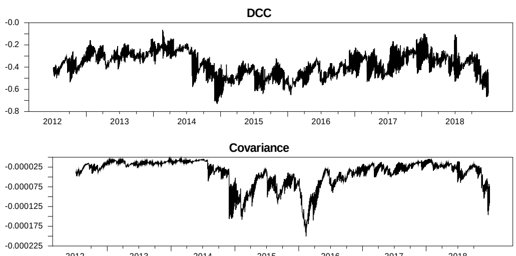
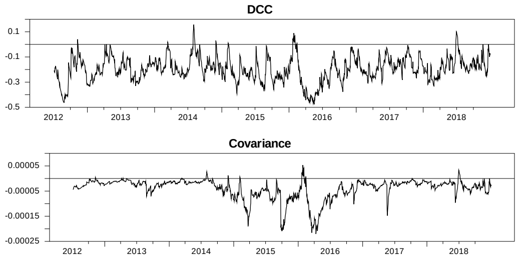
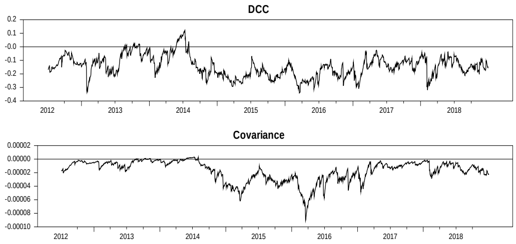


Figure 4.2: Covariance and DCC for oil–commodities currencies portfolios

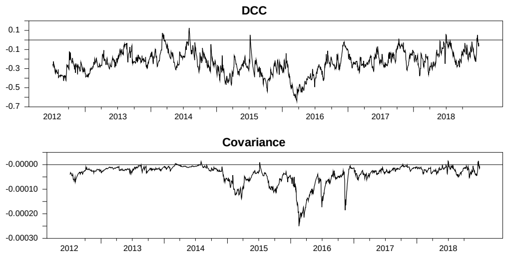
Oil-USDBRL



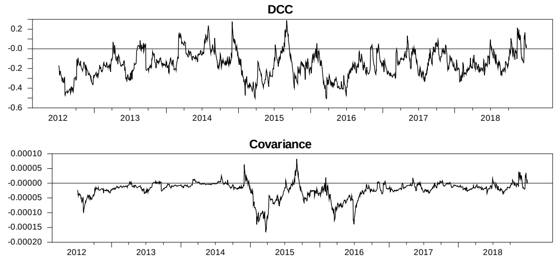
Oil–USDKRW



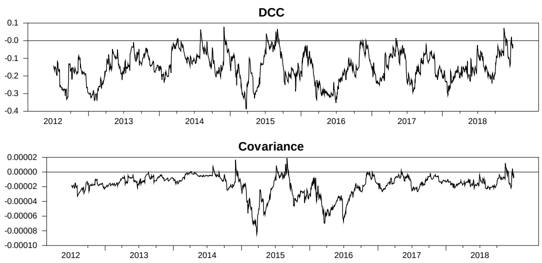
Oil–USDMXN



Oil–USDPLN



Oil–USDSEK



Oil–USDZAR

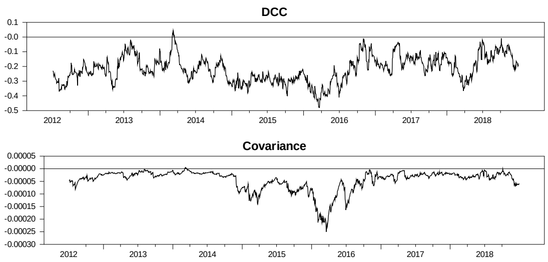


Figure 4.3: Covariance and DCC for oil–emerging currencies portfolios (overall period)

For the DCC results, the commodity currencies reveal that only USDNZD shock affected the dynamic correlation in the overall period. In contrast, the same reaction was only observed for USDCAD during the oil price decline. The impact of past DCCs between oil and commodity currency pairs was observed on all currency pairs except USDJPY for the overall period. During the oil price period, it was statistically significant only for USDAUD and USDCAD. Based on the DCC graph, all commodity pairs showed a negative dynamic correlation with oil.

In the overall period, the DCC model depicts all emerging countries' currencies shocks except USDZAR and USDKRW, which were dynamically correlated with oil shocks. The volatility dynamic correlation was observed for all currency pairs except USDKRW. In the decline period, the DCC model shows all currencies shocks except for USDPLN and USDSEK, which were dynamically correlated with oil shocks. Meanwhile, volatility dynamic correlation was not observed for any currency pairs except USDKRW and USDPLN. The DCC graph shows that all emerging currency pairs were negatively correlated. The USDMXN, USDPLN and USDSEK dynamic correlation was greatly affected during the oil price decline period.

Overall, all coefficients were statistically significant at least in one parameter, except USDJPY and USDCHF, which means that the DCC-GARCH model is effective for studying dynamics volatility. Coefficients were statistically significant at 1%, suggesting that oil and currencies have ARCH and GARCH results. The outcomes indicate that the conditional correlations confirmed our hypothesis that as dynamic correlations occur, conditional correlation will return to the long-term balance after a shock. Figures 4.4–4.6 illustrate a strong link between oil and currencies, since the correlation coefficients were high. The DCC decreased between 2014 and 2016 and became more volatile, perhaps because of the oil decline event. In the overall period, there were more apparent peaks, suggesting that after the oil decline event, arbitrators are less active and the link between oil and currency was loosened more frequently (Tao & Green 2012). The t-test results were consistent with the DCC between oil and currencies.

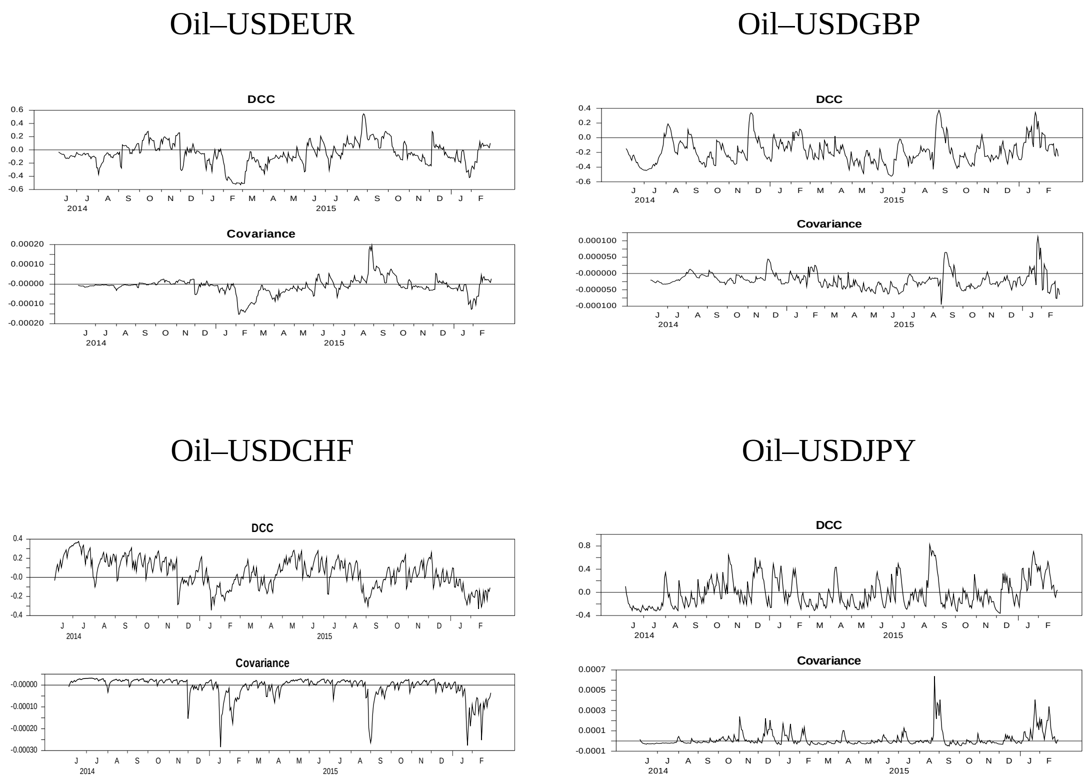
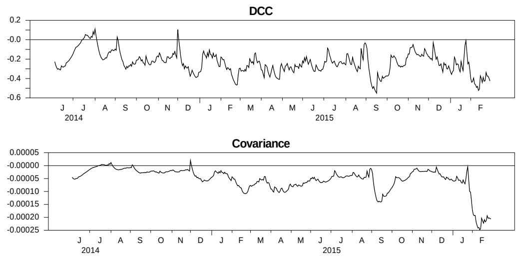
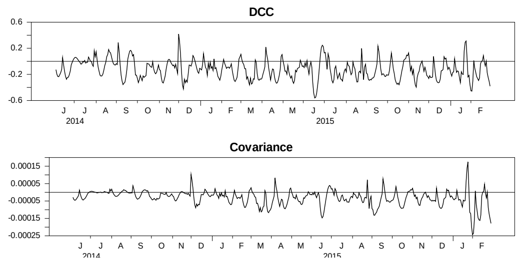


Figure 4.4: Covariance and DCC for oil–major currencies portfolios (oil decline period)

Oil–USDAUD



Oil–USDNZD



Oil–USDCAD

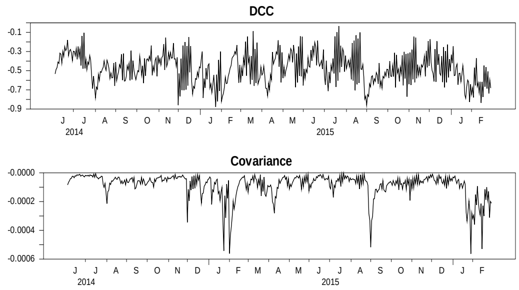


Figure 4.5: Covariance and DCC for oil–commodities currencies portfolios (oil decline period)

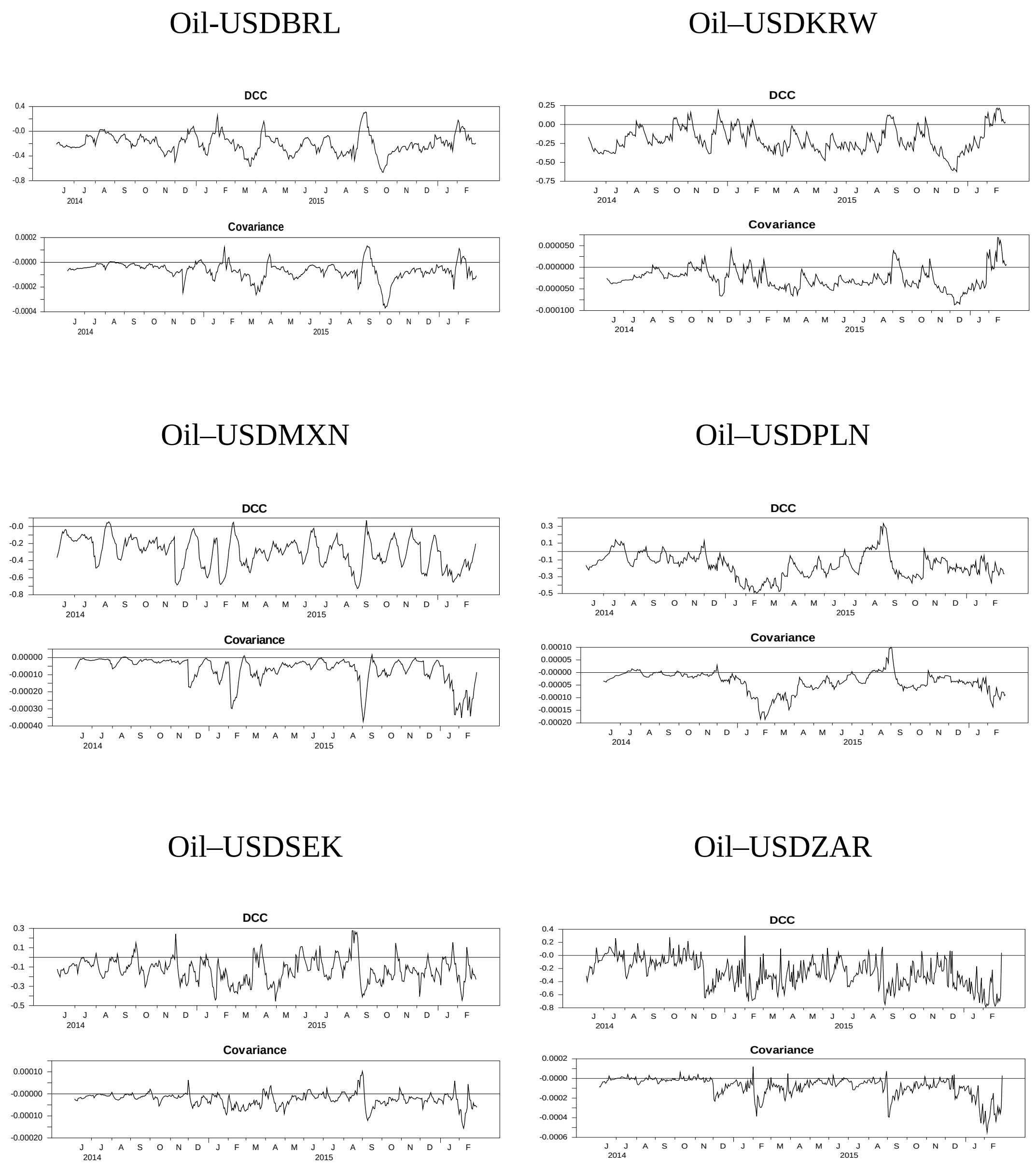


Figure 4.6: Covariance and DCC for oil–emerging currencies portfolios (oil decline period)

4.4.3 3 Cross Correlation Function (CCF)

The CCF results indicated that for test statistics on the null hypothesis, there was no causality in the variance for lag up to the tenth order. As mentioned previously, the CCF test is a two-stage process that confirmed the MGARCH-BEKK results for volatility spillover effect. First, it is essential to obtain an estimation for the univariate EGARCH model and find the standardised squared residuals. The procedure was adopted in calculating and testing for the variables. Tables 4.7–4.19 present 14 causality-in-variance relationships for oil various currency pairs. The results were grouped to present the test statistics for oil and currency pairs, along with their lead and lag values and test statistics. Results for the link between oil and currencies of lagged and lead coefficients and test statistics represented up to 10 lags. These results revealed that the presence of feedback causalities among various returns for different lag values, excluding oil and returns from the Canadian dollar and Mexican peso in the overall period and the Swedish krona in the oil decline period, where the null hypothesis for no causality was accepted. Also, all results for rejecting the null hypothesis had a positive relationship. The causalities in variance among oil and other currency pairs' returns were also represented. The variance of return for the oil market caused the return of variance for currencies at different lags.

The variance of oil return in the overall period caused the return of variance of three major currencies: at lag 6 and lag 8 for USDEUR, lag 1 for USDGBP and USDJPY at lag 1 and lag 6. Conversely, there were observations for the causality ranging from variance of two currencies' returns to variance of oil return: USDCHF at lag 7 and USDJPY at lag 1 and lag 5. Additionally, causality between the variance of return during the oil price decline for oil was present for variance of return concerning some other currencies: at lag 5 for USDEUR and lag 0 and lag 9 for USDGBP. In contrast, most major currencies', including USDEUR, USDGBP and USDCHF, returns variance were caused by the oil variance of return.

Results for variance of oil returns showed that the null hypothesis of no causality was rejected; this extended to two commodity currencies in the overall period. The causality of oil variance applied to USDAUD at lag 0 and USDNZD at lag 0 and lag 4. Contrary to this, there was more evidence of causality ranging from the variance of the Australian and NZDs returns to the oil return. These instances were given at lag 0 and lag 4 for USDAUD, and lag 0 and lag 10 for USDNZD. Further, during the oil price period, there was a 5% significance level for the variance of the return to cause return of variance from oil to all three commodity currencies: at lag 0 and lag 10 for the AUD and Canadian dollar, lag 0 and lag 6 for the NZD. The causality ranging from the commodity currencies' variance returned to variance of oil returns only at lag 0 and lag 4 for the NZD.

For the variance in emerging countries' currencies returns in the overall period, the results provided evidence that the null hypothesis of no causality ranging from a total of five instances of causality were observed for variance of oil to USDBRL at lag 4 was rejected, as well as lag 0 and lag 8 for USDKRW, lag 0 for USDPLN, lag 0 and lag 6 for USDSEK and lag 0 and lag 10 for USDZAR. A causality was observed for variance of emerging currencies' returns to variance of oil return at lag 0 for USDBRL and lag 0 and lag 5 for USDKRW.

Lastly, through the return of oil, there was a considerable rejection of the null hypothesis, which predicted that causality would range from it to returns of various emerging currencies during the oil price decline period: at lag 7 for USDBRL, lag 0 for USDMXN, lag 0 and lag 6 for USDPLN and lag 0 and lag 4 for USDZAR. The causality in variance ranging from currencies to the oil returns were given at: lag 0 and lag 7 for USDBRL, lag 0, lag 4 and lag 6 for USDKRW and lag 0 and lag 3 for USDMXN.

Table 4.7: Cross Correlation Function between oil–USDEUR

	Overall Period				Oil decline period			
	OIL USDEUR(-i)	OIL USDEUR(+i)	CCF statistic		OIL USDEUR(-i)	OIL USDEUR(+i)	CCF statistic	
Lag Order	lag	lead	Lag	Lead	lag	lead	Lag	Lead
0	0.091	0.011	3.748	0.874	0.006	0.006	0.130	0.130
1	0.0055	0.0221	0.227	0.910	-0.026	-0.005	-0.556	-0.100
2	0.0187	0.0134	0.770	0.552	0.026	0.029	0.563	0.616
3	0.0294	-0.0133	1.211	-0.548	0.072	-0.105*	1.538	-2.109
4	0.0077	0.0015	0.317	0.062	0.003	-0.018	0.072	-0.388
5	-0.0074	0.0432	-0.305	1.779	0.111*	0.085	2.363	1.800
6	-0.0073*	0.0334	-1.975	0.301	0.008	-0.031	0.177	-0.665
7	0.0365	-0.0119	1.503	-0.490	-0.042	0.027	-0.903	0.575
8	0.0212*	-0.0274	1.998	-0.873	0.002	-0.001	0.047	-0.030
9	0.007	-0.0183	0.288	-0.754	0.035	-0.035	0.754	-0.754
10	-0.0144	0.022	-0.593	0.906	-0.056	-0.010	-1.189	-0.202

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.8: Cross Correlation Function between oil–USDGBP

	Overall Period				Oil decline period			
	OIL USDGBP(-i)	OIL USDGBP(+i)	CCF statistic		OIL USDGBP(-i)	OIL USDGBP(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.091	0.011	3.748	0.874	-0.1574*	-0.1574*	-3.354	-3.354
1	0.0055*	0.0221	0.227	1.980	0.0191	-0.1308	0.407	-2.787
2	0.0187	0.0134	0.770	0.552	0.0409	0.0427	0.871	0.910
3	0.0294	-0.0133	1.211	-0.548	-0.0226	-0.024	-0.482	-0.511
4	0.0077	0.0015	0.317	0.062	-0.0287	-0.0274	-0.612	-0.584
5	-0.0074	0.0432	-0.305	1.779	0.0378	0.0486	0.805	1.036
6	-0.0073*	0.0334	-1.975	0.301	-0.0001	-0.0218	-0.002	-0.464
7	0.0365	-0.0119	1.503	-0.490	0.0043	-0.004	0.092	-0.085
8	0.0212	-0.0274	0.873	-1.128	-0.0025	-0.1345*	-0.053	-2.866
9	0.007	-0.0183	0.288	-0.754	-0.1204*	-0.0772	-2.435	-1.995
10	-0.0144	0.022	-0.593	0.906	-0.0096	0.0667	-0.205	1.421

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.9: Cross Correlation Function between oil–USDCHF

	Overall Period				Oil decline period			
	OIL USDCHF(-i)	OIL USDCHF(+i)	CCF statistic		OIL USDCHF(-i)	OIL USDCHF(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.0082	0.0082	0.338	0.338	0.0031	0.0031	0.066	0.066
1	0.0063	0.0251	0.259	1.034	0.0418	0.0517	0.891	1.102
2	-0.0134	-0.0144	-0.552	-0.593	-0.0386	0.0507	-0.822	1.080
3	0.0166	0.0124	0.684	0.511	-0.0076	-0.0397	-0.162	-0.846
4	0.0047	-0.0159	0.194	-0.655	0.0218	-0.0828	0.464	-1.764
5	0.0057	-0.0141	0.235	-0.581	-0.0245	0.0553	-0.522	1.178
6	-0.0111	-0.006	-0.457	-0.247	-0.0068	0.0225	-0.145	0.479
7	-0.0077	0.1184*	-0.317	2.346	0.0659	-0.1654*	1.404	-2.393
8	-0.0079	0.0189	-0.325	0.778	0.0009	0.006	0.019	0.128
9	0.0074	-0.0165	0.305	-0.680	-0.0427	0.0028	-0.910	0.060
10	-0.0137	-0.0133	-0.564	-0.548	-0.0079	0.0514	-0.168	1.095

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.10: Cross Correlation Function between oil–USDJPY

	Overall Period				Oil decline period			
	OIL USDJPY(-i)	OIL USDJPY(+i)	CCF statistic		OIL USDJPY(-i)	OIL USDJPY(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.0784*	0.0784*	3.229	3.229	0.0416	0.0416	0.886	0.886
1	-0.0036	0.0257*	-0.148	1.969	0.0054	-0.0132	0.115	-0.281
2	-0.0059	0.0205	-0.243	0.844	-0.0201	0.0934	-0.428	1.990
3	0.0541	-0.0061	2.228	-0.251	0.1111	0.0018	0.367	0.038
4	-0.0199	-0.0064	-0.820	-0.264	0.0099	-0.0017	0.211	-0.036
5	0.0333	0.2385*	1.371	4.586	0.094	0.0951*	0.003	0.1983
6	0.1940*	0.0196	3.684	0.807	0.0422	0.0292	0.899	0.622
7	0.0202	0.0117	0.832	0.482	0.0197	0.0281	0.420	0.599
8	-0.0355	-0.0035	-1.462	-0.144	-0.0534	-0.0002	-1.138	-0.004
9	0.0268	0.0115	1.104	0.474	0.0059	-0.0286	0.126	-0.609
10	0.0334	-0.0017	1.375	-0.070	0.0294	-0.0559	0.626	-1.191

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.11: Cross Correlation Function between oil–USDAUD

	Overall Period				Oil decline period			
	OIL USDAUD(-i)	OIL USDAUD(+i)	CCF statistic		OIL USDAUD(-i)	OIL USDAUD(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.0678*	0.0678*	2.792	2.792	-0.2019*	-0.0019	-4.302	-0.302
1	-0.0025	0.0144	-0.103	0.593	0.0052	-0.0879	0.111	-1.873
2	-0.0214	-0.0325	-0.881	-1.338	-0.0004	0.0342	-0.009	0.729
3	0.0068	-0.0071	0.280	-0.292	-0.0247	-0.0413	-0.526	-0.880
4	0.0092	-0.0384*	0.379	-2.581	0.0247	-0.0115	0.526	-0.245
5	0.0046	0.0396	0.189	1.631	0.0506	-0.0048	1.078	-0.102
6	-0.0252	0.003	-1.038	0.124	-0.1376	0.0315	-2.932	0.671
7	0.0012	0.0281	0.049	1.157	0.0368	-0.0065	0.784	-0.138
8	0.0649	-0.0196	2.673	-0.807	-0.0028	-0.0186	-0.060	-0.396
9	-0.0112	-0.0127	-0.461	-0.523	0.0078	-0.017	0.166	-0.362
10	-0.0307	-0.0175	-1.264	-0.721	0.0102*	-0.0073	2.217	-0.156

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.12: Cross Correlation Function between oil–USDNZD

	Overall Period				Oil decline period			
	OIL USDNZD(-i)	OIL USDNZD(+i)	CCF statistic		OIL USDNZD(-i)	OIL USDNZD(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.0677*	0.0677*	2.788	2.788	-0.1102*	-0.1102*	-2.348	-2.348
1	0.0023	-0.001	0.095	-0.041	-0.0104	0.0063	-0.222	0.134
2	-0.0432	-0.012	-1.779	-0.494	-0.0151	0.0319	-0.322	0.680
3	0.0333	0.0031	1.371	0.128	-0.0062	-0.0813	-0.132	-1.732
4	0.0267*	-0.0391	2.100	-1.610	0.0273	0.0649*	0.582	3.383
5	0.0096	0.0216	0.395	0.890	0.004	0.0005	0.085	0.011
6	-0.0201	-0.0128	-0.828	-0.527	-0.1242*	-0.0007	-2.646	-0.015
7	-0.0149	0.0368	-0.614	1.516	-0.0065	-0.0102	-0.138	-0.217
8	-0.0029	-0.0174	-0.119	-0.717	0.0377	-0.0138	0.803	-0.294
9	0.0288	0.0018	1.186	0.074	-0.0102	-0.004	-0.217	-0.085
10	-0.0167	-0.0334*	-0.688	-4.375	-0.0251	0.0086	-0.535	0.183

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.13: Cross Correlation Function between oil–USDCAD

	Overall Period				Oil decline period			
	OIL USDNZD(-i)	OIL USDNZD(+i)	CCF statistic		OIL USDNZD(-i)	OIL USDNZD(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.1657	0.1657	1.824	1.824	0.1671*	0.0171	3.560	0.560
1	-0.0142	0.0193	-0.585	0.795	0.0016	0.0064	0.034	0.136
2	0.0003	-0.0105	0.012	-0.432	-0.0177	-0.0094	-0.377	-0.200
3	0.0004	-0.0003	0.016	-0.012	-0.0102	0.0015	-0.217	0.032
4	0.0126	0.0123	0.519	0.507	0.0216	-0.0053	0.460	-0.113
5	0.0071	0.0606	0.292	0.496	0.0168	0.0398	0.358	0.848
6	-0.0143	-0.0286	-0.589	-1.178	-0.0029	0.0034	-0.062	0.072
7	0.0103	0.0348	0.424	1.433	-0.0239	0.1207	-0.509	2.572
8	0.025	0.0001	1.030	0.004	-0.0423	-0.0401	-0.901	-0.854
9	0.0103	-0.0269	0.424	-1.108	-0.055	0.0059	-1.172	0.126
10	0.0228	0.0323	0.939	1.330	0.0555*	0.0078	2.183	0.166

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.14: Cross Correlation Function between oil-USDBRL

	Overall Period				Oil decline period			
	OIL USDBRL(-i)	OIL USDBRL(+i)	CCF statistic		OIL USDBRL(-i)	OIL USDBRL(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.0253	0.0253*	1.042	1.992	-0.2039*	-0.2039*	-4.345	-4.345
1	-0.0073	0.0111	-0.301	0.457	0.0348	0.009	0.741	0.192
2	-0.0095	-0.0351	-0.391	-1.446	0.1005	-0.0842	2.141	-1.794
3	0.0008	0.0145	0.033	0.597	-0.0552	0.0476	-1.176	1.014
4	0.1051*	-0.01	4.328	-0.412	0.0248	-0.0008	0.528	-0.017
5	-0.0071	-0.0145	-0.292	-0.597	0.0184	-0.0427	0.392	-0.910
6	-0.003	0.002	-0.124	0.082	-0.0572	0.0276	-1.219	0.588
7	-0.0102	-0.0189	-0.420	-0.778	0.0358*	-0.092*	2.763	-2.960
8	0.0052	0.0123	0.214	0.507	-0.0259	0.0168	-0.552	0.358
9	0.0083	-0.006	0.342	-0.247	-0.0124	-0.0528	-0.264	-1.125
10	0.0289	0.0676*	1.190	2.784	-0.0114	0.031	-0.243	0.661

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.15: Cross Correlation Function between oil–USDKRW

	Overall Period				Oil decline period			
	OIL USDKRW(-i)	OIL USDKRW(+i)	CCF statistic		OIL USDKRW(-i)	OIL USDKRW(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.0631*	0.0631*	2.599	2.599	-0.0063	-0.1793*	-0.820	-3.820
1	0.0143	-0.0018	0.589	-0.074	-0.0087	-0.0337	-0.185	-0.718
2	-0.0162	0.0092	-0.667	0.379	-0.0096	-0.0031	-0.205	-0.066
3	-0.0008	0.0177	-0.033	0.729	-0.0677	0.0606	-1.443	1.291
4	0.0038	-0.0157	0.156	-0.647	0.0077	0.0523*	0.164	3.114
5	0.0118	0.0508*	0.486	2.092	0.0387	-0.0369	0.825	-0.786
6	-0.0373	-0.0042	-1.536	-0.173	-0.0476	0.1604*	-0.145	2.287
7	0.0139	0.0535*	0.572	2.203	0.0358	-0.0421	0.763	-0.897
8	0.0227*	-0.019	3.935	-0.782	0.03	-0.0088	0.639	-0.188
9	0.0225	0.0056	0.927	0.231	-0.0248	-0.0184	-0.528	-0.392
10	0.0032	-0.0235	0.132	-0.968	0.0046	0.0507	0.098	1.080

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.16: Cross Correlation Function between oil–USDMXN

	Overall Period				Oil decline period			
	OIL USDMXN(-i)	OIL USDMXN(+i)	CCF statistic		OIL USDMXN(-i)	OIL USDMXN(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.0822	0.0822	0.385	0.385	-0.2816*	-0.2816*	-6.000	-6.000
1	-0.0031	0.002	-0.128	0.082	-0.0217	0.0132	-0.462	0.281
2	0.0062	0.0071	0.255	0.292	-0.0022	-0.0992*	-0.047	-2.114
3	0.0125	0.0053	0.515	0.218	-0.0862	0.066	-1.837	1.406
4	0.0312	0.0019	1.285	0.078	0.0638	0.0249	1.359	0.531
5	-0.0116	0.0458	-0.478	1.886	-0.0266	-0.0071	-0.567	-0.151
6	0.0014	-0.0302	0.058	-1.244	-0.0873	0.0147	-1.860	0.313
7	-0.0403	0.0386	-1.660	1.590	0.0649	0.0309	1.383	0.658
8	0.0313	0.0119	1.289	0.490	0.0192	-0.0667	0.409	-1.421
9	-0.0027	-0.002	-0.111	-0.082	-0.0592	-0.0382	-1.261	-0.814
10	0.0059	-0.0282	0.243	-1.161	0.0063	0.0682	0.134	1.453

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.17: Cross Correlation Function between oil–USDPLN

	Overall Period				Oil decline period			
	OIL USDPLN(-i)	OIL USDPLN(+i)	CCF statistic		OIL USDPLN(-i)	OIL USDPLN(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.0652*	0.0053	2.685	1.425	-0.2847*	-0.042	-6.066	-0.046
1	0.0095	-0.0156	0.391	-0.642	-0.036	0.0833	-0.767	1.775
2	-0.008	-0.0115	-0.329	-0.474	-0.0217	-0.086	-0.462	-1.832
3	0.0106	0.0065	0.437	0.268	-0.0028	0.0152	-0.060	0.324
4	0.0076	-0.0074	0.313	-0.305	0.0687	0.0657	1.464	1.400
5	0.0071	-0.0092	0.292	-0.379	-0.0221	-0.0031	-0.471	-0.066
6	0.0006	0.0254	0.025	1.046	-0.1095*	0.0312	-2.333	0.665
7	-0.0096	0.009	-0.395	0.371	0.0206	0.0156	0.439	0.332
8	0.048	-0.0269	1.977	-1.108	0.0385	0.0237	0.820	0.505
9	0.0138	-0.0111	0.568	-0.457	0.0092	-0.0163	0.196	-0.347
10	0.0112	-0.017	0.461	-0.700	0.0005	0.0219	0.011	0.467

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.18: Cross Correlation Function between oil–USDSEK

	Overall Period				Oil decline period			
	OIL USDSEK(-i)	OIL USDSEK(+i)	CCF statistic		OIL USDSEK(-i)	OIL USDSEK(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.0712*	0.0207	2.932	1.441	-0.0118	-0.0118	-0.382	-2.382
1	0.0054	-0.0028	0.222	-0.115	0.0378	0.0084	0.805	0.179
2	0.0126	0.0261	0.519	1.075	-0.0125	-0.0472	-0.266	-1.006
3	-0.0136	0.0172	-0.560	0.708	-0.0653	-0.0375	-1.391	-0.799
4	0.0145	-0.0394	0.597	-1.623	0.0022	0.0292	0.047	0.622
5	0.0216	0.0266	0.890	1.095	-0.0508	-0.0021	-1.082	-0.045
6	0.0455*	-0.0127	2.874	-0.523	-0.0391	0.0077	-0.833	0.164
7	-0.0107	-0.0281	-0.441	-1.157	0.0607	-0.0106	1.293	-0.226
8	0.0272	-0.0323	1.120	-1.330	0.0249	0.0368	0.531	0.784
9	0.02	0.0105	0.824	0.432	0.0175	-0.0789	0.373	-1.681
10	-0.0015	-0.0085	-0.062	-0.350	-0.0085	-0.0096	-0.181	-0.205

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

Table 4.19: Cross Correlation Function between oil–USDZAR

	Overall Period				Oil decline period			
	OIL USDZAR(-i)	OIL USDZAR(+i)	CCF statistic		OIL USDZAR(-i)	OIL USDZAR(+i)	CCF statistic	
Lag Order	lag	lead	Lag	lag	lead	Lag	lag	lead
0	0.0273*	0.0076	2.914	1.124	-0.2847*	-0.0147	-6.066	-0.022
1	-0.0338	0.0416	-1.392	1.713	-0.036	0.0833	-0.767	1.775
2	-0.0061	-0.0078	-0.251	-0.321	-0.0217	-0.086	-0.462	-1.832
3	0.0029	0.0176	0.119	0.725	-0.0028	0.0152	-0.060	0.324
4	-0.0069	-0.0226	-0.284	-0.931	0.2687*	0.0657	4.464	1.400
5	-0.0213	0.0764	-0.877	0.146	-0.0221	-0.0031	-0.471	-0.066
6	0.0235	0.0339	0.968	1.396	-0.1095	0.0312	-2.333	0.665
7	-0.0183	0.0026	-0.754	0.107	0.0206	0.0156	0.439	0.332
8	0.0093	0.0139	0.383	0.572	0.0385	0.0237	0.820	0.505
9	-0.0246	0.0098	-1.013	0.404	0.0092	-0.0163	0.196	-0.347
10	0.0222*	-0.033	2.714	-1.359	0.0005	0.0219	0.011	0.467

Notes: The null hypothesis of Cross-Correlation Function (CCF) causality test H_0= there is no causality in variance. * Indicates a rejection of null hypothesis of no causality in variance at 5%. The negative lag (-i) represents causality from oil to currency pair, while the positive lags (+i) represent causality from currency pair to oil.

4.4.4 Implications for portfolio management

Understanding the impact of spillover volatilities is critical for risk management and effective asset diversification to maintain the effectiveness of optimal weights and hedge ratios. Considering the significant volatility spillover effects from oil and currencies, potential opportunities for portfolio diversification are considerable by investing in both oil and currencies. Portfolio managers in SAMA must quantify optimal weights and hedging ratios to mitigate risk exposures of volatile markets and unexpected price changes; this would minimise the increased risk without reducing expected returns. Likewise, SAMA can also achieve greater diversification advantages by investing in both oil and currencies. Since the Saudi government has decided not to disclose SFCR information to public, we simulate a two-asset portfolio of oil and currencies (major, commodity and emerging currencies) to illustrate the effect of the empirical results on optimum portfolio structure and risk management. This was done to reduce the risk posed to both oil and currencies. In this study, we use the in-sample estimation based on VAR(1)-BEKK-GARCH model to obtain its variance and covariance results. These results, therefore, were applied to estimate the optimal portfolio weight and OHRs.

By employing the Kroner and Ng method (1998), we determined optimal portfolio weight by building a simulated risk-mitigated portfolio without decreasing desired returns. The optimal weight of the portfolio investments was based on the two assets in each portfolio. In line with Kroner and Sultan, who determined the OHR, if a long/short one-dollar position in the oil / currency is covered by a short/long one-dollar position on the currency market, the risk of the product portfolio was hedged. Table 4.20 illustrates the estimated values of the optimal portfolio weights and hedging ratios for our variables. Using the VAR(1)-GARCH-BEKK(1,1) model, the optimal weight for oil was between 28.7% for oil–USDKRW and 78.8% for oil–USDZAR for the overall period. However, during the oil price decline period, the optimal oil holding in the portfolio indicated that the lowest weight was in the oil-USDYEN portfolio at 20.4%; meanwhile, the highest optimal weight was 60.7% in the oil-USDBRL portfolio. Consequently, there is evidence supporting the third research hypothesis: that there are optimal weights and hedge ratios to mitigate the oil risk on the SFCR caused by the decreased weight of oil in all portfolios during the oil price decline.

The oil and currency pairs portfolios considered in this thesis were equivalent to the two-asset portfolio OHRs proposed by Kroner and Sultan (1993). The VAR(1)-GARCH-BEKK(1,1) model was used to identify the time-dependent OHRs (see Table 4.20) and confirmed variable trends following the oil price decline in June 2014. This was despite many hedge ratios attaining their maximum values after June 2014. The average OHR provided information for hedge ratios' effectiveness; it was observed that the risk of declining oil revenues could be mitigated by adopting a long/short position for the foreign currency market to rebalance the SFCR. For instance, the ratio of 0.318 during the overall period for the oil–USDJPY portfolio showed that a one-dollar decline in oil was equal to buying 31.8 cents in USDJPY. Applying Kroner and Sultan's (1993) approach to the oil–USDJPY portfolio, we found evidence for the power of using this approach to overcome the oil decline risk. To compare the hedge ratios obtained in both overall and oil price decline periods, the respective OHRs were 31.8 cents and 17.2 cents for the oil–USDJPY portfolio.

Table 4.20: Simulated optimal portfolio weight and hedge ratio

Portfolio	Oil decline period		Overall period	
	Estimated Weight	Estimated hedge Ratio	Estimated Weight	Estimated hedge Ratio
Oil-USDEUR	0.324	0.256	0.457	0.303
Oil-USDGBD	0.302	0.666	0.519	0.368
Oil-USDCHF	0.328	0.163	0.382	0.233
Oil-USDJPY	0.204	0.172	0.469	0.318
Oil-USDAUD	0.319	0.478	0.387	0.309
Oil-USDNZD	0.304	0.425	0.418	0.496
Oil-USDCAD	0.34	0.223	0.375	0.332
Oil-USDBRL	0.607	0.458	0.730	0.406
Oil-USDKWS	0.228	0.542	0.287	0.349
Oil-USDMXN	0.302	0.788	0.555	0.416
Oil-USDPLN	0.289	0.372	0.451	0.275
Oil-USDSEK	0.257	0.325	0.426	0.288
Oil-USDZAR	0.424	0.494	0.788	0.280

Source: Compiled by the author.

In most cases, the allocation of currency to a single dollar currency and oil portfolio indicates that SAMA should have more currency than it does oil to reduce the volatility of a portfolio without lowering the expected return. In a portfolio containing oil and currencies, we examined optimum portfolio weights of a currency pair. Based on our results, most currency pair weights were over 50% during the oil price decline period except USDBRL and USDGBP. It is important to know that the lowest hedge ratio indicates the most effective hedging in a particular portfolio. In contrast, the higher hedge ratio indicates that the investment is the most expensive. Estimated results suggest that oil–USDCHF and oil–USDJPY portfolios should invest in major currencies. Meanwhile, the oil–USDCAD portfolio is the cheaper cost based on the hedging ratio value and the lower weight of oil. However, the aim of this study is to mitigate oil volatility risk on SFCR. Thus, we cannot add the oil–USDCAD portfolio to the SFCR portfolio because Canada is a major oil-exporting country. Oil–USDSEK and oil–USDPLN portfolios were selected among the emerging currencies based on two things: the significant values of the hedging ratios and the high weight of these currencies on their portfolios.

These results show that SAMA should spend more on major currencies than it does on emerging currencies because SAMA may reduce the risks in its investment portfolios. Our findings can also be an incentive to increase investment in currency. However, these findings correspond to the view that oil or emerging currencies as SAMA can benefit from diversification based on the low weight of oil on these portfolios. These also indicate that adding commodity currencies and emerging countries' currencies to current major currencies offers better options for portfolio diversification. When trading in oil and three groups of currencies, SAMA can hedge the risk of SFCR depletion when oil prices decline.

Our empirical results generally show that incorporating major currencies into a well-diversified commodity currencies or emerging countries' currencies portfolio can reduce risk without sacrificing return. This also permits SAMA to balance its risk exposure to global oil decline and events in the domestic economy. Importantly, this makes it possible for SAMA to enhance its risk-adjusted performance through more diversified portfolios and better execution of the hedge strategy.

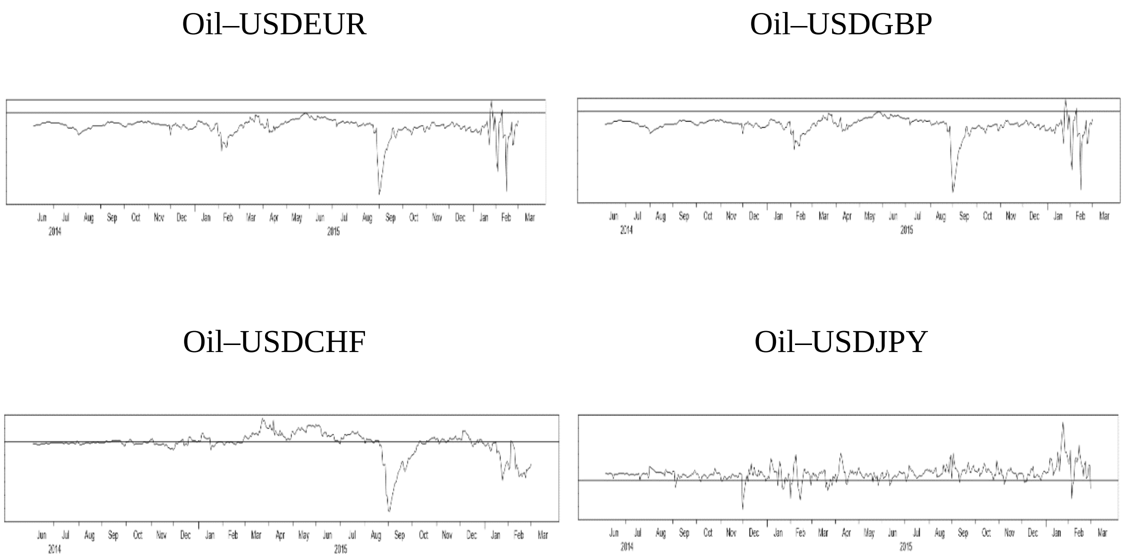


Figure 4.7: Time- varying hedge ratios for oil–major currencies portfolios (oil decline period)

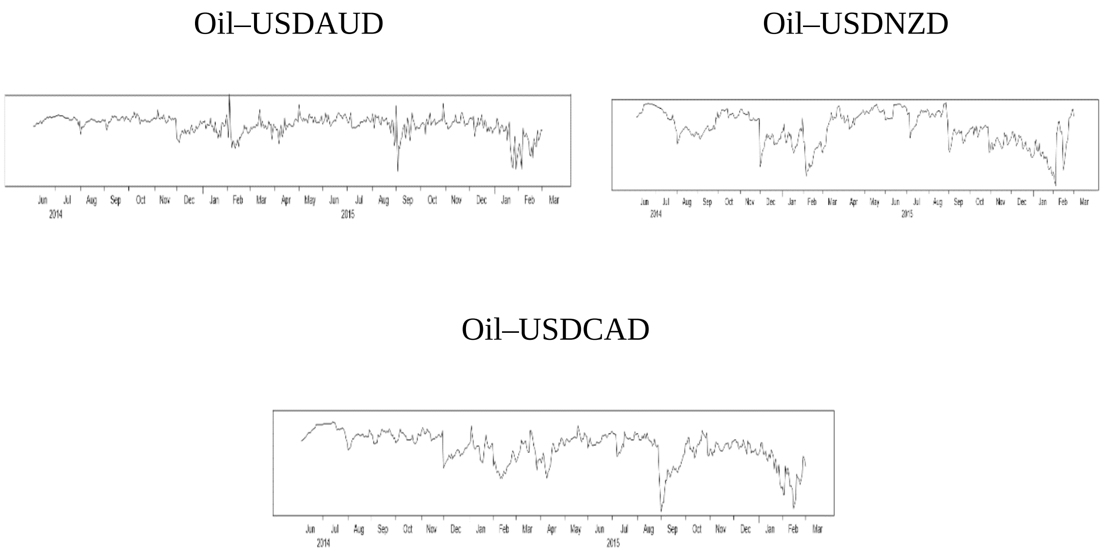


Figure 4.8: Time- varying hedge ratios for oil–commodities currencies portfolios (oil decline period)

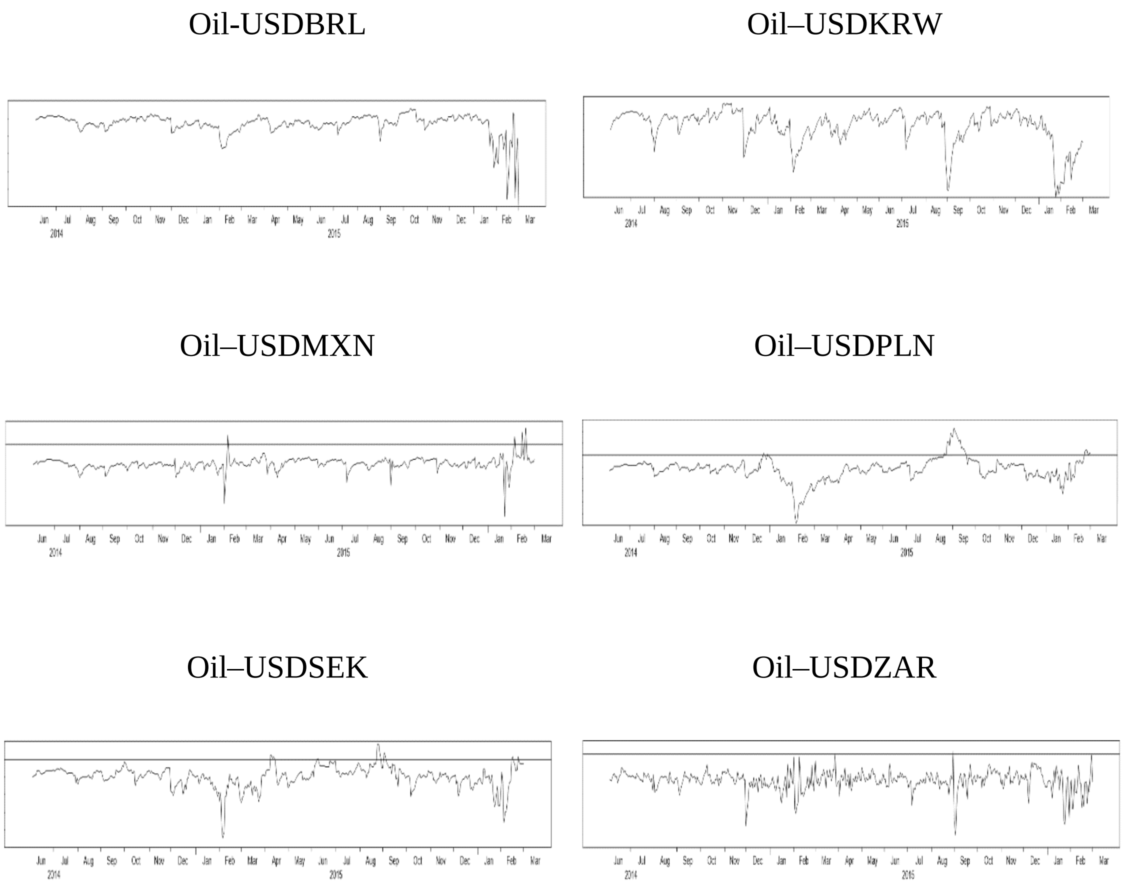


Figure 4.9: Time- varying hedge ratios for oil–emerging currencies portfolios (oil decline period)

4.5 Conclusion Remarks

This chapter show how a country's central bank needs to efficiently manage foreign reserves because these reserves play an important role as a hedge against potential financial crises. This importance was duly amplified after the Asian financial crisis in 1997–1998. The global foreign reserves increased fivefold during the two years following the Asian financial crisis, from $2 trillion in 1997 to $10 trillion in 1999. This emphasises the importance of foreign reserves for sovereign nations, and central banks in managing such reserves. Mean-variance assumes that the role of a country's central bank is to work as an investor concerned with reducing investment risk and increasing return on investment. Therefore, foreign reserves should be used for investing in such assets that can provide higher returns at the lowest possible risk. This chapter also showed how the hedging of foreign reserve currencies is crucial for any country, including Saudi Arabia; this is achieved by diversification in the form of foreign reserves. This has greater significance for Saudi Arabia because it is one of the largest holders of foreign reserves; research shows that composition of reserves is of more significance than level of reserves.

The optimal structure for foreign reserve management is the most important concern for researchers in the post-World War II period, although the optimal quantity problem of foreign reserves management is also valid. It is essential for certain *ex ante* input parameters to apply mean-variance portfolio decision models. For all assets within the investment world, it is essential for investors to establish approximations for expected returns and covariances. However, investors are often not knowledgeable enough about these values. Thus, they retrieve this information from the ex-post estimates of sample assets' past performance. There is an estimation risk problem associated with probability distribution of the asset weights for which ex-post estimates' optimal portfolios are unknown. The efficiency of the mean-variance for foreign reserve portfolios was illustrated, inspired by the ongoing debate over the need for central banks to diversify their reserves.

The problem statement addressed in this chapter is the composition of optimal currency for SFRC. There are two models to study this problem statement according to two schools of thought. The first model uses mean-variance analysis to identify factors that influence foreign exchange reserve composition. The second model identifies foreign exchange market investors in individual countries and the optimal composition of foreign currencies by the central bank and how they should be managed. The conditional volatility in returns were examined in this chapter to capture volatility spillover across oil and currency pairs in overall and oil price decline periods using MGARCH-BEKK results. Moreover, MGARCH-CCC and MGARCH-DCC helped us determine the dynamics of conditional correlations in returns across oil prices and currencies. To undertake portfolio diversification and risk management, time-dependent conditional variance and covariance must be accurately measured. In this chapter, we supposed SAMA to be an investor with oil, wanting to hedge its position against negative price movements; this was done by investing in forex markets. Realistically, the objective of the investor is to minimise risks for the oil portfolio, while maintaining expected returns. For this purpose, the analyses of Kroner and Sultan (1993) and Kroner and Ng (1998) may be utilised by estimating portfolio weights and hedge ratios using variances and covariances derived from the VAR (1)-MGRACH-BEKK (1,1) model.

The estimated results for the overall period revealed that parameters a_{12} and b_{12} were both statistically significant at 1% and 5 %, respectively, indicating that lagging shocks and historical conditional volatility on oil exercises can influence currencies' conditional variance. Therefore, during the overall period, we could only observe the bidirectional shock and spillover effect from oil to major currencies (except the volatility spillover from oil and USDCHF, which is unidirectional). We agree with the findings of Lizardo and Mollick (2010). That is, commodities' currencies also showed bidirectional shock and spillover effects from oil, except for the Canadian dollar, which showed a unidirectional character. This is because of the high correlation between oil and the USDCAD, since Canada is considered an oil-exporting country (as observed by Basher, Haug and Sadorsky [2016]). Emerging countries' currencies showed the bidirectional shock and spillover effect from oil to currencies, except for USDMXN. It is important to note that the shock and volatility spillover from oil to currencies was stronger from the spillover from currencies to oil in most portfolios. Oil's significance as a commodity and the open nature of oil data could explain this finding. Similar to Turhan, Hacihasanoglu and Soytas (2013) findings, it can also absorb information in oil more quickly than the forex markets.

Moving to the oil price decline period, the coefficients a_{12} and b_{12} were also statistically significant, which is in line with Amano and Van Norden (1998). This means that during this particular phase, the spillover effect is from oil to currencies (both in terms of shocks lagged and historical conditional volatility). In line with Chen and Chen (2007), we found the absolute value concerning USDJPY—for instance, a_{21} (0.895)—was significantly greater than a_{12} (0.056). This means that USDJPY is the currency pair with the stronger shock spillover effect to oil among the group of major currencies. This effect of shock and spillover from currencies to oil observed during the oil price decline period means the hypotheses regarding the volatility transmission can be accepted.

Overall, we have observed that the spillover effects among oil and currencies experienced a significant change and contemporary rise in the volatility spillover, powered by the oil price decline period. In the oil decline period, spillover effect from oil to currencies seemed less pronounced than in the overall period. Further, our findings show that the influence of oil on currencies became limited during the oil decline period. SAMA should integrate the spillover-volatility relationship into its asset portfolios; this research sheds light on how SAMA could benefit from diversification. Evidence of a volatility spillover refers to the increasing correlation, which indicates that market diversification between oil and currencies declines because it tends to move together. In line with Ferraro, Rogoff and Rossi (2015), our results will help SAMA better understand how shock and volatility spillover changes as oil price changes; this could be used to forecast exchange rate movements to manage the SFCR.

Although oil is beginning to influence the world's currencies, the magnitude is relatively small, so SAMA can still benefit from the diversification of assets between these two assets. SAMA is, however, advised to reconsider asset allocations across various markets globally and/or different asset classes to maximise portfolio diversification and increase the potential benefits of diversification to achieve the best weight objectives. In agreement with Oana and Alexandra (2013), our empirical results follow the work of Kroner and Ng (1998) for optimal weight and Kroner and Sultan (1993) for obtaining the average OHRs. This generally shows that SAMA should focus more on some commodity and emerging countries' currencies as well as existing major currencies to rebalance the composition of SFCR—this could reduce risk without sacrificing return. This will encourage SAMA to balance its risk exposure to global oil decline and from local economic influences.

Chapter 5: Conclusion, Recommendations, and Study limitation

5.1 Summary of Main Findings

Based on the content of Chapter 2, it is important to note that it is not strange for governments to use assets accumulated during an economic boom to level spending when volatility occurs in fiscal spending, and/or to balance payments. Mitigations are considered in periods of business prosperity because they help steadily control fiscal policy and manage the outcomes of macroeconomic variables. However, this calls for consistency in the continuous amassing of assets. This is, when oil prices are high and realised revenue exceeds expectations, governments should concentrate on accumulating assets rather than increasing expenditure. Managing fiscal policy through frameworks is one way resource-rich nations resolve inconsistencies and effectively manage the allocation of revenues across savings, stabilisation, investment and spending. In Saudi Arabia, policymakers have the discretion to make such arrangements and implement policies that support this initiative; however, the government also instigates other policies and institutional arrangements. The investment arm of SAMA is a quasi-SWF, but it adopts investment strategies used by other developed states (e.g., Kuwait, Norway and the UAE). However, these strategies are nurtured in a rule-based fiscal framework, exposing assets to fiscal and balance-of-payments volatility. In the use of SAMA's assets, no time-consistent savings or spending rules are followed.

McDowall (2014) asserted that the Saudi Ministry of Finance continues to spend when oil prices drop, arguing that the spending is funded by accumulated earnings during boom times, which assists in 'countercyclical fiscal policies'. In this case, the data show that policies cannot be countercyclical for a full financial year. Rather, adjustments are made to policies only for a specific purpose when oil revenues are booming. A good example concerns the Saudi reserve assets, which increased between 2005 and 2013. Although the reserves increased, the level of increase was much less than it would have been if there was a simple fiscal rule. In addition, the Kingdom's expenditure increased over and above the planned amount for all years since 2000, indicating a procyclical and not a countercyclical response to positive oil shocks. This indicates the lack of a rule-based fiscal framework, which has led to ad-hoc spending and decisions regarding savings. There is also evidence of the government turning to countercyclical policies when revenue low and the incorporation of procyclical decisions when there are positive oil shocks.

An ad-hoc accumulation of foreign assets has been deemed problematic in the long term, although it works well in the short term. However, rather than capitalise on its use of SAMA reserves to solve short-term problems, the Saudi government should concentrate on the administration of the savings. Consideration should be around: first, the accessibility of savings; second, the investment of savings for the generation of income for current and future purposes (short- and long-term purposes); and third, methods of accumulating expected savings. From the discussion above, it is evident that Saudi Arabia does not have a serious deficit and enjoys a healthy current account and assets; however, it lacks appropriate rules and structures to govern how finances should be used and invested. This means that reserves are at risk of being expended in situations in which oil prices are low, leading to equally low revenues.

An IV Consultation Article (IMF 2014a) brought this matter to light. For 2014–2019, government spending rose at a rate of 4.5% a year, but revenues continued to decline at 1.3% per year. This shows that government expenditure was not well regulated. The IV Consultation Article highlighted that given the trend of government expenditure between 2014 and 2019, there was a likelihood of reserves falling by $245bn. However, in the second half of 2014, the decline in oil prices led to some optimism in the fund’s baseline scenario that was carried out in the first half of 2014. It was also revealed that a 30% fall below the baseline of oil revenues would lead to a $450bn reduction in SAMA assets by the end of 2019. However, this was only assumed if no reduction in spending occurred. That is, when reserves decline by more than 50%, the minimum required reserve holdings are threatened. As a consequence, the stability of the riyal becomes uncertain.

Declining oil prices and a constantly ascending ‘break-even’ oil price for the Kingdom’s budget can also put reserves at risk because of the divergence between the former two aspects. The ascending ‘break-even’ price of oil is a commonly used criterion for measuring oil price. It has proved suitable for balancing the budget of a fiscal year, assuming that government growth is maintained at a particular level. The level of oil production and revenues realised from other products are not linked to oil. Production in Saudi Arabia is targeted at 9.7 million barrels each day, a steady rate of production. In this case, government spending is highly influenced by the fiscal break-even price for oil.

The break-even oil price has been observed to rise because of increased government spending. Therefore, assumptions around government spending could differ from year to year. Fitch (2013) reported that in 2015, the break-even price was estimated at between $95 and $106 p/b. Prices were: $74 p/b in 2013, $68 p/b in 2012 and $40 p/b in 2008. The benchmark production rate used is 9.7 million b/d, assuming that if the Kingdom reduced oil production, the break-even price would be increase by the same level.

The cyclicality of the share of capital expenditure to total expenditure is another platform through which researchers have identified a lack of rigorous fiscal rules and institutions in the Kingdom. A strong interrelationship between oil prices and the share of capital spending is expected. It is evident that there has been a steady control by policymakers on total spending in times of short- and medium-term oil price fluctuations. However, capital spending is constituent of a budget that has had to carry the responsibility of adjustment.

Fluctuations in oil prices, particularly during the second half of 2014, not only reflected risks to the Kingdom's expenditure policy over the short term, but also highlighted long-term concerns. These included such factors as the ability to maintain a sustainable fiscal path in the long term and consideration of revenue expectations. Windfalls from oil exports have been a source of revenue accumulation for the Saudi government. For instance, in 2005–2008 and 2011–2013, the Kingdom enjoyed high oil prices and accumulated approximately $750bn in foreign reserves. However, in the long term, reducing assets will present fiscal challenges, overriding any benefits realised. As a result of having these reserves, the Kingdom will experience a low debt/GDP ratio. At this point, the long-term challenges related to policy choices arise. These policy choices interact to affect fiscal performance; therefore, they cannot be treated as mutually exclusive.

The first reform option available to Saudi Arabia in saving oil reserves for future use relate to the institutionalisation of sustainable investment to encourage tenable income flows to support future government spending. This first step is of great urgency but will not cost the government economically or socially. Essentially, the main reliance on expenditure of reserves/savings in an impromptu manner is not sustainable or financially healthy. The oil production industry has experienced great uncertainty in prices, which has affected revenue, and thereby, expenditure. Given these experiences, the government has been under pressure to spend; thus, it has had to adopt a rule-oriented fiscal framework to maintain fiscal sustainability beyond the medium and long term. The government had made efforts to promote public disclosure of fiscal rules to promote better transparency. However, the government should take this more seriously with the calibration of rules and measures for institutions and individuals to adhere to in low and high seasons of price increases and reductions.

To develop a strategy to mitigate the risk of depletion of foreign currency reserve in the oil decline period, this study first examined the dynamic behaviour of oil and currencies using the results of univariate GARCH analysis and the half-life approach, as reported in Chapter 3. First, we categorised the currency pair to three groups: major currencies, commodity currencies and emerging countries' currencies. To test the asymmetric effect, the GJR-GARCH was used to examine the asymmetric information for oil and currency pairs. Then, we examined volatility persistence using the univariate GARCH and the half-life approach. This will help SAMA understand how long oil and currency pairs will take to return to normal behaviour after any shock. Further, it will enable SAMA to introduce an efficient strategy for selecting currencies that mitigates the risk of depletion by investing in foreign exchange markets. Moreover, it will enhance SFCR portfolio composition and maximise DAAs when estimating the effect of volatility spillover between oil and currencies.

The magnitude of the $a_{1,}$ 'which represents the shock effect' during the overall and oil decline periods, is statistically significant except the a_1 for USDBRL, USDMXN and USDPLN in the overall period. Meanwhile, the coefficient a for USDSEK during the oil price decline period was statistically insignificant. Coefficient b, which captures the effect of the conditional volatility on current volatility, revealed the effect of old news on current conditional volatility t for oil and all currency pairs in major and commodity currencies. Meanwhile, all emerging currencies, except USDKRW and USDZAR, were more influenced by new conditional volatility on current volatility than they were on the previous day. In line with Gokcan (2000), we found that the GARCH model explained the dynamic volatility of returns. It was also observed to improve forecasting ability, especially in emerging countries. GJR-GARCH results indicated that when the coefficient d for the asymmetric effect is not significant, it becomes negatively significant, as observed for the British pound and Japanese yen in major currencies and for USDBRL, USDPLN and USDSEK in emerging countries' currencies. This result confirmed that currencies' conditional volatility increased in response to bad news in the previous period. Coefficient *d* also reflected the effect of oil decline events on conditional volatility, which means that negative news had more effect than did positive news. This term was negative and statistically significant, which implies that following the introduction of oil price decline, conditional volatility of currencies decreased. This means that emerging countries' currencies were less volatile (or less risky) and more efficient after oil price decline. Thus, these findings confirm Engle and Ng's (1993) results, which held that negative information had a more severe effect in increasing volatility than did positive news.

Applying the half-life approach, which measures persistence to find the mean period necessary for the volatility to return it its long-term mean value, showed that SAMA, through this method, can add significant value to SFCR composition using the power of this model. It has been hypothesised that this strategy would lead to an optimal currency structure that would allow Saudi Arabia greater room for international currency diversification and minimise the risk of volatility persistence. We found evidence for different time horizons in terms of responding to shocks (half-life) in normal and oil decline periods. Most of the observed half-lives periods for emerging countries' currencies responded to shock during the oil price decline period better than during the overall period. Thus, investors' inclination towards risk would swiftly increase or decrease their vulnerability to risky assets, as suggested by Dimitrious et al. (2013).

Having identified the dynamic behaviour of oil and exchange rates by examining the volatility persistence and asymmetric effect for oil and each currency individually, it is important to examine the volatility spillover from oil to these currency pairs and vice versa. The multivariate GARCH models were used to examine the spillover effect. The optimal weights and hedging ratios were then identified to mitigate oil volatility risk. Accordingly, in Chapter 4, we assumed that SAMA seeks to protect its foreign currency reserve portfolio against oil price fluctuation by investing in chosen foreign currencies. In addition, the results of the multivariate GARCH models estimate portfolio weights and hedge ratios using variances and covariances matrices. Based on the BEKK-GARCH model, the diagonal parameters (i.e., a_{11} and a_{22}), which measure the previous shock effects on the current volatility (dependence of volatility on one market on its lagging innovations), for both periods at a 5% significance level. This suggests that both oil and currencies have ARCH effects that explain the effect of the past shock effect of oil or currency pairs on the current volatility. The GARCH effect was captured by diagonal (b_{11} and b_{22}) parameters of matrix *b*, which measured past volatility effects in each market. The b_{11} coefficient was found to be statistically significant in both periods in oil, suggesting that oil has a powerful GARCH effect. The b_{22} coefficient was also statistically significant for currencies in both periods. This indicates that GARCH effects occur during the overall and oil decline periods and that past conditional variance significantly influences current conditional volatility. That means that there is a past long-term persistence of oil and currency pairs that explains conditional volatility in each series. Next, we investigated the distribution of shock and uncertainty through oil and currencies. The off-diagonal elements of matrices *a* and *b* captured the impact of shock and volatility spillover. Focusing on the parameter *a*, coefficient a_{12} showed the overall impact of oil's spillover on every currency pair. Such coefficients were statistically significant for most pairs, except USDCAD and USDMXN during the overall period. In the oil decline period, all a_{12} were significant, except USDGBP, USDAUD, USDKRW, USDPLN, USDSEK and USDZAR, for which shock spillover effects on oil were not significant during the oil decline period.

Conversely, coefficient a_{21} tested the effects on oil from the currencies on shock spillover effect. The effect was enhanced in the oil decline period. Since the impact of shock spillover calculates the short-term effects of innovation from the last day (yesterday), it can be noted that oil is mainly affected by the performance of previous currencies during the crash period. This is consistent with the outcome of our MGARCH models, which also indicated the significant impact of currencies during the oil decline period. We expect that SAMA, which comprises experienced investors who considers bad news internationally and buy/sell currencies, will significantly lower short-term risk by executing the hedge strategy based on the study results. The consequence of this would be significant increases in market volatility because oil market activity closely correlates to currencies.

The estimated results for the overall period revealed that parameters a_{12} and b_{12} were statistically significant at 1% and 5%, respectively. This indicates that lagging shocks and historical conditional volatility on oil influences currencies' conditional variance. Therefore, during the overall period, we could only observe bidirectional shock and spillover effects from oil to major currencies (except the volatility spillover from oil and USDCHF, which was unidirectional). Similar to Lizardo and Mollick (2010), commodities' currencies also showed a bidirectional shock and spillover effect from oil, except for the Canadian dollar, which elicited a unidirectional character because of the high correlation between oil and USDCAD. This is because Canada is considered an oil-exporting country. Emerging countries' currencies showed a bidirectional shock and spillover effect from oil to currencies, except for USDMXN. Based on the above results, shock and volatility spillover from oil to currencies was stronger from the spillover from currencies to oil in most portfolios. Oil's significance and the availability of its data could explain this finding. It can also absorb information more quickly and efficiently than can forex markets.

Using the VAR(1)-GARCH-BEKK(1,1) variance and covariance outcomes, the optimal weight for oil was between 28.7% for oil–USDKRW and 78.8% for oil–USDZAR in the overall period. However, during the oil price decline period, the optimal oil holding in the portfolio (lowest weight) was held in the oil-USDYEN portfolio, at 20.4%. The highest optimal weight was 60.7% in the oil-USDBRL portfolio. Thus, there is evidence supporting the third research hypothesis, which asserted that there are optimal weights and hedge ratios to mitigate oil risk on the SFCR caused by the decreased weight of all portfolios during the oil price decline.

Our empirical results align with those of Kroner and Ng (1998) for optimal weight and Kroner and Sultan (1993) for obtaining the average OHRs. This indicates that SAMA should construct its foreign currency reserve portfolio to reduce the volatility of a portfolio without lowering the expected return. In a portfolio consisting of oil and currencies, we examined optimum portfolio weights of the currency pair. Based on our results, most currency pair weights were over 50% during the oil price decline period, except USDBRL and USDGBP. It is important to understand that the lowest hedge ratio indicates the hedging in a particular portfolio is most effective. In contrast, the higher hedge ratio indicates that the investment in a particular portfolio is most expensive. The estimated results suggest that oil–USDCHF and oil–USDJPY portfolios should invest in major currencies. In agreement with Oana and Alexandra (2013), who suggested diversification of the currency portfolio by investing in the currencies of emerging economies, oil–USDSEK and oil–USDPLN were selected among the emerging currencies based on the significant values of the hedging ratios, and the high weight of these currencies on their portfolios. While oil is beginning to influence currencies, the magnitude is relatively small. Thus, SAMA can still benefit from diversification of these two asset portfolios. SAMA is recommended to reconsider asset allocations across various markets globally or/and different asset classes to maximise portfolio diversification and improve the potential benefits of diversification. This will help achieve optimal weight objectives. Our empirical results align with those of Kroner and Ng (1998) for optimal weight and Kroner and Sultan (1993) for obtaining the average OHRs. They generally show that incorporating major currencies into a well-diversified commodity currencies or emerging countries' currencies portfolio can reduce risk without sacrificing return. In this way, SAMA can balance its risk exposure to global oil price decline and local economic events. This will enable SAMA to enhance risk-adjusted performance through more diversified portfolios and better execution of hedge strategies.

5.2 Policy Recommendations for Managing SAMA's FCR Portfolio

The central bank's portfolio frequently needs to be categorised into investment and liquidity segments; the latter must attend to necessities of Saudi banks regarding foreign exchange for a pegged exchange rate. SAMA's protective mechanism relies first on deposits and then on liquid sellable securities. Most SAMA assets are equities and bonds. Such a mixture ensures that the required level of cash and diversity helps mitigate risk and improve risk-adjusted return. Regarding the allocation of funds, SAMA devotes them to reserve and long-term investment portfolios. In doing so, a rigorous strategy needs to be implemented to account for any possible sources of balance of payment outflows; this is undertaken to safeguard the Saudi economy.

The idea is that, for larger reserve portfolios, may be allotted to the investment portfolio. There is a multistep process recommended for measuring the adequacy of reserves. The first step is an investment matrix based upon market trends, macroeconomic themes and outside predictions for foreign exchange and asset pricing. Second, it is important for the SAMA assets allocation team to review spot flow trends and predictions for the reserve portfolio allocation. Their degree of confidence for the investment portfolio position will encourage SAMA's governor to consider recommendations. In sum, SAMA is required to determine the currency pairs in which to invest. With particular attention paid to credit quality, diversified portfolio, liquidity of assets and risk-adjusted returns, using the results in Chapter 4, SAMA can focus on Swiss, Japanese, Swedish and Polish markets.

The SAMA assets allocation team also needs to conduct meetings centred around a detailed plan for international macro themes, investment matrices, market trends and outlook, previous program execution, foreign exchange flows, custody and securities lending and the behaviour of external managers for actions related to the currency portfolio. Such meetings should yield a strategy for investment programs to determine the optimal weight and dynamic hedge ratios. It is also important to conduct meetings regarding the investment plan to measure performance and analyse potential risk. Once the investment program is approved, the investment deputy governor and other senior members decide upon the strategy for the investment portfolio and reserve portfolio regarding size, timing and coordination of spot flow between asset pools, alongside a separate plan for undertaking portfolio actions.

Based on SAMA's risk forbearance for sovereign bonds, equities and credit-related entities, specific benchmarks are selected, and assets split into categories: a more aggressive investment portfolio and a more conservative reserve portfolio. Both portfolios must be based on specific operational benchmarks and investment guidelines. Given that the reserve portfolio has greater focus on liquidity, its performance is assessed on short-term income yielding investments. Conversely, the investment portfolio's execution is marked based on its combined policy benchmark. An investment portfolio can be designed to participate in active risk by investing in the suggested portfolio, as stated in Chapter 4, but without violating the confines of specific boundaries established by the governing committee. However, this may lead to greater volatility in returns over the short or medium term.

5.2.1 Recommended currency composition

Investment is based on the principle of diversification, and operational benchmarks bind currency exposure. Existing liquidity requirements determine the broad framework for funding foreign exchange issue. Since the US dollar is an essential part of Saudi Arabia's revenue and expense pattern, global finance and trade, it is used as the base currency, followed by other major currencies. The total of benchmark weights for each currency forms the actual composition of the currency. Since trade and investment flows vary, this points to the notion that allocations of currency are not related to trade flows but instead to the availability of investments (indicated by market capitalisation) and instrument liquidity. To meet the daily spot requirement of governments and for dollar purchases for domestic banks, the central bank retains a target call balance. Owing to oil exports, the foreign exchange—which is basically generated by what the general public purchases—allows SAMA to act as the only source of US dollars to private entities through selling to local banks at specific rates. Thus, on a daily basis, it interferes with domestic interbank market competing for spot settlement.

The half-life approach results in Chapter 3 measure persistence to find the mean period necessary for volatility to return it its long-term mean value. We recommend that SAMA select USDCHF, which has the lowest half-life value of 1 day. This is one reason that USDCHF is the safest haven in terms of hedging currency. USDJPY is the second-lowest currency pair, with volatility persisting for 12 days. To select emerging countries' currencies based on half-life estimation, in line with Chaudhuri and Wu (2003), we found that emerging countries' currencies return to their previous mean values better than most major and commodity currencies. We observed the half-life to last 42 days for USDKRW, while the half-life of USDBRL was 47 days. Moreover, USDSEK had 49 days of half-life; finally, USDZAR obtained the lowest half-life value: 9 days.

In terms of the optimal foreign currency reserve composition, this study revealed that based on optimal weights and hedge ratios estimation, SAMA portfolio diversification should focus more on commodity and emerging countries' currencies to rebalance the composition of SFCR. This study recommends that, for example, the Japanese yen, Swiss franc, Swedish krona and Polish zloty be added to the current major currencies to reduce the impact of oil volatility caused by the lower hedging ratio and the lower weight of oil, as estimated in Table 4.20.

It is important to note that the foreign asset portfolio's development 'including the foreign currency composition' is different from the standard modern portfolio theory for two reasons. First, the management of foreign reserves is very restrictive, subject to the authority's control. It must meet several fixed objectives, including safety, profitability and liquidity. Second, risk-averse central banks do not prefer risks that incur financial losses. Research studies tend to detail the risk–return trade-off issues of various asset classes to cast light on the many motivations for asset allocation (León & Vela 2011).

Thus, there is need to develop a model based on the country's foreign exchange reserves' asset allocation, introducing the idea that the most suitable allocation of foreign assets is achieved by balancing preferences of returns and liquidity (Rivadeneyra et al. 2013). This will shed light on the importance of governing foreign reserve allocation according to profitability, safety and liquidity (in increasing order of importance).

The international attitude towards this topic has also helped shape advances made in recent studies. Seeking higher returns, since the late 1990s, there has been increasing emphasis on diversifying investment for rising levels of reserves using the asset classes securely. This often entails expanding the normal investment universe, as recommended by Fisher and Lie (2004), who suggested improvements. They noted the need to differ country and currency allocation and control risk at the portfolio level instead of the country level. In line with Ferket and Zwanenburg (2004), we recommend that SAMA' investment universe be broadened by hedging currency risk; more active duration management must be undertaken by SAMA portfolio managers.

Supporting our recommendations, the IMF conducted research to suggest that central banks' focus on safety should be discouraged. Agreeing with this, Pihlman and van der Hoorn (2010) argued that funding problems would be created for the banking sector if investors were to withdraw deposits from banks because they wanted something safer. These actions would cause other central banks to offset measures and ultimately destabilise the financial market. An IMF (2012) study discussed the post-crisis safety assets' demand and supply, concluding that central banks' moves towards safety would exacerbate the shortage of safe assets, which is not an objective of the central bank.

Based on this, the present study considers what the current context of Saudi Arabia and how to obtain the optimal reserve composition given that the reserve level is externally fixed. As one of the world's greatest reserve holders, most Saudi reserves are held in US dollars, which makes the country vulnerable to currency risk. Such a risk makes it imperative for Saudi Arabia to mitigate currency risk and exposure by including diverse currencies in its reserve assets. Research on reserve management suggests distinct, standard approaches for examining currency construction, namely the mean-variance and transactions approach (Roger 1993). According to mean-variance theory, central banks are similar to an investor, whose only concern is the risk and returns of reserves' investments. Returns are weighed as a form of optimal asset allocation.

We concur with the double-tranche management approach of Cardon and Coche (2004), who proposed a threefold establishment be developed for central banks' asset allocation. An oversight committee would be in charge of currency allocation, an investment committee would manage asset allocation benchmarks and a portfolio management team would conduct portfolio mandates. Such an establishment would ensure the central bank's safety, returns and liquidity requirements. Moreover, an alternative approach—the double-tranche management approach—was suggested by Putnam (2004). It has been argued that the strategy comprising a liquidity-challenged tranche and volatility-premium tranche would help satisfy the reserve management liquid requirement and desire for returns. Finally, the three investment functions of central banks—safety, returns and liquidity—were also recognised by Claessens and Kreuser (2004), who suggested incorporating the three investment objectives with macroeconomic and microeconomic factors and market conditions in a stochastic optimisation framework. A dual benchmark optimisation framework was devised by Gintschel and Scherer (2008) to simultaneously consolidate two features of the liquidity and capital preservation. The specifics of these were detailed by Borio et al. (2008) more than a decade ago. The recommended policy for currency composition are explained on the next sections.

5.2.1.1 Policy Recommendations for Selecting Currency Composition for the SFCR based on the degree of Volatility Persistence Analysis

It is important for SAMA to determine currency pairs volatility in terms of its risk management and predicting future volatility. The results of the half-life approach are based on univariate GARCH model, indicating that SAMA could use this method to significantly improve the composition of the (SFCR). In exchange rate markets, there may potentially be sudden changes in volatility as these countries are more likely to experience economic, political and social events. It is, therefore, important to take these shifts into account when estimating volatility persistence, particularly in emerging markets. These events could have a systematic effect on oil and currencies markets or could only have an impact on a particular market. For this reason, using the half-life approach SAMA's fund managers need to determine whether these major events cause changes in the market volatility persistence in order to create much better diversified portfolios, efficiently predict and accurately assess the future volatility of these currencies' pairs. It was assumed that this strategy would lead to an ideal currency structure, allowing Saudi Arabia more room for international currency diversification and a lower risk of continued volatility.

To develop the currency composition strategy to mitigate the risk of depletion of foreign currency reserve in the oil decline period, this study categorized three groups of currency pairs to examine the dynamic behaviour between oil and currencies. The three groups categorised are; major currencies, commodity currencies and emerging countries' currencies. First, we used the GJR-GARCH to examine the asymmetric information for oil and currency pairs. Then, we examined volatility persistence using the univariate GARCH and the half-life models. The GJR-GARCH results indicated that when the coefficient *d* for the asymmetric effect is not significant during the overall period, it becomes negatively significant during the oil decline period, as observed for the British pound and Japanese yen in major currencies and for USDBRL, USDPLN and USDSEK in emerging countries' currencies. This result confirmed that currencies' conditional volatility increased in response to bad news in the previous period. Coefficient *d* also reflected the effect of oil decline events on conditional volatility, which means that negative news had more effect than positive news. This term, which was negative and statistically significant, implies that following the introduction of oil price decline and conditional volatility of currencies decreased. This means that emerging countries' currencies were less volatile (or less risky) and more efficient after oil price decline. Moreover, we measure the persistence after applying the half-life approach in order to find the mean period, which is necessary for its long-term mean value volatility. As a result, this approach can add a significant value for SAMA through SFCR composition. It has been hypothesised that this strategy would lead to an optimal currency structure that would allow Saudi Arabia greater room for international currency diversification and minimise the risk of volatility persistence. We found evidence for different time horizons in terms of responding to shocks (half-life) in normal and oil decline periods. Most of the emerging countries' currencies observe half-life persistence, which responded to shock, much better in the oil price decline period than the overall period. Thus, investors' inclination towards risk would swiftly increase or decrease their vulnerability to risky assets. The findings indicate that SAMA's fund managers need to pay attention to both developed and emerging currency pairs in their portfolios as shocks may affect the risk-return and optimum asset allocation composition. The results are also consistent with the findings of previous volatility persistence studies i.e. Dimitrious, Kenourgios and Simos

(2013) and Dimitrious et al. (2013), and evidence that ignoring sudden changes in volatility such as the recent decline of oil price could result an overestimation of the degree of volatility persistence and inaccuracy of oil and currency markets volatility estimates for SAMA's fund managers. This will help SAMA understand how long oil and currency pairs will take to get back to normal behaviour after any shock. Further, it will enable SAMA to introduce an efficient strategy for selecting currencies that mitigates the risk of depletion by investing in foreign exchange markets. Moreover, it will enhance SFCR portfolio composition and maximise DAAs when estimating the effect of volatility spillover between oil and currencies.

In the distributions of currency returns, the models of asymmetric GARCH and half-life are analysed. SAMA needs to understand the dynamic behaviour of financial assets to ensure their portfolios can be clearly allocated and rebalanced as financial markets shifts. In addition, SAMA tends to measure its overall asset portfolio on this basis instead of understanding the opportunity for global diversification to achieve significant growth in SFCR. SAMA must allocate large portions of foreign currency reserve to foreign currencies to self-insure against the risks associated with falls in oil prices. We recommend that SAMA select USDCHF, which has the lowest half-life value of 1 day. This is one reason that USDCHF is the safest haven in terms of hedging currency. USDJPY is the second-lowest currency pair, with volatility persisting for 12 days. To select emerging countries' currencies, which based on half-life estimation, we found that emerging countries' currencies return faster to their previous mean values than most major and commodity currencies. We observed that the half-life of USDKRW, USDBRL and USDSEK had 42, 47 and 49 days respectively, while the lowest half-life value is 9 days for USDZAR. Thus, SAMA should select USDCHF and USDJPY as major currencies. Moreover, the result suggested that SAMA select emerging countries' currencies (USDKRW, USDBRL, USDSEK and USDZAR) because they had the lowest value based on the half-life estimation.

5.2.1.2 Policy Recommendations for Selecting Currency Composition for the SFCR based on the Volatility Spillover Analysis

Understanding the impact of spillover volatilities is critical for risk management and an effective asset diversification to maintain the effectiveness of optimal weights and hedge ratios. Considering the significant volatility spillover effects from oil and currencies, potential opportunities for portfolio diversification are considerable by investing in both oil and currencies. Portfolio managers in SAMA must quantify optimal weights and hedging ratios to mitigate risk exposures of volatile markets and unexpected price changes; this would minimise the increased risk without reducing expected returns. Since the Saudi government has decided not to disclose SFCR information to public, we simulate a two-asset portfolio of oil and currencies (major, commodity and emerging currencies) to illustrate the effect of the empirical results on optimum portfolio structure and risk management. This was done to reduce the risk posed to both oil and currencies. We use the in-sample estimation based on VAR(1)-BEKK-GARCH model to obtain its variance and covariance results. These results, therefore, were applied to estimate the optimal portfolio weight and OHRs.

Overall, our findings show that oil influenced currencies during the oil decline period. Thus, SAMA should integrate the spillover-volatility relationship into its asset portfolios in order to take advantage from diversification. Moreover, the study results show that there is evidence of a volatility spillover refers to the increasing correlation. This indicates that SAMA can still benefit from the diversification of assets between oil and the currency pairs on SFCR. That can also rebalance its portfolio through diversification between oil and currencies because it tends to move together. Our multivariate results will help SAMA to obtain a better understanding of how changes on oil shock and volatility transmitted to currencies; this could be used to forecast exchange rate movements to manage the SFCR. SAMA should focus more on some commodity and emerging countries' currencies as well as existing major currencies to rebalance the composition of SFCR. This could reduce risk without sacrificing return. This will encourage SAMA to balance its risk exposure and protect its FCR from both the decline and from local economic influences.

Estimated results suggest that oil–USDCHF and oil–USDJPY portfolios should invest in major currencies as their hedge ratio are 16 and 17 cents, respectively. Meanwhile, the oil–USDCAD portfolio is the cheapest cost based on the value of hedging ratio and the lower weight of oil. However, the aim of this study is to mitigate oil volatility risk on SFCR. Thus, we cannot add the oil–USDCAD portfolio to the SFCR portfolio because Canada is a major oil-exporting country. Oil–USDSEK and Oil–USDPLN portfolios were selected among the emerging currencies based on the significant values of the hedging ratios which are 32 and 37 cents, respectively.

5.2.1.3 Summary of the Policy recommendation for Currency Composition

The currency composition recommendation can be summarized as follows: i) SAMA should spend more attention on major currencies than it does on emerging currencies because SAMA may reduce the risks in its investment portfolios. Our findings can also be an incentive to increase an investment in currency. Based on the low optimal weight findings, the oil and emerging currencies pairs portfolios can help SAMA to benefit from its diversification assets. For instance, based on the estimated results, this study suggests that oil–USDCHF and oil–USDJPY portfolios should invest in major currencies. Meanwhile, Oil–USDSEK and oil–USDPLN portfolios were selected among the emerging currencies based on the significant values of the hedging ratios and the high weight of these currencies on their portfolios. Thus, ii) adding commodity currencies and emerging countries' currencies to current major currencies may offer better options for portfolio diversification. iii) as we assumed, trading oil with the three groups of currencies offer an opportunity for SAMA to hedge the risk of SFCR depletion in the times of decline of oil prices. Even Saudi Arabia does not have a serious deficit and enjoys a healthy current account, SAMA fund managers need to apply appropriate rules and structures to govern how finances should be used and invested in case of experiencing a decline on oil revenues. This means that SAMA fund managers should consider the FCR which may be at risk when oil prices are low.

The Saudi government should concentrate on accumulating assets rather than increasing expenditure when oil prices are expected to be increased and realised revenue exceeds expectations. Managing fiscal policy through frameworks is one-way resource-rich nations resolve inconsistencies and effectively manage the allocation of revenues across savings, stabilisation, investment and spending. Policymakers, in Saudi Arabia, have the discretion to make such arrangements and implement policies; however, the government also instigates other policies and institutional arrangements like e.g., Kuwait, Norway and the UAE. This study shed the light to use its results to help SAMA fund managers to consider this approach as general guideline to build their portfolio management strategy. Thus, the Saudi government should concentrate on the administration of the savings and regulate its expenditure well. Consideration should be around: first, the accessibility of savings; second, the investment of savings for the generation of income for current and future purposes (short- and long-term purposes); and third, methods of accumulating expected savings and covering expenditure.

To conclude, this study encourages SAMA fund managers to make adjustments of its portfolio management policies to manage their FCR when oil revenues are declining. It is important to note that incorporating currencies from major currency, commodity currencies and emerging countries' currencies into SFCR will enhance their portfolios to be well-diversified so that can help to reduce the risk without sacrificing return. Also, this permits SAMA to rebalance its risk exposure to any shock or other events in the domestic economy. Importantly, this study makes it possible for SAMA to enhance its risk-adjusted performance through using more diversified portfolios and better hedging strategies.

5.2.2 Recommended performance and risk management

To analyse currencies' managed portfolios, it is necessary to implement portfolio benchmarking (performance measurement). This measurement is conducted on the basis of total return. The existing performance of SAMA's overall portfolio was compared with that of Norway's royal wealth fund for the medium term. Nevertheless, because it has a considerably conservative approach, it can perform better in economic downswings. For example, when investors incurred considerable losses in 2008, SAMA contained the crisis through its defensive position. SAMA frequently uses the recommendations of the Global Investment Performance Standards (GIPS) to measure portfolio performance. GIPS yields a group of standardised industry-prevalent guidelines to dictate how investment firms calculate and present investment results.

In terms of risk management, there has been greater importance imparted to risk management and compliance after the GFC. This, in part, is because of the fickle nature of markets and greater regulatory inspection. The deleveraging and caps for proprietary trading may be associated with risk management and governing of central and commercial banks. Although regulation must be implemented, it must be done sensitively and properly to assure investors that innovativeness and initiative remain unharmed. No active currency bets can be taken, so currency risk depends on asset allocation. Although tactical opportunities are prevalent, some SAMA managers may not take currency views to ensure their revenues remain non-volatile. Capital must be preserved more so that returns must be accounted for, so credit criteria remains conservative. SAMA is focused on investing in markets and liquid assets to ensure low liquidity risk. However, according to this study's results in Chapter 4, we recommend that SAMA focus on the Swiss franc, Japanese yen, Swedish krona and Polish zloty during oil price decline periods. Adding the above to the SAMA FCR portfolio with the current major currencies would reduce the impact of oil volatility. The reason is that the above currencies provided the highest weights and lowest costs of hedging during the oil price decline period (see Table 4.20).

Market risk is mainly a function of the composition of benchmark portfolios and the lack of limitations for expected tracking error (how well a portfolio can follow the index to which it has been benchmarked). Following the Lehman Brothers collapse, counterparty risk has increased. SAMA only deals with reputable and financially strong entities. By segregating front- and back-office dealings, the operational risk for intrinsically handled portfolios is resolved. The risk associated with different currency portfolios may be mitigated by separating managers and custodians and implementing strict guidelines and reporting requirements. Instances of unintentional breaches in the rules (e.g., as a result of downgrades) have been met with managers instructed to not sell securities immediately to mitigate losses for lower prices. We conclude that major, commodity and emerging currencies together in the SAMA portfolio can mitigate risk.

5.2.3 Recommended portfolio tranches

Following the currency crisis in Latin American and Asian markets in the late 1990s, accumulation of large reserves motivated some central banks to restructure and split their foreign reserves into multiple tranches. While the likelihood of a currency crisis is mitigated by having more reserves, it is costly to hold large amounts of liquidity because of central banks' preference for investing reserves in very liquid and safe assets that earn low returns. Reserves may be divided according to banks' specific requirements through portfolio tranching, such as for liquidity, investment and policy considerations. Osorio (2007) suggested a procedure for lowering opportunity costs incurred by holding massive amounts of foreign reserves by tranching, based on the theoretical model of central bank liquidity management of Caballero and Panageas (2005). Osorio (2007) argued that the procedure would allow central banks to invest some of their reserves more efficiently during normality, without the need to create large liquidation or transaction costs in the case of a crisis.

The Banco de la República of Colombia provided an example of portfolio tranching, as demonstrated by Reveiz (2004), who explained that the central bank used three distinct portfolios: working capital, intermediate and stable portfolio tranche. A working capital portfolio was necessary to account for intervention needs, whereas the intermediate (passive) portfolio tranche was held in US, Japanese and German government bonds, which did not allow for active management. Further, the working capital and intermediate portfolio as an aggregate must be sufficiently large for one-year intervention at a 99% confidence level. It is possible for the stable tranche portfolio to deviate from the benchmark and incur active risk for preset *ex ante* tracking error limits.

García-Pulgarin, Gomez-Resrepo and Vela-Baron (2015) also focused on the Colombian central bank, exploring an alternative framework for strategic asset allocation. The objective was to maintain liquidity and the safety of a reserve portfolio while maximising risk-adjusted returns. To achieve this objective, the authors suggested dividing the entire portfolio into two tranches: safety and wealth tranches. The former was composed of liquid, low volatility, default-free assets with safety and liquidity as the objectives function. The latter aimed to maximise the return within a broader asset universe and a taller horizon. The historical and forward-looking analysis found that while sustaining liquidity and safety requirements of a standard reserve portfolio, the framework could deliver better reserve portfolio performance.

In line with the aforementioned studies, it is suggested that, based on the return enhancement objective, it is sensible for central banks to split their reserve portfolios into tranches. The strategic asset allocation framework suggested by Reveiz (2004), Osorio (2007) and García-Pulgarin et al. (2015) aimed to maximise portfolio return for a specific risk level while satisfying the liquidity objectives of central banks. Thus, the present study encourages the Saudi Central Bank to invest in foreign reserves in tranches, based on the results documented in Chapters 3 and 4. Portfolio safety and mitigating oil revenue depletion risk are the primary objectives of the reserve portfolio

5.3 Limitations and Future Improvements

There are several limitations of this study. The major limitation is that Saudi Arabia, as an oil-dependent country, is accumulating its foreign currency reserve from oil revenues. The IMF implemented a new policy in which it required participating countries to provide information through IMF's Special Data Dissemination Standard (SDDS) on the asset structures of their foreign reserve portfolios. However, to date, only 68 nations have agreed to subscribe to the initiative. Major economic powers such as China and Saudi Arabia have opted not to disclose the necessary information by not being SDDS subscribers. Therefore, one major shortcoming of research on the topic of foreign currency reserves and their decomposition is the lack of information provided by major countries (Dominguez 2012). Moreover, Saudi official asset class distribution data are confidential and unavailable to the public. Still, the US Treasury International Capital (TIC) system's yearly report of foreign holdings of US securities presented information related to Saudi foreign reserves' dollar asset allocation. Nonetheless, it must be understood that TIC data cannot account accurately for the US securities held by Saudi Arabia. According to Setser and Pandey (2009), information presented by TIC does not document the percentage of countries' holdings allocated to the US from outside investment entities. Zhang et al. (2010) further argued that an additional element causing TIC data to be imprecise for a country's holdings was the lack of clarification on investments by private and official investors. Thus, the recommendations of this study must be considered general guidelines to SAMA authorities to help them manage their SFCR portfolio.

As a result of the limited studies on the interdependence between oil and currencies, the researcher exerted his best efforts to search for specific reviews of the literature related to exchange rates stock and oil markets, and volatility spillovers topics. Thus, this thesis literature also relied on spillovers in other markets' literature. The various transmission channels that are prevalent have also been highlighted based on market analysis.

Further, this analysis only investigates oil spillover from the Saudi perspective, but not from other oil-exporting countries' viewpoints. While Saudi Arabia is the largest oil exporter, there are still many other oil-exporting countries; this study focused only on oil's effect on SFCR, ignoring other factors such as GDP and inflation. In particular, this study explored the relationships between oil and the major currencies, commodity currencies and several emerging countries' currencies. Although they are the major markets and have a strong relationship with oil, countries such as China were ignored. Therefore, this thesis does not note other variables (i.e., macroeconomic factors), since the main objective was to investigate the interdependence between oil and currencies and their co-movements. Although the econometric models used in this study are advanced, qualitative insights are required for future studies by conducting interviews with the authorities and SAMA governor and chief executive officers. Finally, future work could investigate similar issues raised in this study by using a longer period to measure the influence of other crises (i.e., the 2008 GFC).

This thesis's results provide some avenues for future studies. First, our empirical findings are only based on the in-sample data . Thus, it will be important to determine the optimal hedging strategy for the out-of-sample which may provide much forecasting information about currencies and oil markets to help Central banks. Moreover, extending the current analysis to include more currencies would be important for more diversification strategies.

It is important to mention that investment in currencies has led to concerns based on the large proportions of equity held by SWFs in target countries' markets, and the danger that SWFs could hit a country's economy hard if its investments were politically motivated. Moreover, there are concerns about national security because SWFs could acquire vast sections of critical industries (Langland 2009).

5.4 Conclusion

This research addressed the status of oil revenue and the accumulation of foreign assets and its economic importance. Over the first five decades, oil revenues helped pay public expenses for much-needed infrastructure, but there were some indications that, to avoid a government deficit, the economy had to diversify as oil revenues decreased. The purpose behind the establishment of SAMA was to monitor two factors: accumulation of surpluses in the current account and foreign currency reserve. Efforts are underway for creating a more diverse economy, particularly in terms of human resources, yet Saudi Arabia continues to rely heavily on oil revenues, making it sensitive to oil price decreases similar to the present situation. The country's GDP is 60% composed of oil revenues. It is also sensitive to price changes, particularly when much is spent on defence and domestic purposes, allowing depleted reserves for future downturns. Although Saudi Arabia has saved much revenue from its oil boom years compared with other Gulf countries, its foreign exchange reserves have decreased by more than one-third since 2014.

To mitigate the risk of the foreign currency reserve depletion, this study sought to develop a financial management strategy to identify an optimal foreign currency composition to provide a higher return during the oil price decline period. Two approaches were considered regarding foreign currency reserve composition: univariate and multivariate GARCH models for institutional management. The volatility persistence using the univariate GARCH and half-life approach were discussed in Chapter 3. They recommended that SAMA select USDCHF and USDJPY as major currencies. Moreover, they suggested that SAMA select emerging countries' currencies based on the half-life estimation; USDKRW, USDBRL, USDSEK and USDZAR had the lowest reported value.

By using a univariate analysis individually for each time series SAMA is likely to consider the dynamic behaviour of oil and currency exchange rates. Univariate analysis will permit SAMA to introduce an efficient strategy for selecting currencies that enhance the SFCR portfolio composition and maximise DAAs when estimating the effect of volatility spillover between oil and currencies. Therefore, the findings will help SAMA portfolio managers improve tactical portfolio management, thereby maximising DAAs when estimating volatile oil and currency behaviours. Employing univariate and multivariate approaches will enable SAMA to make significant contributions to SFCR composition and management. It was hypothesised that this strategy would lead to an optimal currency structure that would give Saudi Arabia greater space for international diversification and minimise the risk of persistence of volatility.

In terms of the optimal foreign currency reserve composition, this study revealed that based on optimal weights and hedge ratios estimation, SAMA portfolio diversification should focus more on commodity and emerging countries' currencies to rebalance the composition of SFCR. This study recommends that, for example, the Swedish krona and Polish zloty be added to the current major currencies to reduce the impact of the oil volatility. To that end, analyses by Kroner and Sultan (1993) and Kroner and Ng (1998) may be used by estimating portfolio weights and hedge ratios using variances and covariances derived from the results of the GARCH multivariate. Empirical analysis revealed that SAMA's portfolio diversification should focus more on emerging countries' currencies to be added into the SFCR portfolio to reduce the impact on oil revenue during the oil price decline period. Based on the results of the study, overall policy recommendations for SAMA and conclusions were provided. The limitations of the study were also discussed. As a result of the concealment of SFCR information, this study provides comprehensive recommendations for SAMA portfolio managers, who will need to categorise their portfolios into investment so that the SAMA FCR portfolio will be managed appropriately.

To this end, the recommendations of this study were provided as general guidelines for SAMA authorities to use to help them manage their SFCR portfolio. In terms of managing SAMA's FCR portfolio, we recommended that meetings regarding the investment plan need to be conducted to measure the performance and analyse potential risk. Once the investment program is approved, the investment deputy governor and other senior members should decide upon the strategy for the investment portfolio and reserve portfolio. The study showed that market risk is mainly a function of the composition of benchmark portfolios, having few limitations for expected tracking error (how well a portfolio can follow the index to which it has been benchmarked). By segregating front- and back-office dealings, the operational risk for intrinsically handled portfolios is resolved. The risk associated with different currency portfolios may be mitigated by separating managers and custodians and implementing strict guidelines and reporting requirements. Using this study approach, we conclude that major, commodity and emerging currencies, together in the SAMA portfolio, can mitigate oil volatility risk.

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