



Oil Price Shocks and Financial Stress in Sub-Saharan African Countries

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ABSTRACT

This study examines the nexus between financial stability and oil shocks within South Africa, a net-oil importer, and Nigeria, a net-oil exporter. A signal theory approach utilising pAUROC analysis is used to capture relevant indicators. Furthermore, sub-market indices are weighted using a diagonal BEKK-GARCH model, allowing for time-varying cross-correlations to determine sub-market weights, allowing the constructed financial stress index (FSI) for each economy to focus on systemic events of financial stress. The FSI for each economy is then incorporated into a SVAR model which disaggregates oil demand shocks into three components (economic activity, oil consumption demand, and oil inventory demand) following the framework of Baumeister and Hamilton (2019) to capture the effects of oil market shocks on financial stability. This paper finds that positive shocks to oil supply, economic activity, and oil inventory demand tend to reduce financial stress in South Africa. Interestingly, demand driven increases in the real price of oil reduces systemic stress, even though the economy is a net-oil importer. Oil supply shocks and economic activity shocks tend to have no significant effect on Nigerian financial stress while demand driven increases to real oil prices tend to decrease financial stress. Interestingly, shock increases in demand for oil inventories tends to raise financial stress.

Keywords: Oil price, financial stability, VAR framework, signal theory, BEKK GARCH, financial stress index.

DEDICATION

This thesis is affectionately dedicated to my parents, Jacqueline and Jonathan Frost.

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CONTENTS

ABSTRACT	i
DEDICATION	ii
ACKNOWLEDGEMENT	ii
CONTENTS	iii
LIST OF TABLES AND FIGURES	v
CHAPTER ONE	1
1.1. Problem Statement	1
1.2. Research Questions	2
1.3. Research Objectives	3
1.4. Justification for the Research	3
1.5. Scope of the Study	5
1.6. Organisation of the Study	5
CHAPTER TWO	6
2.1. Financial Stress Indices	6
2.1.1. Methodology	6
2.1.2. Findings in sub-Sahara Africa	7
2.2. Oil price shocks and financial markets	8
2.2.1. Methodologies	8
2.2.2. Findings in developing countries and the sub-Sahara context	9
CHAPTER THREE	12
3.1. Data Sources	12
3.2. Construction of the FSI	13
3.2.1. Candidate indicators	13
3.2.2. Episodes of financial stress	14
3.2.2.1. South Africa	14
3.2.2.2. Nigeria	15
3.2.3. Methodology to capture episodes of crisis	17
3.2.3.1. Signal Theory	17
3.2.3.2. Area under receiver operating characteristic curve (AUROC)	18
3.2.3.3. Partial AUROC	19
3.2.4. Selection of indicators	20
3.2.5. Normalisation and construction of sub-indices	21
3.2.6. FSI construction	23
3.2.7. Insights from constructed FSI	25

3.3.	Oil Shocks and Financial Stability.....	28
3.3.1.	SVAR Representation.....	28
3.3.2.	Preliminary Analysis.....	30
3.3.3.	SVAR Analysis.....	31
CHAPTER FOUR		33
4.1.	Impulse Response Analysis	33
4.1.1.	South Africa	33
4.1.1.1.	FSI response to other variable shocks	33
4.1.1.2.	Other variable responses to FSI shock.....	34
4.1.2.	Nigeria	36
4.1.2.1.	FSI response to other variable shocks	36
4.1.2.2.	Other variable responses to FSI shock.....	37
CHAPTER 5		40
5.1.	Summary of findings and implication for policy	40
5.2.	Limitations and Suggestions for future research.....	41
REFERENCES.....		43
Appendix		48
A.	Additional Information relating to the FSI methodology.....	48
A.1.	Candidate Indicators	48
A.2.	AUROC Analysis Results	49
A.3.	Raw Indicators	51
A.3.1.	Equity Market	51
A.3.3.	Foreign Exchange Market.....	53
A.3.4.	Money Market.....	54
A.3.5.	Resource Market	54
A.3.6.	Property Market	56
A.4.	GARCH estimation.....	56
B.	Impulse Responses.....	58
.....		59

LIST OF TABLES AND FIGURES

Tables

Table 1: Data sources used to construct FSI.....	12
Table 2: Data sources used to perform VAR analysis.	13
Table 3: Mann-Kendall Trend Test.....	30
Table 4: Unit Root Tests.....	31
Table 5: Var diagnostic tests.....	32
Table 6: List of candidate indicators to be included in the FSI for South Africa and Nigeria	48
Table 7: AUROC and pAUROC Indicator Values.....	49

Figures

Figure 1: AUROC for ZAR/EUR exchange rate in comparison to the maximum level over a two-year moving period for South Africa	20
Figure 2 Normalised Indicators for South Africa	22
Figure 3 Normalised Indicators for Nigeria	23
Figure 4:Snapshot of South African market correlations	25
Figure 5: South African FSI	26
Figure 6: Nigerian FSI	27
Figure 7: SA FSI shocked by other variables.....	35
Figure 8: Other variables shocked by SA FSI.	36
Figure 9: NG FSI shocked by other variables.....	38
Figure 10: Other variables shocked by NG FSI	39
Figure 11: Cross-Correlations of SA.....	57
Figure 12: Cross-Correlations of Nigeria	57
Figure 13: IRF for SA.....	58
Figure 14: IRF for Nigeria.....	59

CHAPTER ONE

Introduction

1.1. Problem Statement

The sub-Saharan Africa (SSA) region proves to be the exception to the rule of the global decline in poverty levels, with the region expected to occupy a larger share of total future poverty (Karahan, 2020). Most countries of SSA are oil-dependent states, except eight of the 46 countries, meaning that the role of crude oil in production and transportation proves vital to the operation of an already vulnerable economic region. Hence, understanding how oil-based shocks interact with the financial stability of these economies is an important tool for preventing further economic decline and exacerbated poverty levels through informed policy decisions. Studies answering this problem have proven to be few in the SSA context. Hence, this study aims to provide insight into the energy-finance nexus in SSA by analysing the issue in a Nigerian (net-oil exporter) and South African (net-oil importer) context. South Africa and Nigeria are selected as these are the largest net-oil exporter and importers respectively in SSA, furthermore, these economies are the largest in the region with the most sophisticated financial systems. Thus, analysing South Africa and Nigeria will provide an SSA context for policymakers to follow while ensuring there is sufficient data to justify the results.

Understanding oil shock effects is crucial to maintaining stability within the macroeconomy. The effects of oil provide insight during periods of recession where there exists a significant relationship between periods of US recessions and the price of crude petroleum (Hamilton, 1983), and the effect oil has on inflation risk exposure where it is evident that higher oil prices tend to increase domestic inflation (Choi *et al.*, 2018). The financial market of an economy contributes largely to the greater macro economy, with shocks to the economy being amplified by the financial markets (Bernanke *et al.*, 1994).

Hence, the impacts of oil shocks and their ability to generate financial distress is an important branch of literature to study. Kling (1985) finds oil price shocks lead to negative impacts on stock returns, which is further supported by the works of Jones and Kaul (1996). Conversely, Chen *et al.* (1986) and Huang *et al.* (1996) find no such negatively significant relationship between oil prices and stock returns. Furthermore, the link between the financial system and oil is shown to be closely tied by the fact that commodities (such as oil) and stock movements can aid in forecasting the directions of both commodity prices as well as stock market indices (Choi and Hammoudeh, 2010). There also exists a significant volatility spillover between oil

and stock returns (Arouri *et al.*, 2011), further emphasised by the correlation between BRENT and major equity indices being greater after the financial crisis of 2008 (Escribano *et al.*, 2023). In the sub-Sahara Africa (SSA) this link between financial markets and oil is present with Tumala *et al.* (2023) finding that oil supply shocks raise stock market volatility in Nigeria and South Africa, furthermore, Enwereuzoh *et al.* (2021) find that oil-specific shocks affect the equity markets of both oil-importing and oil-exporting SSA countries.

Thus, understanding the transmission of oil shocks into episodes of financial distress is an important analysis due to the link between the financial system and oil. Killian and Park (2009) pioneered the use of a Structural Vector Autoregression (SVAR) in the analysis of oil shocks and their effects on financial stability, finding that the source of the oil shock is important in determining the effect on the financial market. However, the study of Killian and Park only provides an insight into a single market segment of the greater financial system which may not accurately capture the true extent of financial stress compared to a composite index (Nazlioglu *et al.*, 2015). A more accurate gauge of total financial stability can be found by a financial stress index (FSI), which incorporates multiple market segments of the financial system to generate a deeper insight into the overall view of total financial stability (Illiang and Liu, 2003).

However, analysing the nexus between oil shocks and their effects on overall financial stability by use of an FSI within an economy is to the best of our knowledge scarce within emerging market structures, particularly within the context of oil-importing and oil-exporting African countries. Studies within the context of China (Liu *et al.*, 2021), India (Anand *et al.*, 2023), and Russia (Sohag *et al.*, 2023) have been performed, but these emerging market structures tend to differ from other emerging market structures, such as African market structures, due to differences in regions, politics, market structures, and economic activity. In addition, the methodology utilised in the construction of the FSI for many similar studies (Hakkio and Keeton, 2009; Park and Mercado, 2014) struggle to capture the dynamic effects of varying weightings and hence are vulnerable to raising false alarms. Furthermore, the majority of constructed FSIs tend to fit the characteristics of more advanced market structures, such as heavy corporate credit market weightings present within the works of Chatterjee *et al.* (2017) and Duprey *et al.* (2017). However, such frameworks are not a one-size-fits-all solution and there is a need to tailor FSI constructions to better suit emerging market structures.

1.2. Research Questions

This study aims to answer the following questions:

- i. What characterizes Financial Stress Indices for South African and Nigeria?
- ii. How does the disaggregated components of oil shocks affect the financial stability of South Africa, an oil net-importing country?
- iii. How does the disaggregated components of oil shocks affect the financial stability of Nigeria, an oil net-exporting country?

1.3. Research Objectives

This paper aims to build upon the literature relating to the creation of financial stress indices and the effects oil shocks have on the stability of the financial system within Nigeria and South Africa. This paper aims to:

- i. Derive financial stress indices for South Africa and Nigeria.
- ii. Analyse the impact of the disaggregated components of oil shocks on the financial stability of South Africa, an oil net-importer, using the created financial stress indices.
- iii. Analyse the impact of the disaggregated components of oil shocks on the financial stability of Nigeria, an oil net-exporter, using the created financial stress indices.

1.4. Justification for the Research

Several studies on energy-finance literature have applied several methodological and empirical analyses to examine the relationship between oil price movements and financial stability within emerging economies. Anand *et al.* (2023) explores the time-varying effects of oil price shocks on financial stress in India using the NYSE Arca Oil Index and CBOE Volatility Index. The financial stress index in this study is calculated using variance equal weighting (VEW) and principal component analysis (PCA). Sohag *et al.* (2023) explores the oil-finance nexus in Russia using a TVP VAR model. This study uses the ACRA financial stress index. Liu *et al.* (2021) find the non-linear effects of oil price shocks on financial stress using a Markov regime-switching (MRS) model to capture non-linear effects. This study utilises an FSI using the Park and Mercado (2014) methodology. Dagher and Hasanov (2023) study the impacts of oil shocks on the regional FSI for Asian economies. This study utilises three sources of oil shocks against the regional Asian FSI which was computed using the Park and Mercado (2014) methodology. However, the FSI methodologies used for the India and China FSI utilises composite indicators from the banking, foreign exchange, debt, and equity sub-markets. Thus, only using four sub-markets will yield fewer systemic measures of stress as other important sub-markets such as

housing are not directly captured in these measures. This issue is improved upon by the Russian ACRA index by including oil prices and the Russian consumer price index's inclusion in addition to the above. However, this still doesn't capture the likes of housing nor the full commodity market effects (as oil is a single product within the commodity market).

This study utilises partial area under root of characteristic (PAUROC) analysis to construct the FSIs across six market segments, following Chatterjee *et al.* (2017) and Kisten's (2021) methodologies. This methodology is shown by both Kisten and Chatterjee to outperform PCA and equal weights approaches. Kisten applies this methodology to the South African economy. However, this paper expands the commodity market to include more natural resources to reflect the higher importance of commodity trade in African economies (Kisten, 2021; Asiamah *et al.*, 2022; Mesegan *et al.*, 2023), while also introducing real estate investment trusts (REITs) to establish a consistent measure for African economies lacking refined housing indices unlike advanced economies, helping navigate the data collection issues plaguing much of sub-Saharan Africa.

This study utilises the SVAR analysis framework pioneered by Kilian (2009). This framework is updated to use Kilian's improved real economic activity index (Kilian, 2019). The study also utilises the updates to the framework proposed by Baumeister and Hamilton (2019). Hence this includes four sources of oil shocks by adopting the oil inventory shock data provided by Baumeister, as well as the variable ordering proposed.

This study contributes to the literature in the following ways. Firstly, by disaggregating global oil demand into separate sources, namely: real economic activity, real oil prices, and oil stockpiles from Baumeister and Hamilton's (2019), while moving away from proxying economic activity from the OECD world production index to Kilian's (2019) improved real economic activity index. To the best of our knowledge, testing the nexus of energy against financial stress at a multi-market systemic level using the above-mentioned disaggregation is not often conducted for emerging market structures, particularly in sub-Saharan Africa which has unique economic structures when compared to other emerging economies. Hence it is necessary to examine the relationship to provide insights that help improve immature policy and investment decisions which currently rely on analyses aimed at advanced economies whose underlying structures differ.

1.5. Scope of the Study

This study covers the period from 2000 to 2023 for South Africa and 2010 to 2023 for Nigeria. These periods are chosen to ensure enough events are present to sufficiently test the efficacy of the FSI which will be created, furthermore ensuring the oil-based shocks provide a comprehensive analysis of the effects on the financial stability within South Africa and Nigeria. Data availability provides a limitation which prevents using a larger sample, particularly for Nigeria, where obtaining the necessary data prior to 2010 is not possible.

1.6. Organisation of the Study

This study is organised as follows. Chapter one introduces the problem and objectives of the study, in addition to how this study is structured, Chapter two expands on the current body of literature pertaining to the topic, Chapter three discusses the estimable model and the econometric methodology, Chapter four discusses the results of estimation, and Chapter 5 provides concluding remarks.

CHAPTER TWO

LITERATURE REVIEW

This paper draws from two major strands of literature, namely: development and use of Financial Stress Indices (FSI) to proxy financial markets in quantitative analysis; and the effect of oil price shocks on the financial markets of a country, with a focus on economies located within sub-Saharan Africa.

2.1. Financial Stress Indices

2.1.1. Methodology

Hakkio and Keeton (2009) defines key features of financial stress as “increased uncertainty about the fundamental value of assets” , “increased uncertainty about the behaviour of other investors” , “increased asymmetry of information” , “decreased willingness to hold risky assets” , and a “decreased willingness to hold illiquid assets”.

Furthermore, Hakkio and Keeton (2009) created the Kansas City Financial Stress Index (KCFSI) which incorporated 11 standardised financial indicators from the equity market such as asset return volatility, the debt market such as the performance of 10-year sovereign bonds, as well as the credit market such as the LIBOR and T-bill spread. A PCA approach is used to construct the KCFSI. This allows for the creation of a common factor from the 11 standardised financial indicators which forms the KCFSI. However, the resulting index is stationary and has a zero mean, this means that predicting any turning points in the business cycle proves difficult as the given index fails to capture dynamic patterns.

Park and Mercado (2014) use the methodologies of Balakrishnan *et al.* (2009), Cardarelli *et al.* (2009, 2011), and Yiu *et al.* (2010) to obtain composite indicators from the banking sector, foreign exchange market, equity market, and debt market while employing the variance-equal weight approach to create a FSI for various countries. The limitation of using equal weights lies in the fact that varying correlations and variances between various variables are not captured, hence variables of greater importance will not dynamically receive greater weights. Furthermore, while the varying variances of different variables are captured using the variance-equal weighted average approach, the variables by assumption are normally distributed which may not reflect reality.

Duprey *et al.* (2017) expands the FSI framework by creating a FSI for 28 European countries. Chatterjee *et al.* (2017) further expands upon Duprey (2017) by incorporating three more markets (corporate bond market; money market and housing market) into their analysis of developing a FSI for the UK economy using the Area Under the Receiver Operating Characteristic Curve (AUROC) to analyse the effectiveness of their estimated indicators. This approach utilises signalling theory where a binary event indicates that a crisis is present (indicated by a one) or no crisis is present (indicated by a zero), which is then rated by the AUROC curve to determine the informational quality. Receiver Operating Characteristic (ROC) analysis is used in signal detection theory to depict the trade-off between false alarm rates and hit rates of variables (Egan, 1975) before being expanded upon for use in multiply disciplines such as medicine, and machine learning (Lusted, 1960; Spackman, 1989). Utilising a partial AUROC allows for variables to be ranked according to its informational content in being able to successfully capture the correct binary events. This allows dynamic information weights across variables to be captured. A significant advantage of this methodology over the previously stated methodologies is that the risk of over-weighting a given aggregated segment is reduced due to the dynamic weighting, hence there is a lower likelihood of incorrectly signalling a crisis occurring. In addition, Chatterjee *et al.* (2017) and Kisten (2021) find that the PCA and equal variance approaches are outperformed using the signalling theory approach to the construction of the FSI. Hence the partial AUROC approach is utilised in this study due to the evident advantage and performance over other such approaches used to create an FSI.

2.1.2. Findings in sub-Saharan Africa

The literature on FSIs in Africa is limited, with majority of the studies focusing on the South African and Nigerian economies. Gumata *et al.* (2012) constructs a Financial Conditions Index¹ (FCI) based on quarterly data from South Africa over the period of 1999 to 2011. This study uses principal component analysis to determine that their estimated indicators outperform the SARB leading indicator. The work of Gumata *et al.* (2012) is improved by Thompson *et al.* (2015) by solving the issue of endogeneity in the original PCI by adding three new macroeconomics variables (interest rates, inflation, and output). Ilesanmi and Tewari (2019) creates a FSI for Nigeria using the variance equal weighting and principal component analysis approach, similarly to procedure of Park and Mercado (2014). However, these studies face the

¹ Note the use of FSI and FCI are interchangeable in this paper. FSIs observe financial variables which increase the likelihood of a crisis to monitor financial stability, while FCIs aggregate various financial variables to identify the condition of the financial markets.

methodological vulnerabilities discussed in the prior section, such as assuming stationary and normally distributed variables for equal-variance analysis and difficulty in capturing turning points in the business cycle for PCA. However, Kisten (2021) adapts the framework of Chatterjee *et al.* (2017) to suit the South African economy, which overcomes these methodological issues using partial AUROC analysis. In addition, the effects of the commodity market are added to the framework of Chatterjee to account for the fact South Africa is a resource-based economy. This extends the framework to include 17 financial market indicators in the creation of the South African FSI (SA FSI).

While the recent literature has proven that FSIs are effective measures of total financial stability within an economy, many of the economies in question where these existing FSIs are applied do not only have more advanced financial systems compared to sub-Saharan Africa, but also have different market structures, and placing emphasis on certain market segments that don't hold the same importance in many African economies (Asiamah *et al.*, 2022; Mesegan *et al.*, 2023; Mu *et al.*, 2013). Hence using such instruments isn't ideal in the context of Africa, especially when performing analysis which have policy implications.

2.2. Oil price shocks and financial markets

2.2.1. Methodologies

The use of a Structural Vector Autoregression (SVAR) in studying oil price shocks on the economy and financial system stems from the work of Killian (Killian, 2009; Killian and Vega, 2011; Kilian and Park, 2009, Kilian and Zhou, 2020). Prior to this method, oil prices were assumed exogenous, hence in the study of oil price shocks all other variables were assumed constant. Such studies failed to integrate various types and origins of oil price shocks. Killian and Park (2009) amend this shortcoming by allowing for the categorisation of four types of oil shocks, namely: political oil supply shocks, aggregate demand shocks, oil-specific demand shocks, and other oil supply shocks. However, Hamilton (2018) critiques the proxy for global real economic activity created by Killian (2009). This finding suggests that the variable is conceptually flawed due to a normalisation used by Kilian which leads to substantive consequences. In response, Kilian (2019) noted that the issue stems from a coding error which when corrected answered all the raised concerns by Hamilton (2018). Furthermore, Baumeister and Hamilton (2019) critique the strict formulation assumptions used by Killian (2009), finding that when using a Bayesian interpretation, it is evident that the analyst assumes supply has zero response on the impact to the oil price, and no useful information at all about the response of

demand to price. In addition, the VAR framework is expanded to a four-variable system with the inclusion of oil inventory demand. However, Kilian (2019) argues that the finding is not due to a superior econometric methodology but rather to relaxing a key assumption in oil market models by imposing a one-month oil supply elasticity larger than 0.4. Furthermore, Kilian argues that there is not enough empirical support to warrant the change of this assumption. Hence this study will incorporate will use the traditional framework laid out by Kilian (2009) with an expansion of the inclusion of the oil inventory demand used by Baumeister and Hamilton (2019) as well as the corrected real economic activity measure from Kilian (2019).

Kilian and Park (2009) use the percentage change in world crude oil production, global real economic activity, the real oil price, and the return on stocks in the United States to investigate the relationship between US stock prices and oil price shocks in the framework from Killian (2009). This finds that oil demand shocks result in declines in US stock returns while oil supply shocks have less impact on US stock returns. Similarly, Fang and You (2014) find negative responses from oil market shocks. Conversely, Bai and Koong (2018) find evidence of positive responses to oil shocks in China and the US. Apergis and Miller (2009) find that oil market shocks don't have a significant impact on the stock prices within Australia, Canada, France, Germany, Italy, Japan, the UK, and the US. Similarly, Chen *et al.* (1986) states oil prices do not affect stock price trends.

2.2.2. Findings in developing countries and the sub-Saharan context

There are also studies into the effects of oil shocks in developing countries, such as Sachez (2011) who found the oil-importing developing countries of Bangladesh, El Salvador, Kenya, Nicaragua, Tanzania, and Thailand tend to see a decrease in GDP leading to higher unemployment in the presence of oil price shocks. Dagher and Hasanov (2023) applies Killian's (2009) framework to Asian countries, including both developed and developing economies, however instead of stock returns, Park and Mercado's (2014) FSI is applied. This study finds the source of oil shocks is important as oil-specific supply shocks tend to have greater effects on financial instability compared to oil-specific demand shocks. Furthermore, Nkomo (2006) finds Southern African countries tend to be vulnerable to oil shocks due to being completely dependent on imported oil, apart from Angola whose an active exporter of crude petroleum.

South Africa is a net-oil importer due to a lack of naturally occurring crude oil reserves domestically, hence the movement of the oil market does have an impact on the real economy (Hollander *et al.*, 2018). Furthermore, a large body of literature corroborates the findings that South Africa experiences inflationary pressure in response to oil market shocks (Sibanda & Mlambo, 2014; Gupta & Kotze, 2017; Chiweza & Aye, 2018; Hollander *et al.*, 2018; Sanusi & Kapingura, 2021). However, there is a divergence of findings on how oil affects other economic variables within the South African economy, ranging from positive to negative. For instance, the real price of oil is found to have a significant impact the three-month Treasury bills rate (Gupta & Kotze, 2017), exchange rates (Sibanda & Mlambo, 2014, Sanusi & Kapingura, 2021), stock market returns (Gupta & Modise, 2013; Sanusi & Kapingura, 2021), as well as a driver of output, interest rates (Hollander *et al.*, 2018). However, proxies of the financial system within South Africa tend to be tied to stock market performance or foreign exchange movements. This fails to capture the broader multimarket level systemic effects of the South African financial system in response to such shocks as the entirety of the financial system comprises of all the discussed variables and more. Hence there is a need to examine the relationship between oil market shocks and systemic financial health within the South African economy at a multi-market level.

Nigeria is a net-oil exporter and hence the commodity export of crude oil plays an important role for the Nigerian economy. Aliyu (2009) finds that oil price shocks to affect exchange rate volatility, showing that an oil price shock and appreciation in the exchange rate positively impact the real economic growth of Nigeria, while Babatunde (2015) finds that positive oil price shocks tend to depreciate the exchange rate and negative oil price shocks tend to cause an exchange rate appreciation. Furthermore, stock market returns from oil supply shocks are found to be insignificantly negative but are significantly positive to aggregate demand and oil-specific demand shocks (Effiong, 2014; Enwereuzoh *et al.*, 2021). In addition, oil price shocks are further observed to have a negative impact on domestic prices within Nigeria in the short term, while also having an effect within the long term (Alimi *et al.*, 2021; Orekoya *et al.*, 2024). Similarly to South Africa, the effect of oil shocks is evident within the Nigerian economy. However, the effect on the financial system is generally explained from a narrow view of singular variables such as stock market returns or exchange rate volatility which fails to capture the overall effect on the financial system. Hence there appears to be a gap analysing the effect oil shocks have on the Nigerian financial system at a multi-market systemic level.

Therefore, since the study of the impact of oil-based shocks on financial stability largely relies on individual market segments as proxies for the entire financial system within SSA, this study aims to fill the gap by showing how oil market shocks affect the entire financial system of an economy at a systemic level to inform policies to mitigate such shocks for South Africa and Nigeria, while providing a relevant framework with a similar market structure for other SSA Countries to consider when implementing such policy.

CHAPTER THREE

MODELLING AND ESTIMATION

This chapter describes the methodology and the data structure used within the study. The signal theory and SVAR framework are used to characterise the effect of the oil market on financial stability of countries.

3.1. Data Sources

Table 1 depicts data sources used within the FSI estimation process.

Table 1: Data sources used to construct FSI.

Variable	Data Description	Data Source
All Share Index	Main index of the local share market	Bloomberg, EquityRT
Banking Sector Index	Index representing the performance of the local banking sector	Bloomberg, EquityRT
10-year Sovereign Bond	Return on a ten-year local government bond	Bloomberg, SARB ²
5-year Sovereign Bond	Return on a five-year local government bond	Bloomberg, SARB
3-year Sovereign Bond	Return on a three-year local government bond	Bloomberg, SARB
3-month T-bill	Return on a local government three-month T-Bill	CBN ³ , SARB
10-year Corporate Bond ⁴	Return on a ten-year local corporate bond	Quantec EasyData
Private Sector Credit Growth	Total debt instruments provided to the private sector	CBN, Quantec EasyData
Bilateral Exchange Rate	The value of local currency relative to a foreign currency	Bloomberg, EquityRT
Real Exchange Rate	Nominal exchange rate multiplied by the ratio of prices between two countries	Bloomberg, EquityRT, CBN, SARB
Interbank Interest Rate	The interest rate which commercial banks lend to one another	CBN, Quantec EasyData
Prime Lending Rate	The default interest rate charged to consumers	IMF Online Statistical Data, CBN, SARB, Quantec EasyData

² South African Reserve Bank.

³ Central Bank of Nigeria.

⁴ Due to data limitations this study is unable to acquire Nigerian corporate bond data, however relevant corporate bond data is available for South Africa which is why we choose to include Eskom 10-year corporate bond yields for the South African FSI. This is evident by the fact the CMIN_CORP indicator is selected to form part of the SA FSI in section 3.1.5.

Gold Price	The Price of gold per ounce (USD)	Bloomberg, EquityRT
Property Index ^{5 6}	Index showing the growth of local real estate	Bloomberg, EquityRT, Quantec EasyData
Household Disposable Income	National level of Disposable Income from Households	National Bureau of Statistics Nigeria, Quantec EasyData
Foreign Direct Investment (FDI)	Inward foreign direct investment	CBN, Quantec EasyData
SRISK	A measure of Systemic Risk within a country's financial system	https://vlab.stern.nyu.edu/srisk
CPI	Consumer Price Index	CBN, FRED ⁷
US CPI	United States CPI	FRED

Source: Author's Own Compilation

Table 2 depicts the variables used for the oil analysis in addition to the relevant data source.

Table 2: Data sources used to perform VAR analysis.

Variable	Variable Name	Data Description	Data Source
Real Brent Crude Oil Price	BRENT	Price of Brent Crude	US Energy Administration
World Crude Oil Production	GOP	Total world petroleum production (million barrels per day)	US Energy Administration
World Real Economic Index	REA	Kilian's improved index for global economic activity ⁸	FRED
Oil Inventory Demand Shocks	OID	Monthly world crude oil inventory stocks	Baumeister, C. and J.D., Hamilton
South African FSI	SA_FSI	Financial Stress Index	Author's own calculation (section 3.1)
Nigerian FSI	NG_FSI	Financial Stress Index	Author's own calculation (section 3.1)

Source: Author's Own Compilation

3.2. Construction of the FSI

3.2.1. Candidate indicators

Table 6 in the *Appendix* depicts a list of potential stress indicators across six market segments to be included in development of the FSI. Several candidate indicators are selected due to their

⁵ South Africa uses the ABSA Housing Price Index (HPI) which is extrapolated past its discontinuation date using the annual rate of growth of the FNB housing price index, since the annual growth has a 91% correlation.

⁶ Due to data limitations Nigeria uses Real Estate Investment Trust performance as a proxy to HPI.

⁷ Federal Reserve Economic Data (FRED), St. Louis Federal Reserve.

⁸ This index improves upon Killian's (2009) index with the correction discussed in Killian (2019). The advantages of using this index are discussed in Killian and Zhou (2018).

efficacy in the work of Duprey (2017), Chatterjee *et al.* (2017) and Kisten (2021). Each indicator's predictive ability will be tested against the benchmark episodes identified for each country in the next section.

3.2.2. Episodes of financial stress

The identified benchmark episodes are identified below, where each period of financial distress is given a value of one, otherwise zero is given.

3.2.2.1. South Africa

The baseline events of financial distress for South Africa are:

- 2001-2003: The rand depreciates 26% against the US dollar between September and December 2001 (driven by the dot com bubble bursting), however unlike the 1998 episode of crisis, the short-term interest rates stayed constant, the yields on long-term bonds rose by 100 basis points, and the spreads on dollar-denominated bonds reduced by 40 basis points (Nowak and Ricci, 2006). Furthermore, share prices rose by 28%, accompanied by a real GDP increase. The action of the SARB within in this episode of crisis greatly lessened the macroeconomic impact when compared to the 1998 actions of the SARB, this was achieved by the SARB opting to abstain from intervention which allowed the crisis to recede faster without greater macroeconomic consequence. Furthermore, the global impact of the dot com bubble bursting caused a global slowdown in economic activity, meaning South Africa experienced a decrease in demand for its goods and services. Thus, the country experienced a decline in net international reserves in the last quarter of 2001. In addition, the South African Reserve Bank (2002) finds that the banking sector of South Africa is experiencing a deterioration on returns on assets and equities over the period of 2001-2002 due to the fact foreign banking activity within the local banking sector decreased significantly for the first time in six years. In 2002, the country then experienced a small banks crisis set off by the collapse of Saambou bank in February 2002, creating a contagion which rapidly spread amongst the country's small and medium sized banks. Resulting in half of the banks within South Africa deregistering by the end of 2003 (Havemann, 2021).
- 2008-2009: The collapse of the Lehman Brothers bank in 2008 kickstarted the global financial crisis of 2008. Causing a severe slump in global economic activity, since South Africa is an open economy the country experienced severe macroeconomic consequences, like the estimated loss of 900,000 jobs, placing further pressure on an economy already facing an unemployment crisis (Verick, 2010). Consequently, the economy fell into a recession in the last

quarter of 2008, driven by the contraction in the manufacturing, mining, financial, real estate and, wholesale and retail trade sectors (Statistics South Africa, 2009; SARB, 2009). In addition, capital inflows decreased, deteriorating South African share prices and the rand value. The JSE All Share Index (ALSI) decreases by 20% while the Rand deteriorated by upwards of 40% against the dollar in 2008 (Saayman, 2010). According to SARB (2009), the leading contributor to the decline in economic growth is the manufacturing sector. Share prices started recovering by the end of 2009, due to global equity recovery and substantial increases to commodity prices supporting the commodity sector of South Africa. The rand value furthermore recovered while the banking sector remained relatively stable throughout the crisis.

- 2020-2021: The first reported case of Covid-19 to hit South Africa was in March 2020. The Covid pandemic caused severe macroeconomic stress globally, including South Africa. According to Gruzd *et al.* (2020), the decrease in global economic activity and foreign capital flows due to the pandemic causing multiple sectors to contract significantly (with construction, retail, and hospitality being particularly hard hit). The interest rate was cut by a total of 300 basis points in 2020 by SARB which helped alleviate debt servicing pressure. StatsSA (2020) finds that in the first two weeks of April 2020 almost 90% of businesses reported turnovers below normal levels, of which 48% opted to ceased operations temporarily, and finally 9% decided to permanently remain closed. As a result, business confidence took a significant hit. These figures were driven by the first lockdown reported at the end of March 2020. With on and off lockdowns, the South African economy stagnated until early 2021 once the state of disaster was lifted. Daniels and Casale (2022) states that the Covid pandemic severely impacted the South African economy with GDP levels returning to that of the end of 2019 only in June 2022. Furthermore, the contraction in 2020 caused by the pandemic is equivalent to a massive 6.3% contraction in GDP, which recovered by only 4.9% in 2021. This emphasises the long reaching consequences of this period of crisis. In addition, during the employment-to-population ratio fell from 56.6% to 48.3% during the initial pandemic wave for the working-age population (18–64-year-olds).

3.2.2.2.Nigeria

The benchmark episodes of financial distress for Nigeria are:

- 2015-2016: The Nigerian economy is described as a mono economy, due to its reliance on the exportation of oil for its survival (Ogochukwu, 2016). The lucrative value of the oil market helped minimise the 2008 global financial crisis's impact on the Nigerian economy. Hence, post 2008, the price of oil began to rise steadily which provided a major boon to economies

such as Nigeria which specialise in oil exportation. However, in 2015 the global price of oil experienced a decline which placed significant strain on the Nigerian economy⁹. According to Ogochukwu (2016), the over reliance on oil during price drop led to three commercial banks within Nigeria to fail to meet their capital adequacy ratio of 10%. As a result, the Central Bank of Nigeria (CBN) embarked on a recapitalisation plan to ensure the banking sector can recover from the crisis and maintain stability. Furthermore, the energy sector owed a ₦5 trillion debt to Nigerian banks which was at risk of defaulting. Hence, the CBN intervened by implementing policies to rigorously recover loan defaulter to help protect the banking sector and hence the financial sector of the Nigerian economy due to the close link between the energy sector and banking sector within the economy. In addition, the oil price decreasing caused a subsequent depreciation of the Naira. Imimole and Enoma (2011) state the depreciation of the Naira will affect the prices of goods and services due to Nigeria's reliance on importing such goods and services. This in turn leads to greater inflation within the economy.

- 2020-2021: According to Ekeruche and Adeniran (2021), the Nigerian economy experienced a deep incline in GDP growth of 6.1% in the second quarter due to the first lockdown enacted in March 2020, shortly after the first reported case in February 2020. The GDP continued to decline by 3.6% in the third quarter of 2020, officially beginning a recession. However, the agricultural and services sectors provided much needed growth to economy which helped facilitate Nigeria's exit from the recession in the fourth quarter of 2020 when GDP recorded a 0.11% growth rate. The decrease in global activity furthermore causes a contraction in the demand for oil which accounts for 80% of Nigeria's export earnings (World Bank, 2020). This led to the decline in the fiscal and foreign exchange space of the Nigerian economy. Since Nigeria is an import-dependent economy which imported an estimated \$100 billion worth of goods and services in 2019 (World Bank, 2021), a weaker foreign exchange meant that the price of commodities (particularly food) increased significantly. Food inflation increased from 13.98% to 17.25% while general inflation rose from 11.5% to 14% over the same period. The recovery efforts for the economy included the addition of \$1.4 billion in spending by the Nigerian government, mainly aimed at non-health sectors affected by the pandemic (IMF, 2021). Furthermore, tax refunds were offered to businesses that did not layoff any workers in 2020. In addition, the Central Bank of Nigeria (CBN) cut interest rates from 13.5% to 11.5% to provide credit relief to the private sector (CBN, 2021).

⁹ Press Release: IMF Executive Board Concludes 2014 Article IV Consultation with Nigeria, March 2015, available at: <https://www.imf.org/en/News/Articles/2015/09/14/01/49/pr1591>

3.2.3. Methodology to capture episodes of crisis

With the benchmark episodes of financial distress identified, this study utilises pAUROC values to rank the quality of information which the candidate indicators from Table 6 provide.

3.2.3.1. Signal Theory

A fundamental aspect of AUROC analysis is the concept of signal theory, essentially at every period a signal is generated from the variable currently being processed each time the variable exceeds a given threshold, otherwise no signal is generated. This is useful in an economic sense since signalling theory can be used to identify leading indicators of financial stress by the tested variable's ability to exceed the defined threshold in an early enough manner for policy makers to have enough time to successfully implement mitigation measures.

The relevant outcomes are defined as follows:

	Crisis	No Crisis
higher than threshold	W	X (Type II error)
lower than threshold	Y (Type I error)	Z

Where W represents a good signal since a signal is generated during an identified benchmark episode of financial distress, X represents a bad signal since a signal is generated while there is not an identified period of financial distress (this is a type II error as a false hypothesis is accepted), Y represents a missed signal since no signal is generated during an identified benchmark of financial distress (this is a type I error as a true hypothesis is rejected), and finally Z represents a correctly identified period of calm since no signal is generated while there are no identified periods of financial distress.

The lower the threshold is the more likely signals are to be generated (and hence type II errors are to occur), while the higher the threshold the less likely signals are to be generated (and hence more type I errors occurring). Thus, there is a trade-off policy makers need to make when using this model between missing too many crises or incorrectly predicting events of crises. Since the benchmark episodes of financial crises are identified, the signal ratio (1 – Type I error) and the noise ratio (Type II error) of a given variable is defined as:

$$S = \frac{W}{W + Y} \dots (1)$$

$$N = \frac{X}{X + Z} \dots (2)$$

For a low threshold, both the signal and noise ratios should be high as more signals are being generated, while a high threshold will produce the opposite effect. The noise-to-signal ratio provides further insight into the significance of the quality of an indicator, with values below one indicating a useful indicator while a value of exactly one finds the indicator to be equivalent to a purely random indicator. A limitation of the noise-to-signal ratio is the fact it depends on a particular threshold which often reaches its greatest value at very low signal and noise ratios (which is associated with high thresholds).

Furthermore, the value assigned to a threshold has an economic interpretation. A low threshold value would occur when the cost of intervention of policymakers is low and the reward for intervention is high. Hence, avoiding type I errors is more important than type II errors. While a high threshold infers that intervention is costly and as a result policymakers are risk averse, meaning avoiding type II errors is more important than type I errors.

3.2.3.2. Area under receiver operating characteristic curve (AUROC)

The receiver operating characteristic curve (ROC) illustrates the trade-off between type one and type two errors by plotting the noise ratio on the x-axis against the signal ratio on the y-axis for every threshold value. The AUROC curve tests the predictive ability of an indicator, independent of preference.

Figure 1 shows the AUROC for the ZAR/EUR exchange rate in comparison to the maximum level over a two-year moving period for South Africa. The AUROC will always be a value in-between zero and one due to the area of the plot being that of a unit circle. Furthermore, the 45-degree line represents the signals of a purely random indicator, having an AUROC value of 0.5. Hence, any AUROC value larger than 0.5 indicates a more informative indicator as it outperforms the purely random case. While any value below 0.5 means the indicator is a poor predictor since a purely random indicator outperform the tested indicator.

Furthermore, high threshold values occur close to the origin (0,0) as few signals are emitted which would mean less type II errors and more type I errors. The further away from the origin the threshold values are the lower they become which is why type II errors occur more and type I errors occur less. As the threshold value decreases, the number of generated signals increase

and hence the percentage of type II errors increase from 0% to 100% (from no false alarms to 100% of false alarms generated).

The AUROC value represents the precision of the indicator over all conceivable threshold values and hence doesn't consider the preferences of policy makers. This value simply depicts type-one and type-two trade-off. This has the advantage of being a 'threshold-free' test of how good an indicator generates signals in a binary event. For example, in figure 1 the AUROC value is 0.7626. However, preferences greatly impact the decision-making process of policymakers and hence an adjustment to the AUROC test needs to be made to account for such preferences.

3.2.3.3. Partial AUROC

Alessi and Detken (2014) states prior to the 2007/2008 global financial crisis, policymaker preferences were likely inclined towards a greater dislike of type-two errors (creating false alarms). Whereas post 2008 the preferences have been shifted towards a greater dislike of type I errors (missing crisis signals). The loss function for policymakers is thus:

$$L(\theta) = \theta T_1 + (1 - \theta) T_2 \dots (3)$$

Where θ represents relative risk aversion, T_1 represents the share of type-one errors relative to the share of overlooked crises $\left(\frac{Y}{W+Y}\right)$, while T_2 represents the share of type II errors $\left(\frac{X}{X+Z}\right)$. Hence, prior to the 2008 global crisis, policymakers had preferences such that $\theta < 0.5$, meaning policymakers had a stronger dislike for false alarms occurring. Whereas after the 2008 global crisis, preferences were now inclined such that $\theta > 0.5$, meaning policy makers now have a stronger dislike for missing crises.

The advantage of using the pAUROC values arises from the fact policymaker preferences can now be mapped using a suitable range of values from the loss function defined in (3), removing all threshold values (θ) representing implausibly high and low values. Chatterjee *et al.* (2017) estimate the pAUROC values using the range $\theta = [0.2, 0.8]$. Hence, this study will also adopt this threshold range to account for policymaker preferences.

Figure 1 depicts the effect of preferences on the predictive efficiency of the ZAR/EUR exchange rate in comparison to the maximum level over two-year moving period for South Africa. The shaded region under the ROC represents the partial area under the ROC which corresponds to policymakers with preferences ranging from 0.2 to 0.8. The new value considering preferences is now 0.8059, which is higher than the AUROC value, meaning that when preferences are considered the predictive ability of the indicator improves.

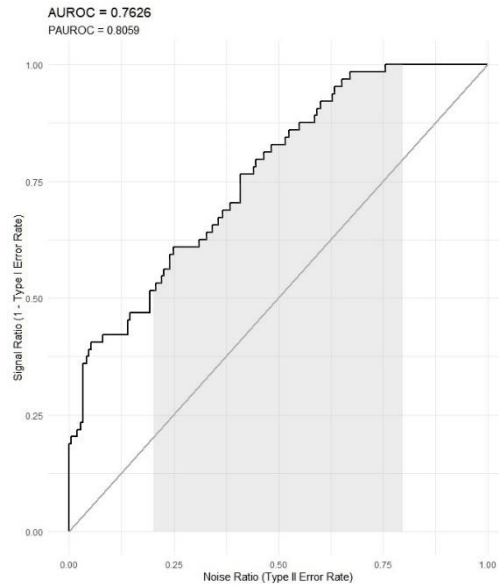


Figure 1: AUROC for ZAR/EUR exchange rate in comparison to the maximum level over a two-year moving period for South Africa

3.2.4. Selection of indicators

Every indicator listed in Table 6 may not meaningfully contribute to providing a more insightful and accurate prediction of financial distress. Hence the following procedure is implemented to prune all irrelevant indicators:

- 1) Rank every candidate indicator for each market segment in descending order by its pAUROC value. If any pAUROC value is less than 0.5 then discard the candidate indicator as a purely random indicator will outperform the candidate indicator.
- 2) The first selected indicator is always the candidate indicator with the highest pAUROC value in each market segment. This is denoted as the market indicator. For example, in the credit market segment ABS_SPR becomes the market indicator.
- 3) Select the candidate indicator with the next highest pAUROC value and aggregate the candidate indicator with the market indicator. If the pAUROC value of the market indicator is then subtracted the pAUROC value of the aggregate yielding incremental pAUROC. If the incremental pAUROC is positive, then the candidate

indicator adds meaningful information and hence set the market indicator equal to the aggregate value. If the incremental pAUROC is negative, then reject the candidate indicator. For example, the next highest candidate indicator in the credit market segment is CDIFF_SPR, hence the aggregate is calculated as:

$$I'_{CM} = \frac{ABS_SPR(pAUROC_{ABS_SPR} - 0.5)}{(pAUROC_{ABS_SPR} - 0.5) + (pAUROC_{CDIFF_SPR} - 0.5)} + \frac{CDIFF_SPR(pAUROC_{CDIFF_SPR} - 0.5)}{(pAUROC_{ABS_SPR} - 0.5) + (pAUROC_{CDIFF_SPR} - 0.5)} \dots (4)$$

Where I'_{CM} is the temporary market indicator for the credit market.

The incremental pAUROC is then $pAUROC_{I'_{EM}} - pAUROC_{ABS_SPR}$. This yields the following two scenarios:

- The incremental pAUROC is positive, or $pAUROC_{I'_{EM}} > pAUROC_{ABS_SPR}$. Then adding CDIFF_SPR improves the informational content of the market indicator.
- Otherwise, adding CDIFF_SPR doesn't improve the informational content and hence it is rejected.

4) Repeat steps 1 to 3 for every indicator in a market segment. Then perform the same procedure for each remaining market segment.

Table 7 in the *Appendix* shows the AUROC and pAUROC values for each candidate indicator for South Africa and Nigeria. The values in bold represent the selected indicators for Nigeria and South Africa. 16 indicators are selected for South Africa and 17 are selected for Nigeria.

3.2.5. Normalisation and construction of sub-indices

With the selected indicators it is now possible to begin constructing the sub-indices for each market segment. However, the selected indicators need to first be standardized as all the raw indicators do not share the same unit of measurement.

The indicators are normalised using the empirical cumulative distribution function (ECDF), which transforms each indicator to lie in a new domain of [0,1]. An advantage of ECDF standardisation over more common standardisation methods is the fact that ECDFs don't assume variables are distributed normally, which is particularly useful when normalising indicators which are not necessarily normally distributed. Hence according to Hollo *et al.* (2012), the ECDF provides a more robust result since the transformations depend on location

and dispersion measures. The ECDF replaces the values with a ranked number scaled by the size of the sample for every indicator. I.e., Consider a sample of size n and:

$$x = (x_1, x_2, \dots, x_n)$$

The values are transformed by ranking the sample in increasing order, hence:

$$x[1] \leq x[2] \leq \dots \leq x[n]$$

Where the maximum of the sample is $x[n]$, the minimum of the sample is $x[1]$, and $[r]$ is the sample ranking number. Generalising this result shows that an ECDF can be calculated by:

$$f_n(x_t) = \begin{cases} \frac{r}{n} & \text{for } x[r] \leq x_t < x_{r+1}, r=1,2,3,\dots,n-1 \\ 1 & \dots \end{cases} \quad (5)$$

The ECDF thus transforms every value into a range of $[0,1]$ (which is now unit free) which forms a non-decreasing function which rises by $\frac{1}{n}$ for every period. However, in this study the ECDF values are matched to the period when the observation occurred to be able to capture the effects of periods of financial distress. Figure 2 depicts the 16 normalised indicators for South Africa, while Figure 3 depicts the 17 normalised indicators for Nigeria.

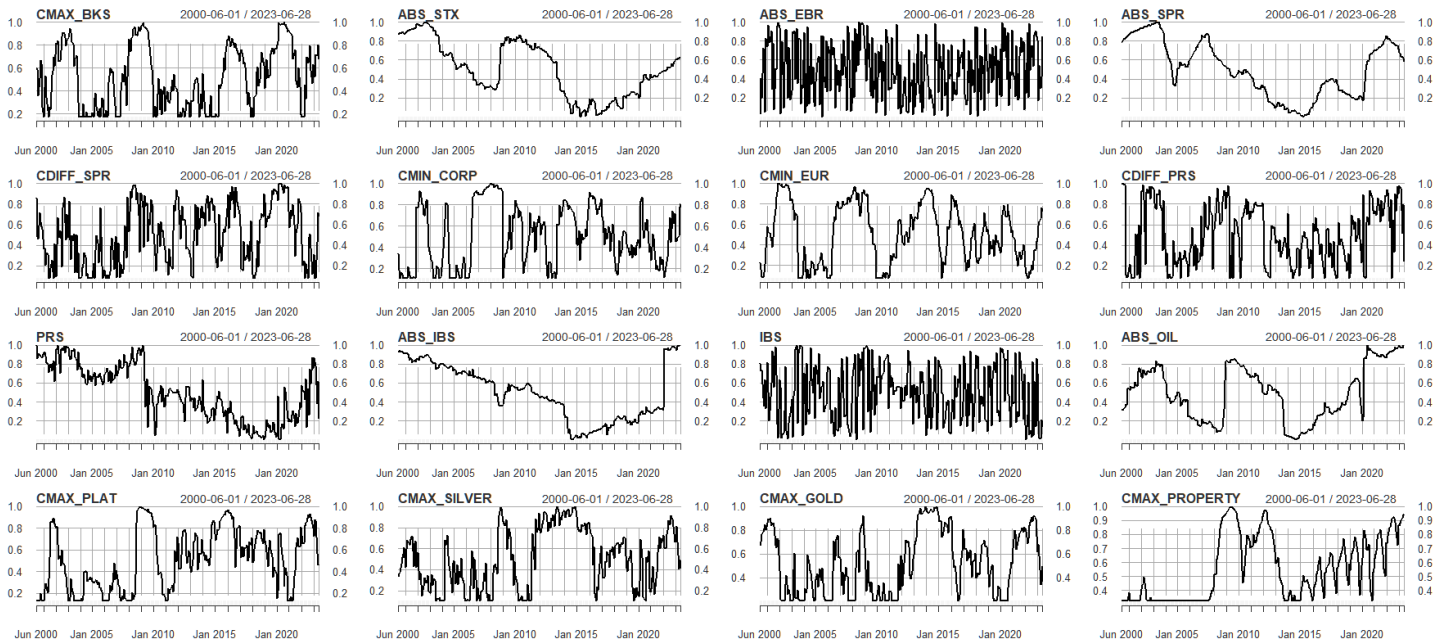


Figure 2 Normalised Indicators for South Africa

With indicators normalised, creating the sub-indices for each market segment is possible. The aggregation of the indicators for each market segment is calculated by taking the average of

the normalised indicators weighted by their pAUROC value indicating the informational content.

For instance, the credit sub-market index for South Africa is computed by the following:

$$I_{CM} = \frac{\sum_{j=1}^3 CM_{j,t} \times (pAUROC_j - 0.5)}{\sum_{j=1}^3 (pAUROC_j - 0.5)} \dots (6)$$

Where $j = 1, \dots, 5$ since five indicators are selected for the credit market sub-index, and $CM_{j,t}$ represents the ECDF of indicator j .

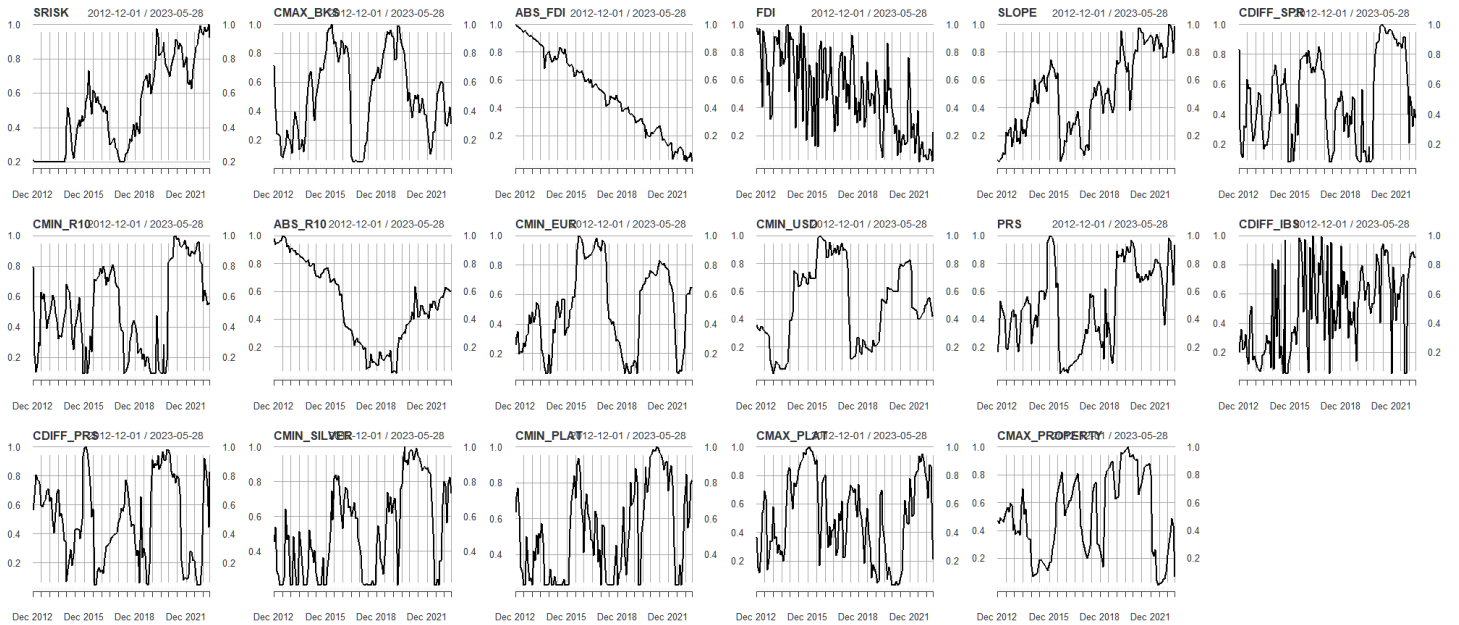


Figure 3 Normalised Indicators for Nigeria

3.2.6. FSI construction

Standard portfolio theory is used to aggregate market sub-indices as the weights for every sub-index is determined by its cross-correlation to other sub-indices, since similar risk is captured by the indicators¹⁰. Hence the effectiveness of the FSI capturing systemic instances of stress depends on its ability to record any co-movement across the financial markets. This means that positive correlations across sub-indices implies the overall effect of the FSI is greater than the sum of its components. This also implies negative correlations will generate an effect smaller than the components of the FSI. In addition, variations in time allows for more weight to be

¹⁰ Holl *et al.* (2012), Vermeulen *et al.* (2015), Louzis and Vouldis (2012), Chatterjee *et al.* (2017), and Kisten (2021) aggregate using portfolio theory.

placed on periods of stress where several markets indicate elevated levels of stress which emphasises the systemic dimension of the FSI. The FSI is calculated as follows:

$$FSI_t = (w_t \times I_t)' \times C_t \times (w_t \times I_t) \dots (7)$$

Where I_t is the vector standardised of the market sub-indices for the equity, credit, foreign exchange, money, resource, and housing market. Given as:

$$I_t = (I_{EM,t}, I_{CM,t}, I_{FM,t}, I_{MM,t}, I_{RM,t}, I_{HM,t}).$$

w_t is a vector of the average pAUROC values of each sub-index representing information weights for each sub-market index. This is a 1×6 vector which where each element equals:

$$w_{CM} = \frac{pAUROC_{CM} - 0.5}{\sum_i (pAUROC_i - 0.5)} \dots (8)$$

In this instance the weight for the credit market sub-index is calculated by taking the value of the pAUROC minus 0.5 (since the information greater than 0.5 is useful, everything up to 0.5 is the same as a purely random indicator) divided by the sum of the of all the sub-indices' pAUROC value minus 0.5. Hence $i = \{EM, CM, FM, MM, RM, HM\}$.

And finally, C_t is the matrix of cross correlations. This is a 6×6 matrix of the cross-correlations of each sub-index varying over time. Given as:

$$C_t = \begin{pmatrix} 1 & \rho_{EM,CM,t} & \rho_{EM,FM,t} & \rho_{EM,MM,t} & \rho_{EM,RM,t} & \rho_{EM,HM,t} \\ \rho_{EM,CM,t} & 1 & \rho_{CM,FM,t} & \rho_{CM,MM,t} & \rho_{CM,RM,t} & \rho_{CM,HM,t} \\ \rho_{EM,FM,t} & \rho_{CM,FM,t} & 1 & \rho_{FM,MM,t} & \rho_{FM,RM,t} & \rho_{FM,HM,t} \\ \rho_{EM,MM,t} & \rho_{CM,MM,t} & \rho_{FM,MM,t} & 1 & \rho_{MM,RM,t} & \rho_{MM,HM,t} \\ \rho_{EM,RM,t} & \rho_{CM,RM,t} & \rho_{FM,RM,t} & \rho_{MM,RM,t} & 1 & \rho_{RM,HM,t} \\ \rho_{EM,HM,t} & \rho_{CM,HM,t} & \rho_{FM,HM,t} & \rho_{MM,HM,t} & \rho_{RM,HM,t} & 1 \end{pmatrix} \dots (9)$$

This allows for episodes of simultaneous stress across multiple sub-indices to be emphasized. Each element of the matrix is estimated using a multivariate GARCH methodology which is explained in further detail in the *appendix B.2*. By using time-varying correlations the systemic dimension of financial stress can be emphasized since episodes of systemic stress will be more clearly identified by the increased correlations amongst the sub-indices. This helps the FSI distinguish between market specific shocks which do not have large systemic impact versus multi-market shocks with a large systemic impact. It is important to note that according to Hollo *et al.* (2012), the cross correlations don't act as a forecast of risk arising

from correlation, rather indicating the extent of historical similarities between any two market segments at any given point in time.

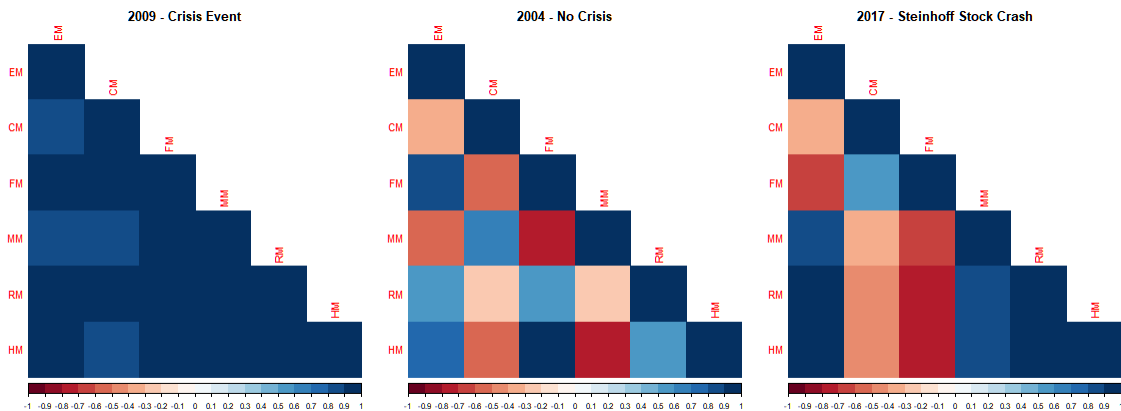


Figure 4: Snapshot of South African market correlations

Figure 4 illustrates how the time-varying correlations have significant and strongly positive values in a period of stress identified in 2009 by the South African FSI, whereas another identified period of calm in 2004 shows far less correlations between each market, and finally a period of single market stress is identified in December 2017 whereupon the Steinhoff stock crash occurred.¹¹ However, this period is not an identified period of systemic stress, which is supported by the weaker correlations compared to the 2009 period.

The constructed FSI using the methodology employed within this study has the benefit of ensuring a market segment which is more relevant than the other segments is assigned more weight during periods of crisis. This is done by creating weights determined by not only the relative pAUROC values of each market segment but also the cross-correlations between each market segment. Hence, the values of the FSI in periods of crisis are optimised by assigning more weight to relevant information and minimising the effect of redundant information. Figure 5 and 6 depicts the South African FSI (SA_FSI) and the Nigerian FSI (NG_FSI) respectively. The benchmark episodes of stress are represented by the shaded regions.

3.2.7. Insights from constructed FSI

The South African FSI, depicted in figure 5, spikes for each of the benchmark episodes of stress over the 23-year span, which is expected as these episodes are used to help the model identify episodes of stress. Namely for the 2001 currency crisis, the 2008 global financial crisis and

¹¹ See: [https://www.reuters.com/article/us-steinhoff-intl-nl-results/steinhoff-scandal-knocks-12-billion-off-value-in-blow-to-tycoon-wiese-idUSKBN1E11U8/#:~:text=JOHANNESBURG%2FBERLIN%20\(Reuters\)%20%2D,for%20the%20South%20African%20retailer.](https://www.reuters.com/article/us-steinhoff-intl-nl-results/steinhoff-scandal-knocks-12-billion-off-value-in-blow-to-tycoon-wiese-idUSKBN1E11U8/#:~:text=JOHANNESBURG%2FBERLIN%20(Reuters)%20%2D,for%20the%20South%20African%20retailer.)

2020 Covid-19 pandemic. However, it is worth noting that the FSI identified minor stress episodes outside of the baseline stress events. The 2006 is captured by the FSI where a credit boom driven by increased household debt which increased the probability of defaulting occurring. This due to the tightening of a loose interest rate which reflected in the latter half of 2006 the financial stress due to the higher likelihood of household defaults. The index furthermore captures the 2021 South African riots as show by the upturn by the index in mid-2021, before its continued decline into 2022. These riots were driven by supporters of the

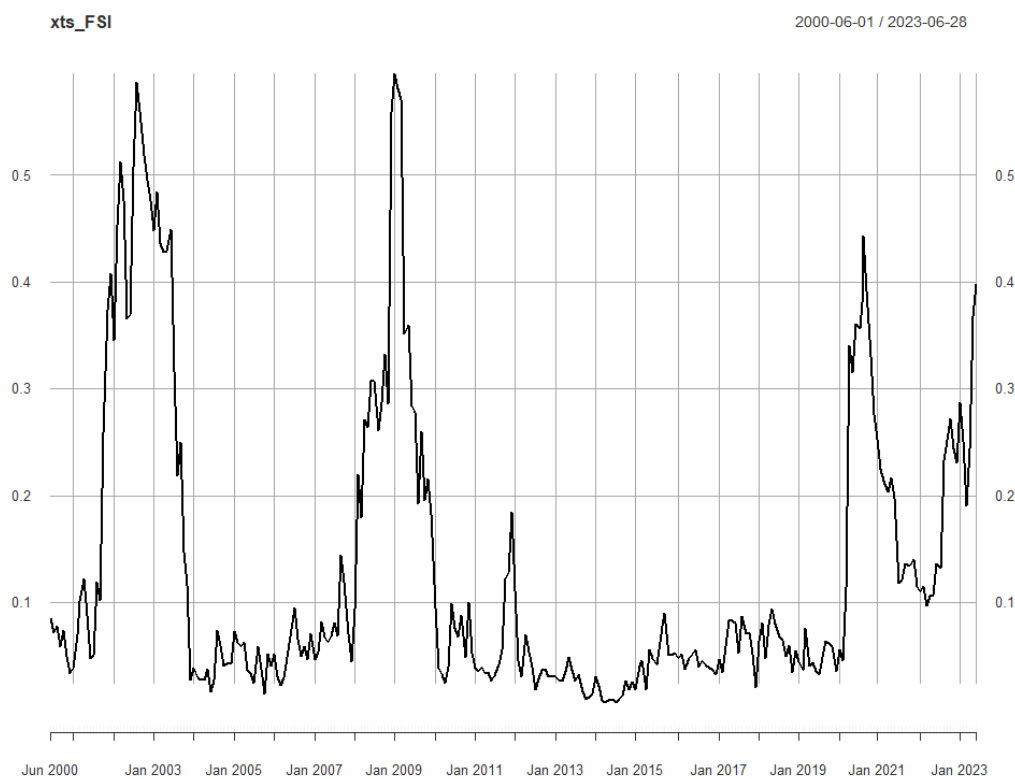


Figure 5: South African FSI

recently incarcerated former president Jacob Zuma calling for his freedom. However, these riots quickly turned violent, leading to the looting and destruction of property around the country. The index then upturns in early to mid-2022 which falls in line with the severe flooding experienced in Kwa-Zulu Natal during April 2022. In addition, the country was also in the middle of a severe energy crisis during this period due to strike action by the National Union of Metalworkers of South Africa (NUMSA) and the National Union of Mineworkers (NUM)

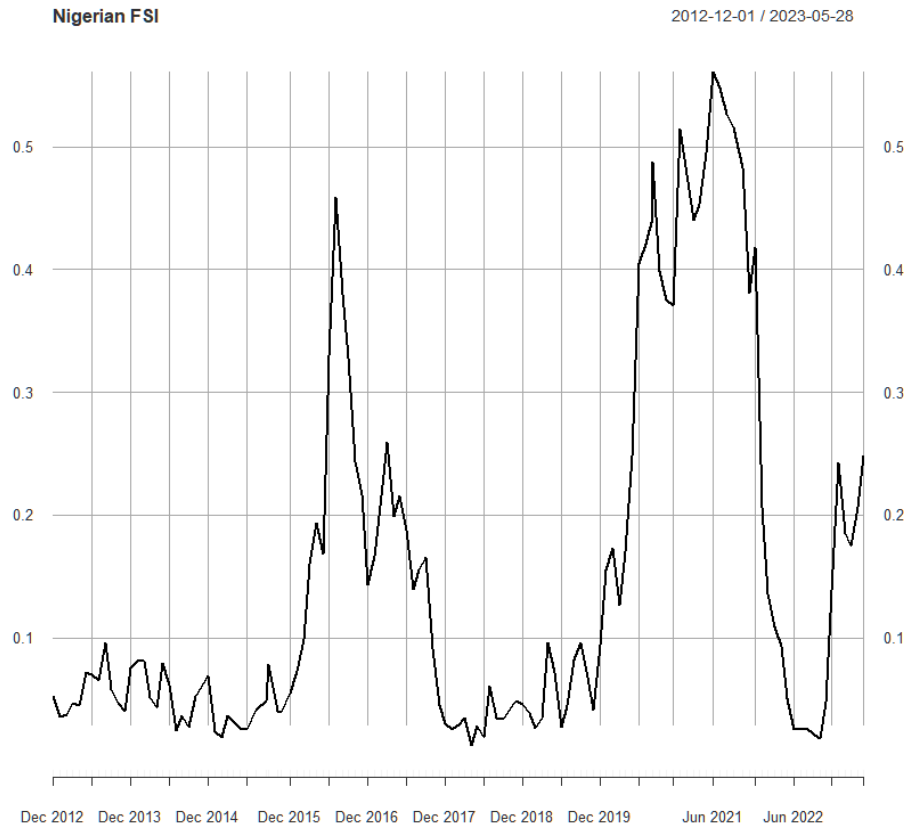


Figure 6: Nigerian FSI

placing strain on energy generation which was then followed by half of South Africa's generating capacity due collapsing infrastructure. The energy crisis continued to worsen into 2023 which is evident by the upturn in financial stress at the end of the index.

The Nigerian FSI spans over 11 years, as depicted in figure 6. Within this period there are two identified periods of financial stress which are used as benchmarks for the model to identify periods of stress. These periods refer to the Oil price plummet from 2015 which placed heavy financial stress on the Nigerian economy until late 2016, and the 2020 Covid-19 pandemic which caused a spike in financial stress from early 2020 until early 2022. The Nigerian FSI furthermore indicates a spike in financial stress from early 2023 until the end of the sample period in mid-2023. This makes sense since during this period Nigeria faced a currency crisis due to a shortage of cash currency (naira) caused by the Government forcing citizens to use a newly created digital currency from the Nigerian Central Bank (CBN). This caused a significant crippling of trade activities for the economy.

An interesting insight from both FSIs created is that there is a peak in financial stress at the end of each respective sample period. Although both countries have justifiable reasons for these

peaks individually (energy crisis for South Africa and currency crisis for Nigeria), it would be an interesting study to incorporate further economies into this analysis to conclude whether the synchronicity of these peaks are due only to individual circumstance or part of global long-lasting effects from the Covid-19 pandemic debt leniency on the global financial system, in which case the synchronicity of such peaks would occur amongst many economies.

3.3. Oil Shocks and Financial Stability

3.3.1. SVAR Representation

The oil analysis employs a SVAR approach which follows the assumptions and restrictions of prior studies on this topic (Kilian, 2009; Kilian and Park, 2009; Kilian and Vega, 2011). These assumptions require that all variables used within the dataset must be stationary to create meaningful impulse response functions. The SVAR is represented as:

$$A_0 X_t = \alpha + \sum_{i=1}^k A_i X_{t-i} + \epsilon_t \dots (3.2.2.1)$$

Where $X_t = (\Delta gop_t, \Delta REA_t, \Delta brent_t, OI D_t, \Delta FSI_t)'$ is a vector of the global crude oil production (Δgop_t), world real economic activity (ΔREA_t), the real price of Brent crude oil ($\Delta brent_t$), and finally the FSI, consisting South Africa (Δsa_fsi_t) and Nigeria (Δng_fsi_t). All the variables in lowercase indicate log form. FSI has small values near to zero, hence better suited not in log form. The first difference is taken from the level form of FSI. The lag order is selected a priori due to the theoretical underpinning discussed extensively within the literature that lags need to be selected to capture potential two-year effects (Kilian, 2009; Kilian and Vega, 2011; Chen et al., 2014). Hence 24 lags are selected in this study since monthly data is utilised when possible. A_0 is the contemporaneous coefficient matrix of the variables. A_i is the coefficient matrix of the lagged variables. α is a vector of constants. ϵ_t is a vector of serially and mutually uncorrelated structural shocks.

To estimate (3.2.2.1), the SVAR representation must be converted into its reduced form VAR representation. This is achieved by dividing the SVAR by its contemporaneous coefficient matrix, yielding:

$$X_t = (A_0)^{-1} \alpha + (A_0)^{-1} \sum_{i=1}^k A_i X_{t-i} + (A_0)^{-1} \epsilon_t \dots (3.2.2.2)$$

Letting $e_t = (A_0)^{-1} \epsilon_t$ then yields the innovations of the reduced form VAR from (3.2.2.2). The structural innovations can then be obtained by using Cholesky Decomposition to place the

necessary short run exclusion restrictions such that the reduced form innovations are represented as the product of the Cholesky lower triangular matrix form of the contemporaneous coefficient matrix and the structural innovations:

$$e_t \equiv \begin{pmatrix} e_t^{\Delta gop} \\ e_t^{\Delta REA} \\ e_t^{\Delta brent_t} \\ e_t^{OID} \\ e_t^{\Delta FSI} \end{pmatrix} = \begin{bmatrix} a_{11} & 0 & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} \end{bmatrix} \begin{pmatrix} \epsilon_t^{oil\ supply\ shock} \\ \epsilon_t^{economic\ activity\ shock} \\ \epsilon_t^{oil\ consumption\ demand\ shock} \\ \epsilon_t^{oil\ inventory\ demand\ shock} \\ \epsilon_t^{other\ shocks\ to\ \Delta FSI} \end{pmatrix} \dots (3.2.2.3)$$

This model suggests that crude oil follows a vertical short run supply curve. The demand curve shifts due to any of the above demand shocks resulting in an immediate fluctuation in the real price of oil, as well as unexpected changes to the vertical short run supply curve. Furthermore, all above-mentioned effects result in instantaneous changes to the FSI of the country in question. The recursive relationship holds due to the following reasons. Innovations to the supply of crude oil are defined as unpredictable (Kilian, 2009). Such disruptions tend to stem from political tension, conflict, or updates to supply quotas of OPEC (Bastianin & Manera, 2018; Abhyankar *et al.*, 2013). Hence crude oil supply is assumed to not react to innovations in demand for oil within the same month as the innovation occurs, which makes sense as crude oil producers tend to delay action in response changes in demand due to the associated costs of altering supply and market uncertainty (Kilian, 2009).

Innovations in the global real economic activity are found to only have a contemporaneous relationship with the supply oil. The effects of shocks to oil prices having no immediate influence on global economic activity is in line with empirical evidence which finds that that changes in the price of oil will take longer than a month to impact global economic activity (Kilian, 2009; Kilian and Vega, 2011).

Innovations to the real price of oil (consumption demand) which cannot be explained by oil supply shocks or economic activity demand shocks will be captured by oil-specific demand shocks. Hence changes in demand for oil is reflected rather than changes in demand for all industrial commodities. This shock is usually due to unexpected oil price changes and hence reflects fluctuations in precautionary demand for oil because of uncertainty around potential oil supply shortfalls.

Innovations to demand for crude oil inventories which cannot be explained by oil supply shocks, economic activity demand shocks, or consumption demand shocks will be captured by oil inventory demand shocks.

Finally, the FSI is affected by all four prior shocks contemporaneously because financial markets tend to react speedily to any new macroeconomic information introduced (Bai and Koong, 2018). Hence innovations to any of the prior shocks will be incorporated into the FSI within the same month, however changes to the FSI will not have an immediate effect on the prior variables.

3.3.2. Preliminary Analysis

The variables strictly positive and greater than one are expressed in natural logarithms, so gop, and brent. Furthermore, REA, OID, SA_FSI and NG_FSI have small enough values to suggest keeping them in the level form. SA_FSI, REA, and NG_FSI are first differenced, while gop, and brent are first differenced in log form.

Prior to performing the unit root tests each variable undergoes the Mann-Kendall Trend test to test for the existence of a trend which will allow for the correct type of unit root test (intercept, intercept, and trend, or none) to be selected for each variable. The optimal lag order is also calculated using the AIC values for each variable, ensuring that the correct lag order is tested in the unit root tests. Table 3 summarizes the results of the Mann-Kendall Trend test and optimal lag order. All the level forms of the variables, with exception to SA_FSI, have a trend present. The first difference forms however all show that there are no significant trends present.

Table 3: Mann-Kendall Trend Test

Variable	Tau-Statistic	P-value	Decision ¹²	Lag Order ¹³
gop	0.831	0.000***	Trend	0
REA	-0.21	0.000***	Trend	1
OID	-0.115	0.004***	Trend	0
SA_FSI	-0.0187	0.644	No Trend	0
NG_FSI	0.246	0.000***	Trend	1
brent	0.163	0.000***	Trend	1
Δ gop	0.025	0.541	No Trend	1
Δ REA	0.010	0.806	No Trend	0
Δ SA_FSI	0.026	0.516	No Trend	0
Δ NG_FSI	0.0098	0.873	No Trend	0
Δ brent	-0.035	0.388	No Trend	1

Source: Author's own calculation

¹² The Mann-Kendall trend test has a null hypothesis of no trend present in the data.

¹³ The lag order is selected using the Schwarts information Criterion (SIC).

Each variable undergoes the ADF, DF-GLS, PP, and KPSS test to decide as to whether a unit root is present or not. Table 4 summarizes the unit root testing procedure. It is evident that all the level form variables convincingly contain a unit root, with exception to SA_FSI which has conflicting results. Hence, the decision of non-stationarity for SA_FSI is due to the first difference form of the variable strongly suggesting stationarity. All first differenced variables show no unit roots present at a 1% significance level. Hence the first difference form of all the variables will be used in the SVAR oil analysis, with exception to OID.

Table 4: Unit Root Tests

Variable	ADF ¹⁴	DF-GLS ¹⁵	PP ¹⁶	KPSS ¹⁷	Decision
Level Form					
gop	-3.2182*	-3.1465**	-3.1536*	0.1548**	Non-Stationary
REA	-3.6125**	-3.3887**	-2.8939	0.1855**	Non-Stationary
OID	-16.9976***	-17.0153***	-16.9976***	0.0629	Stationary
SA_FSI	-2.3474	-2.1925**	-2.7288*	0.2042	Non-Stationary ¹⁸
NG_FSI	-2.4186	-2.4384	-2.4053	0.0617	Non-Stationary
brent	-2.7915	-2.6214*	-2.3802	0.3170***	Non-Stationary
First Difference Form					
Δgop	-13.7702***	-5.3372***	-17.1502***	0.0420	Stationary
ΔREA	-13.6328***	-13.5898***	-13.6263***	0.0504	Stationary
ΔSA_FSI	-15.5303***	-14.7215***	-15.5539***	0.0680	Stationary
ΔNG_FSI	-9.1447***	-8.7822***	-9.1308***	0.0470	Stationary
$\Delta brent$	-11.7124***	-11.9714***	-12.5914***	0.0637	Stationary

Source: Author's own calculation

3.3.3. SVAR Analysis

Two SVARs are estimated, as there are two countries present in this study. An unrestricted VAR model is specified for each country with the endogenous variables ordered as $(\Delta gop_t, \Delta REA_t, \Delta brent_t, OID_t, \Delta FSI_t)$. ΔFSI_t is represented by Δsa_fsi_t for South Africa and Δng_fsi_t for Nigeria. The unrestricted VARs are estimated with a maximum lag length of 24 months for South Africa and 12 months for Nigeria while conserving all necessary Gaussian properties of the residuals. Table 5 shows that the residuals for both models are serially uncorrelated from the Serial Correlation LM Test, multivariate normal from the Urzua (1996) system normality test, and there is no cross-terms heteroscedasticity present from the White

¹⁴ The Augmented Dickey-Fuller test has a null hypothesis that the variable contains a unit root.

¹⁵ The Elliot, Rothenberg, and Stock DF-GLS test has a null hypothesis that the variable contains a unit root.

¹⁶ The Phillips-Perron test has a null hypothesis that the variable contains a unit root.

¹⁷ The Kwiatkowski-Phillips-Schmidt-Shin test has a null hypothesis that the variable does not contain a unit root.

¹⁸ The unit root tests provide conflicting views; hence the decision of non-stationarity is based on the fact the first difference form of the variable is strongly stationary.

Heteroscedasticity test. Furthermore, all inverse roots of the AR component lie within the unit circle, indicating system stability.

Finally, by using the $(A_0)^{-1}$ the matrix, the unrestricted VARs are transformed into SVARs which then allows for Impulse-Response functions to be generated for each country, allowing for IR analysis to take place. Following with the literature (Kilian and Vega, 2011; Kilian and park, 2009; Chen *et al.*, 2014), a one-standard error band and a two-standard error band are reported to provide differing confidence levels.

Table 5: Var diagnostic tests

SVAR – South Africa (24 lags)				SVAR – Nigeria (12 lags) ¹⁹			
Serial Correlation LM Test ²⁰							
Lags	LM-statistic	P-value		Lags	LM-statistic	P-value	
1	20.1594	0.7384		1	28.46575	0.2869	
2	24.2839	0.5030		2	25.32622	0.4442	
3	20.1117	0.7409		3	33.19503	0.1263	
4	25.4090	0.4396		4	18.16560	0.8353	
5	27.3350	0.3394		5	24.70220	0.4792	
Normality Test ²¹							
Statistic	χ^2	d.f.	P-value	Statistic	χ^2	d.f.	P-value
Skewness	44.13904	5	0.0000	Skewness	12.44085	5	0.0292
Kurtosis	225.3720	5	0.0000	Kurtosis	18.48016	5	0.0024
Jarque-Bera	1559.306	105	0.0000	Jarque-Bera	213.1036	105	0.0000
Heteroscedasticity Test ²²							
Statistic	χ^2	d.f.	P-value	Statistic	χ^2	d.f.	P-value
White	3618.389	3600	0.4113	White ²³	1659.085	1650	0.4327

Source: Author's own calculation

¹⁹ Due to data limitations, a 12-month lag length is selected for Nigeria to ensure model stability, otherwise the some of the inverse roots lie outside the unit circle.

²⁰ The serial correlation LM test has a null hypothesis of no serial correlation at lag order h of the residuals.

²¹ The Urzua (1996) test is used which has a null hypothesis that the residuals are multivariate normal.

²² The White Heteroscedasticity Test has a null hypothesis that there is no cross-terms heteroskedasticity in the residuals.

²³ These results are for an 11-month lag; due to the sample size, testing for 12 months is not possible.

CHAPTER FOUR

DISCUSSION OF RESULTS

4.1. Impulse Response Analysis

In this study, the impulse response functions (IRFs) trace out the current and future responses of the global oil market and its disaggregated demand components in addition to the financial stress index (FSI) of South Africa and Nigeria. The IRFs are depicted with a one and two-standard deviation denoted by a dotted and solid red line respectively. The response is denoted by a solid blue line. When the confidence band contains the zero value of the y-axis then the impulse is not statistically significant.

4.1.1. South Africa

The impulse response analysis, depicted by figures 7 and 8 yields several noteworthy findings that contribute to our understanding of the nexus between the global oil market and the South African Financial Stress Index (FSI).

4.1.1.1.FSI response to other variable shocks

The analysis reveals that a positive shock to the global supply of oil leads to a significant decrease in the South African FSI from the third to the seventh month. This is consistent with the expectation that an increase in oil supply would reduce the real price of oil (depicted by figure 13, in *appendix*), thereby making oil imports cheaper for South Africa, an oil-importing country. This, in turn, reduces financial stress within the country as the cost of any goods requiring transport (and hence oil) will decrease. Fuel prices within South Africa has a direct impact on the inflation outcomes of the economy, where increases in fuel prices contribute to higher inflation (Rangasamy, 2017). Hence an expected decrease in the price of oil will lead to a drop in fuel prices and hence an inflation cooldown, which will decrease systemic stress within the economy. This finding is consistent with Qin (2020), which finds that within Europe, ten out of twenty-one countries experience a similar decline in systemic stress.

A positive shock to global economic activity also causes the South African FSI to decrease significantly from the third to the seventh month, and then again in the ninth month. This decrease in systemic stress is likely attributable to the increased global demand for goods, which would boost South African exports, which leads to an increase in economic output and subsequently alleviate financial stress.

Interestingly, an increase in the real price of oil causes a decrease in the South African FSI, showing a decrease in the first 12 months and then in month-14 and month-15. The decrease in systemic stress is somewhat surprising given South Africa's status as an oil importer, where an increase in systemic stress might be expected. However, when viewed in the light of business cycle theory this makes sense. When treated as a macroeconomic indicator, increases in oil prices caused by demand shocks indicate great potential for good conditions, which then bolsters the financial sector and drives investment, lowering financial stress (Chen and Lv, 2015; Liu *et al.*, 2021).

Furthermore, an increase in the demand for oil inventory has a negative impact on the FSI at month-18, which is likely because raising oil inventories provides future safeguards against oil crises which will decrease financial pressures. However, over the rest of the 19-month horizon there isn't any significant change from zero for South African systemic stress. This suggests that changes in oil inventory demand doesn't have any substantial positive impacts on South Africa's financial stress levels, likely because oil stocks are accrued to create reserves. Thus, increasing the reserves will have no impact on the oil consumed by the South African economy, with exception to times of crisis (such as a shortage of crude oil supply) in which case reserves would alleviate financial pressure. This finding is supported by Tumela et al. (2023), where a shock in oil inventory demand does not increase stock volatility in South Africa.

Finally, a financial shock within South Africa leads to a significant increase in the South African FSI over the 19-month horizon. This finding underscores the extent to which the South African economy is tied to market expectations. It suggests that if the market anticipates worsening conditions following a financial shock, these conditions are likely to materialize in a self-fulfilling prophecy.

4.1.1.2. Other variable responses to FSI shock

The analysis reveals that when a systemic financial shock occurs within South Africa, there will not be any significant effects on the supply of crude oil until the month-9 to month-12 and then month 14, where there is a decrease in the supply of oil. This decrease is due to the fall in demand from South Africa because of contractionary actions aimed to mitigate the financial shock. South Africa in this instance most likely uses its oil inventory stocks to offset any immediate crude oil imports to decrease its expenditures during consolidation, which reflects in the decrease in the supply of oil. The drop in oil supply is reinforced by the fact that real

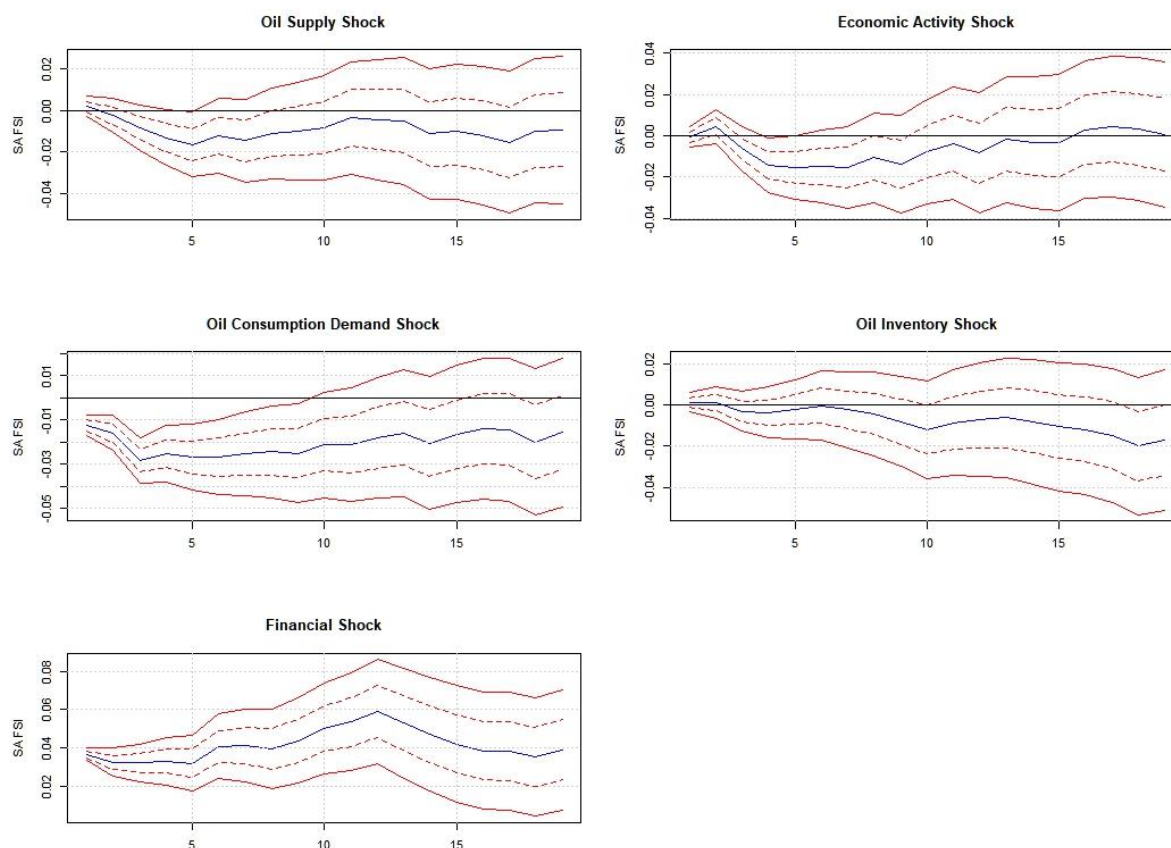


Figure 7: SA FSI shocked by other variables.

economic activity declines from the eighth month until the eleventh month, reflecting the impact of South Africa's economic contraction due to the financial shock, as South African investment and subsequently consumption will have negative effects on South Africa's ability to trade globally, realising the drop-in real economic activity. This drop off in real economic activity due to a financial shock is found by Chen *et al.* (2014), however the magnitude of the effect is minor due to the relatively small size of the South African economy globally.

The real price of oil increases within the second and third month, likely due to investment action by the South African financial sector as investors move away from South African assets to safer assets such as commodities or foreign-based assets after experiencing a financial shock. Furthermore, the real price of oil drops from the eighth month up until the twelfth month, likely a result of the fall in demand for oil by South Africa as well as the drop off in real economic activity globally discussed above.

Finally, there is no significant impact on oil stocks globally due to a financial shock occurring in South Africa. This makes sense as South Africa is a net-oil importer, thus will have no direct

impact on the supply of oil to other economies globally. Hence, the global economy would have no needs to buffer their oil stocks.

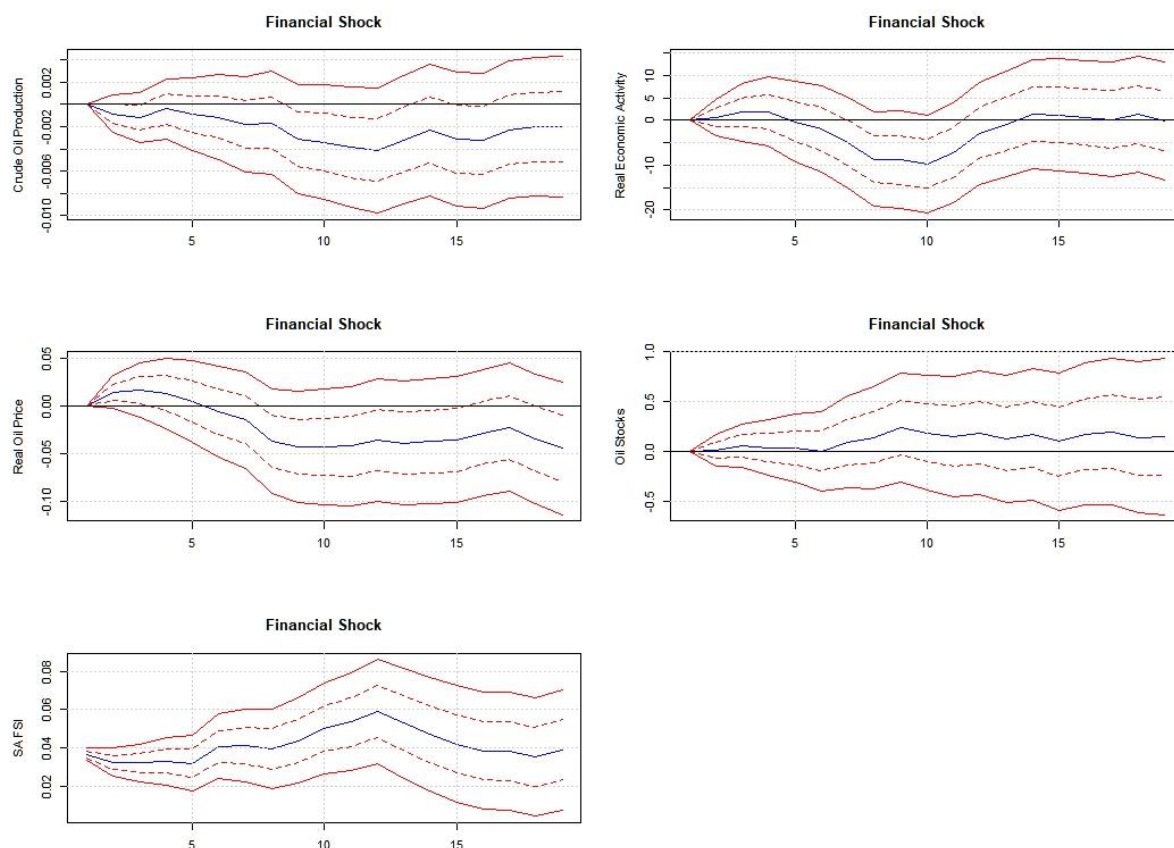


Figure 8: Other variables shocked by SA FSI.

4.1.2. Nigeria

The impulse response analysis, depicted by figures 9 and 10 yields several noteworthy findings that contribute to understanding the nexus between the global oil market and the Nigerian Financial Stress Index (FSI).

4.1.2.1.FSI response to other variable shocks

The analysis shows that a positive shocks to the supply of global crude oil or real economic activity have no significant impact on the Nigerian financial stress index.

In addition, a positive shock to the real price of oil shows a significant and sustained decrease in the Nigerian FSI from month 4 over the entire 19-month horizon. This is because Nigeria is an oil exporter and hence an increase in the real price of oil will mean that the Nigerian economy will generate excess revenues from oil exports which reduces any systemic financial

distress. This is in line with the Qin's (2020) findings for oil exporting economies. Furthermore, this type of shock is a good macroeconomic indicator for great conditions which will further alleviate financial stress (Chen and Lv, 2015).

Interestingly, a positive shock to oil inventories shows a significant positive increase in the Nigerian FSI from the first month to the eleventh month. Baumeister and Hamilton (2019) defined oil inventories as the amount of oil stockpiled and not used globally, hence a shock increase in the demand for oil inventories will first react through the demand channel by reducing the global demand of oil consumed to stockpile oil reserves, this negatively impacts the global supply of oil in the first 5 months (see figure 14 in *appendix*). This demand effect results in an increase in systemic financial pressure within the Nigerian economy due to the importance of oil exports. However, as inventory demand stabilises from month-12 the effect of the inventory shock becomes insignificant on the FSI. This is in line with Priya and Pal (2024), which finds that US oil inventory shocks heighten oil price volatility. Heightened oil price volatility would have an impact on net-oil exporters such as Nigeria. This finding is further corroborated by Tumela *et al.* (2023), finding that oil inventory demand shocks positively increase Nigerian stock market volatility.

Finally, a systemic financial shock within the Nigerian economy leads to further systemic pressure, evident by the increase in the FSI from month-1 to month-13, due to negative expectations and sentiment within the financial markets. Unlike South Africa, the Nigerian FSI returns to zero within the 19-month horizon.

4.1.2.2. Other variable responses to FSI shock

In the event of systemic financial shock occurring in Nigeria there is an evident decline in the global supply of oil in the second month of the shock before returning to zero. This is likely due to the decrease in volume of oil exported by the Nigerian economy due to the oil shock. This decreases global real economic activity as there is a brief decline in global oil supply, which is explained by the decrease in real economic activity in month 2 before returning to zero. As a result, oil briefly becomes scarcer which leads to an increase in the real price of Brent oil in the second month. Furthermore, countries use oil stockpiles to buffer against the sudden decline in oil supply within the second month which leads to an increased demand for oil inventory in the second month.

However, as the global economy adjusts the change the real price of oil experiences a decline in month-5, then from month-8 to month-12 there is an increase in global economic activity as

economies recover from the supply decline in month-2 with the help of the drop in the real oil price. The increase in global real economic activity prompts economies to increase the oil stockpiles used to buffer the oil shortage in month-2 which is why there is an increase in demand for oil stocks from month-9 to month-11.

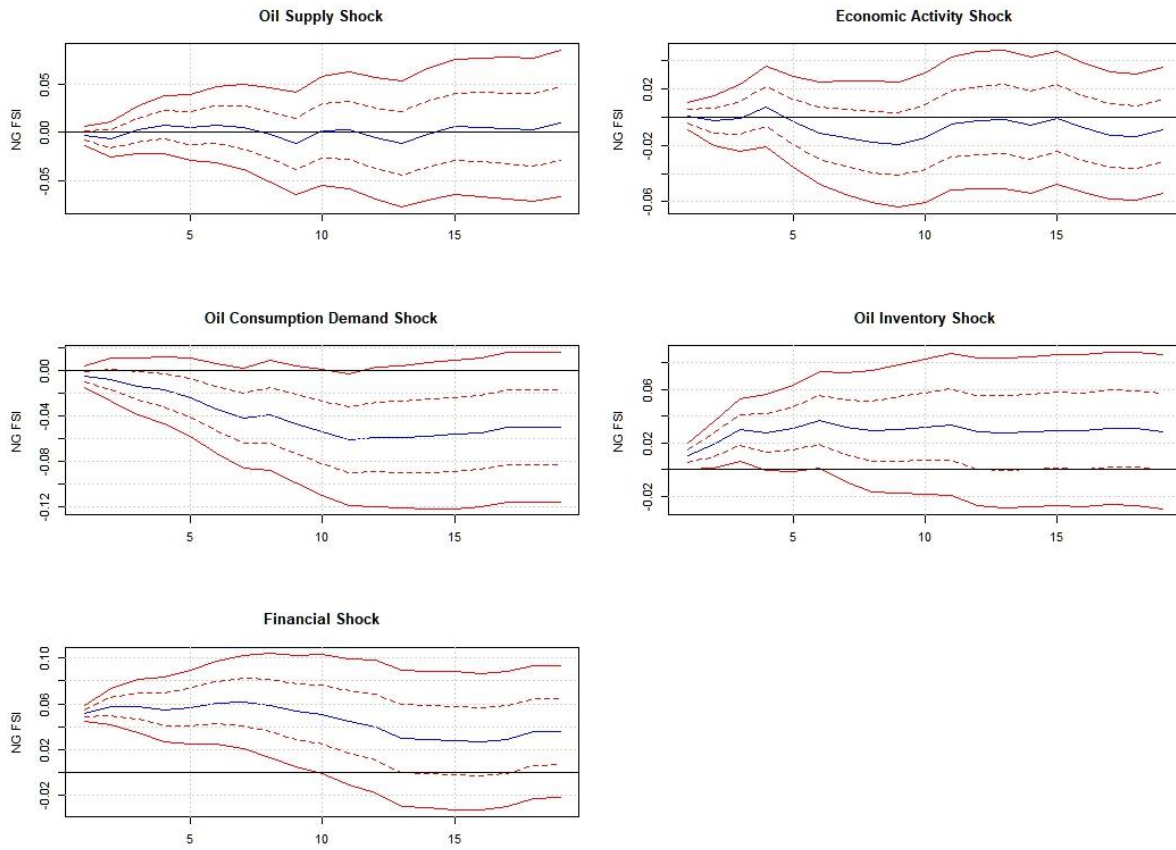


Figure 9: NG FSI shocked by other variables.

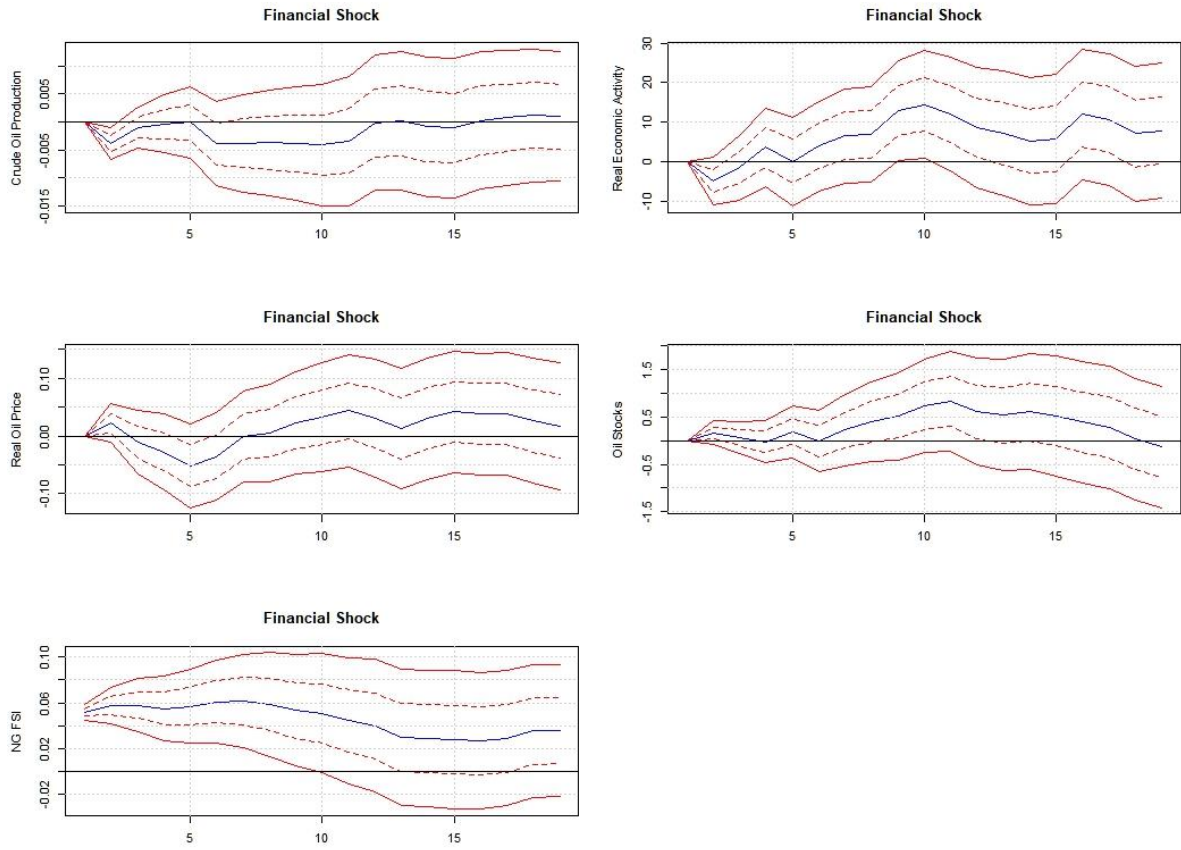


Figure 10: Other variables shocked by NG FSI

CHAPTER 5

CONCLUSION

5.1. Summary of findings and implication for policy

In this study a financial stress index is created for two sub-Saharan African economies to investigate the relationship between oil markets and financial markets in net-oil importers (South Africa) and net-oil exporters (Nigeria). From the impulse response analysis, it is evident that the source of the oil shock is an important factor in how the respective financial market responds. In addition, whether the economy is a net-oil importer or net-oil exporter plays a vital role in how the financial market will respond to certain shocks.

The policy implications from this analysis are as follows. In the case of the net oil-importer (South Africa) a shock in the supply of oil will result in a negative reaction to the FSI at about 5 months, whereas a shock to the price of oil (demand side) will cause an immediate decline in the FSI for about 10 months. Policy makers from net-oil importing countries in SSA can utilise these findings to inform economic policy decisions. This implies that these economies should not worry about the presence of an increase in the price of oil or an increase in the supply of oil as the financial stress is expected to decline in value. However, such economies should consider hedging against uncertainty using strategic stockpiling of oil reserves as this has been shown to alleviate FSI levels and will provide buffers to the economy in times of crisis, in particular oil supply shortages. These economies must develop plans to safeguard energy intensive industries from oil price increases which will place increased stress on the current account balance and hence exchange rate stability as well as monetary stability. These include investing in alternative forms of energy where possible (such as renewable energy like solar) or building strategic reserves which can be burned in times of volatility. The broader implication for net-oil importers in the region of SSA is that policymakers should proactively build financial resilience through tailored policies such as strategic oil reserves as well as promoting diversification of institutional investors to favour investments resilient to oil shocks. In addition, systemic financial resilience can be achieved through the adoption of green financing to build renewable energy infrastructure which will lessen the dependency of such economies on crude oil.

In the case of the net-oil exporter (Nigeria), when there is a surge in oil prices, international demand for crude oil, or an increase in supply of crude oil, the fiscal and monetary authorities should consider investing the additional revenues into public savings funds to provide buffers

to future instability, maintaining trade relationships with other countries through the use of foreign exchange interventions (such as maintaining pegged rates for fixed exchanges). Like the net-oil importer, a shock increase to the real price of oil will reduce financial stress over a longer period, while oil supply shocks have an insignificant effect likely due to reserves of oil from local production. Furthermore, an interesting insight lies in the fact that a financial shock to the economy will lead to oil producers reducing the global supply of oil which leads to a subsequent decline in every disaggregated component of oil demand within the first two months. Hence, policymakers from net-oil exporting countries in SSA can use these findings to formulate prudent policy structures to ensure that any additional damages from a fall in oil exports due to the decrease in supply for crude oil from reduced demand will not worsen financial crises experienced by the oil-exporter. Thus, the broader implication for policymakers in net-oil exporting economies within SSA should be focused, similarly to net-oil importers, on the resilience of the financial system from oil market volatility. This highlights the importance of public savings from additional revenues generated during booms as the revenue generated from excess revenue from oil exports can be used to create a sustainable public wealth fund which can be used to further fund social policies as well as provide needed relief to the economy in times of financial distress. In addition, such a fund will prove invaluable to economies reliant on oil exports with the rise of green financing and the push for renewable energy which will inevitably reduce the demand for crude oil.

5.2. Limitations and Suggestions for future research

The main limitation of this study lies in a lack of data availability, hence future work in this topic should focus on extending the period of the study. In addition, to gain a more holistic understanding of the relationship between the oil markets and financial markets of net-oil importers and exporters within sub-Saharan Africa further studies should incorporate more countries from the region and focus on aggregating the individual FSIs to gain insights into the entire regions.

Future research into introducing new forms of uncertainty within the FSI framework by expanding the number sub-markets included or finding individual indicators which better perform or methodologies which outperform signal theory FSIs will prove valuable to improving the FSI's stress identifying capacities. In addition, this study opted to test the impact of oil-based shocks on the constructed financial stress indices, however the effect of volatility spillovers from major trade partners such as the United States or China on financial stress may

provide further valuable policy insight for SSA countries. Furthermore, studying the nexus of financial stability and other market structures (such as commodity markets like precious metals in the context of SSA) will provide further insight to economies and investors alike within SSA.

Another potential avenue of future research would be to analyse the effect of oil-based shocks on the constructed financial stress indices using a differing methodological approach such as the Bayesian interpretation used by Baumeister and Hamilton (2019). Relaxing key identifying restrictions may provide further insight into the energy-finance nexus within SSA.

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APPENDIX

A. Additional Information relating to the FSI methodology

A.1. Candidate Indicators

Table 6: List of candidate indicators to be included in the FSI for South Africa and Nigeria

Market Segment	Variable Name	Stress indicator
Equity Market-EM	EBR	Excess bank returns over All Share Index (ASI).
	ABS_EBR	Historical volatility of EBR.
	CMA_X_BKS	Cumulative maximum depreciation in bank returns over two-year rolling period.
	ABS_STX	Historical volatility of ASI.
	CMA_X_STX	Cumulative maximum depreciation of ASI returns over two-year rolling period.
	DIFF_STX_BR	Differenced monthly ASI returns over monthly bank returns.
	SRISK	A measure of Systemic Risk within a country's financial system.
Credit Market-CM	FDI	Real inward foreign direct investment.
	ABS_FDI	Historical volatility of inward foreign direct investment.
	MG_PSCE	Monthly growth of domestic private credit extensions.
	SPR	Spread of sovereign ten-year domestic and US bond (sovereign risk spread).
	ABS_SPR	Historical volatility in spread between ten-year sovereign domestic and US bond.
	ABS_R10	Historical volatility of ten-year sovereign bond yield.
	CDIFF_SPR	Cumulative difference of SPR.
	CMIN_R10	Increase in yield for ten-year bonds compared to the minimum yield over two-year moving period.
	SLOPE	Difference of ten-year bond and three-month treasury bill yield.
	3Y_SLOPE	Difference of three-year bond and three-month treasury bill yield.
	5Y_SLOPE	Difference of five-year bond and three-month treasury bill yield.
	CORP_SPR	Difference of ten-year domestic bonds and ten-year corporate bonds yield.
	CMIN_CORP	Increase in the ten-year corporate bond yield compared to the minimum yield over a two-year moving period.
Foreign Exchange Market-FX	ABS_CORP	Historical volatility of ten-year corporate bond yield
	CUMUL_REER	Cumulative change of real effective exchange rate (REER).
	CUMUL_USD	Cumulative change of USD/Domestic currency exchange rate.
	CMIN_USD	Domestic/USD exchange rate in comparison to the maximum level over two-year moving period.
	CUMUL_EUR	Cumulative change of EUR/Domestic currency exchange rate.
	CMIN_EUR	Domestic/EUR exchange rate in comparison to the maximum level over two-year moving period.
	ABS_USD	Historical volatility of USD/Domestic exchange rate.
Money Market-MM	ABS_EUR	Historical volatility of EUR/Domestic exchange rate.
	ABS_REER	Historical volatility of REER.
	IBS	Spread between interbank rate and three-month T-bill rate.
	PRS	Spread between prime lending rate and three-month T-bill rate .
	ABS_PRS	Realised volatility of PRS.
	ABS_IBS	Realised volatility of IBS.

	CDIFF_IBS CDIFF_PRIME	Cumulative difference of IBS in comparison to highest level. Cumulative difference of prime rate in comparison to highest level.
Resource Market- RM	MG_GOLD MG_OIL MG_PLAT MG_SILVER MG_IRON ABS_OIL ABS_GOLD ABS_PLAT ABS_SILVER ABS_IRON CMIN_OIL CMIN_GOLD CMIN_PLAT CMIN_SILVER CMIN_IRON CMAX_GOLD CMAX_PLAT CMAX_SILVER	Monthly real gold price growth (USD). Monthly real brent crude oil price growth (USD). Monthly growth of real platinum prices (USD). Monthly growth of real silver prices (USD). Monthly growth of real iron prices (USD). Historical real price volatility of brent crude oil. Historical real price volatility of gold. Historical real price volatility of platinum. Historical real price volatility of silver. Historical real price volatility of iron. Increase of real brent crude oil price compared to its highest level over a two-year moving period. Increase in the real gold price in comparison to the greatest level over two-year moving period. Increase in the real platinum price in comparison to the greatest level over two-year moving period. Increase in the real silver price in comparison to the greatest level over two-year moving period. Increase in the real iron price in comparison to the greatest level over two-year moving period. Cumulative maximum depreciation of gold returns over two-year moving period. Cumulative maximum depreciation of platinum returns over two-year moving period. Cumulative maximum depreciation of silver returns over two-year moving period.
Housing Market- HM	MG_PROP CMAX_PROP AFFORD	Monthly growth of the real Property Index. Cumulative maximum depreciation in the real Property Index over a two-year rolling period. Affordability index corresponding to the ratio of the monthly real property index growth divided by the real income per household.

Source: Author's Own Compilation

A.2. AUROC Analysis Results

Table 7: AUROC and pAUROC Indicator Values

	South Africa					Nigeria			
Indicator	AUROC	pAUROC			Indicator	AUROC	pAUROC		
	Individual	Individual	Market	Increment		Individual	Individual	Market	Increment
Equity Market									
CMAX_BKS	0.8509	0.8859	0.8859	0	SRISK	0.788	0.9266	0.9266	0
ABS_STX	0.6963	0.7065	0.919	0.0331	CMAX_BKS	0.7155	0.7642	0.9352	0.0086
ABS_EBR	0.6381	0.6636	0.9227	0.0037	ABS_FDI	0.6579	0.736	0.9447	0.0095
ABS_FDI	0.5723	0.6517	0.6517	-0.271	CMAX_STX	0.6477	0.6776	0.9286	-0.0161
FDI	0.6345	0.6512	0.9195	-0.0032	FDI	0.609	0.6373	0.9458	0.0011
CMAX_STX	0.6188	0.6267	0.9006	-0.0221	EBR	0.5863	0.625	0.9432	-0.0026
SRISK	0.5926	0.6112	0.6218	-0.3009	ABS_STX	0.548	0.602	0.945	-0.0008

EBR	0.5202	0.5306	0.9195	-0.0032	DIFF_STX_BR	0.5588	0.5583	0.9427	-0.0031
DIFF_STX_BR	0.5144	0.5285	0.92	-0.0027	ABS_EBR	0.4786	NA	NA	NA
Credit Market									
ABS_SPR	0.7816	0.8771	0.8771	0	SLOPE	0.7043	0.7909	0.7909	0
CDIFF_SPR	0.6768	0.7109	0.9513	0.0742	SLOPE_5Y	0.6857	0.7678	0.7829	-0.008
ABS_R10	0.6749	0.7034	0.9326	-0.0187	SLOPE_3Y	0.6586	0.7126	0.7772	-0.0137
SPR	0.6832	0.702	0.8872	-0.0641	CDIFF_SPR	0.6188	0.626	0.8014	0.0105
MG_PSCE	0.6605	0.6938	0.8535	-0.0978	CMIN_R10	0.6068	0.6191	0.8056	0.0042
CMIN_CORP	0.5669	0.5581	0.9532	0.0019	SPR	0.6033	0.5996	0.6953	-0.1103
CORP_SPR	0.5637	0.5306	0.9531	-0.0001	MG_PSCE	0.5038	0.5368	0.7893	-0.0163
SLOPE_5Y	0.523	0.5197	0.9417	-0.0115	ABS_R10	0.5032	0.5053	0.8062	0.0006
SLOPE	0.4972	0.5084	0.9458	-0.0074	ABS_SPR	0.4863	NA	NA	NA
SLOPE_3Y	0.5098	0.508	0.9494	-0.0038					
CMIN_R10	0.4715	NA	NA	NA					
ABS_CORP	0.4421	NA	NA	NA					
Foreign Exchange Market									
CMIN_EUR	0.7626	0.8059	0.8059	0	CMIN_EUR	0.8136	0.9493	0.9493	0
CUMUL_REER	0.7027	0.7558	0.7642	-0.0417	CMIN_USD	0.8119	0.9431	0.9853	0.036
CUMUL_USD	0.7055	0.7359	0.7919	-0.014	CUMUL_USD	0.7292	0.7679	0.8366	-0.1487
CUMUL_EUR	0.6646	0.6981	0.7891	-0.0168	CUMUL_EUR	0.7235	0.7504	0.7534	-0.2319
CMIN_USD	0.676	0.6755	0.7769	-0.029	CUMUL_REER	0.6643	0.6962	0.7235	-0.2618
ABS_EUR	0.5403	0.6027	0.7979	-0.008	ABS_USD	0.7014	0.6911	0.7384	-0.2469
ABS_USD	0.5442	0.6017	0.797	-0.0089	ABS_EUR	0.5914	0.58	0.6752	-0.3101
ABS_REER	0.3903	NA	NA	NA	ABS_REER	0.4834	NA	NA	NA
Money Market									
CDIFF_PRS	0.6896	0.7608	0.7608	0	PRS	0.7326	0.8227	0.8227	0
PRS	0.6631	0.667	0.787	0.0262	ABS_PRS	0.6304	0.7269	0.6668	-0.1559
CDIFF_IBS	0.5847	0.6278	0.7788	-0.0082	CDIFF_IBS	0.6525	0.6948	0.8293	0.1625
ABS_IBS	0.5713	0.5799	0.7877	0.0007	CDIFF_PRS	0.6418	0.6563	0.8456	0.0163
IBS	0.5419	0.5422	0.7879	0.0002	ABS_IBS	0.5841	0.6349	0.7742	-0.0714
ABS_PRS	0.4616	0.5207	0.7752	-0.0127	IBS	0.5881	0.6021	0.7895	-0.0561
Resource Market									
ABS_OIL	0.7305	0.8042	0.8042	0	CMIN_SILVER	0.8972	0.918	0.918	0
ABS_PLAT	0.6662	0.7799	0.7722	-0.032	CMIN_PLAT	0.8686	0.9107	0.9226	0.0046
CMIN_PLAT	0.6119	0.6708	0.8006	-0.0036	CMIN_GOLD	0.8154	0.8702	0.92	-0.0026
CMIN_GOLD	0.5942	0.6299	0.7986	-0.0056	CMIN_OIL	0.8021	0.8497	0.8938	-0.0288
ABS_SILVER	0.5952	0.6097	0.6844	-0.1198	CMAX_SILVER	0.77	0.8258	0.7839	-0.1387
CMIN_OIL	0.5873	0.5854	0.7969	-0.0073	CMIN_IRON	0.7391	0.787	0.9046	-0.018
CMIN_IRON	0.5302	0.5739	0.7931	-0.0111	ABS_PLAT	0.6669	0.7781	0.8154	-0.1072
ABS_GOLD	0.5297	0.5707	0.7859	-0.0183	ABS_IRON	0.6317	0.7082	0.5521	-0.3705
MG_IRON	0.55	0.5661	0.7841	-0.0201	MG_IRON	0.6519	0.7066	0.7213	-0.2013
CMIN_SILVER	0.5341	0.562	0.7943	-0.0099	MG_OIL	0.6672	0.6999	0.7186	-0.204
ABS_IRON	0.4992	0.5568	0.621	-0.1832	ABS_OIL	0.6509	0.6996	0.7055	-0.2171
CMAX_PLAT	0.5635	0.5545	0.805	0.0008	CMAX_GOLD	0.6424	0.6769	0.9109	-0.0117
MG_PLAT	0.5296	0.5398	0.7824	-0.0226	ABS_GOLD	0.6212	0.6509	0.6231	-0.2995
MG_OIL	0.5274	0.539	0.7519	-0.0531	MG_PLAT	0.5726	0.5811	0.6562	-0.2664
MG_SILVER	0.5211	0.5286	0.786	-0.019	MG_SILVER	0.5598	0.5624	0.6328	-0.2898

CMAX_SILVER	0.5194	0.5263	0.8051	0.0004	CMAX_PLAT	0.5707	0.5605	0.951	0.0284
CMAX_GOLD	0.4967	0.5132	0.8055	0.0004	MG_GOLD	0.4958	0.5109	0.9096	-0.0414
MG_GOLD	0.4914	NA	NA	NA	ABS_SILVER	0.499	NA	NA	NA
Housing Market									
CMAX_PROPERTY	0.6041	0.6206	0.6206	0	CMAX_PROPERTY	0.7986	0.8411	0.8411	0
AFFORD	0.5973	0.5999	0.6075	-0.0131	MG_PROPERTY	0.6365	0.7318	0.6906	-0.1505
MG_PROPERTY	0.5829	0.597	0.5902	-0.0304	AFFORD	0.4578	NA	NA	NA

Source: Author's own calculation

A.3. Raw Indicators

A.3.1. Equity Market

Historical Volatility of the All-Share Index (ABS_STX):

$$rSTX_t = \left(\frac{STX_t}{CPI_t} \right) \times 100 \dots (A.1.1.1)$$

$$\ln(STX_t) = \log(rSTX_t) - \log(rSTX_{t-1}) \dots (A.1.1.2)$$

$$ABS_STX_t = \left| \frac{\ln(STX_t)}{\sigma \ln(STX_{t-59})} \right| \dots (A.1.1.3)$$

Cumulative maximum depreciation in the real All-Share Index over two-year rolling period (CMAX_STX)

$$CMAX_STX_t = 1 - \frac{rSTX_t}{\max_{i=0}^{23} [rSTX_{t-i}]} \dots (A.1.1.4)$$

Cumulative maximum depreciation in the real Banking Index over two-year rolling period (CMAX_BKS)

$$rBKS_t = \left(\frac{BKS_t}{CPI_t} \right) \times 100 \dots (A.1.1.5)$$

$$CMAX_BKS_t = \frac{rBKS_t}{\max_{i=0}^{23} [rBKS_{t-i}]} \dots (A.1.1.6)$$

Excess Banking Index returns over All-Share Index (EBR) – The excess banking index returns are calculated by regressing the monthly log returns of the real All-Share Index against the log monthly returns of the banking index, where the residual (ϵ_t) of the OLS regression represents the excess bank index returns:

$$\ln(STX_t) = a + b \ln(BKS_t) + \epsilon_t \dots (A.1.1.7)$$

$$EBR_t = \epsilon_t \dots (A.1.1.8)$$

Historical Volatility in excess bank index returns (ABS_EBR)

$$ABS_EBR_t = |\epsilon_t| \dots (A.1.1.9)$$

Difference in monthly real All-Share index returns over monthly real Banking Index returns (DIFF_STX_BR):

$$DIFF_STX_BR_t = [\log(rSTX_t) - \log(rSTX_{t-1})] - [\log(rBKS_t) - \log(rBKS_{t-1})] \dots (A.1.1.10)$$

A.3.2.Credit Market

Monthly growth of real private credit extension (MG_PSCE):

$$rPSCE_t = \left(\frac{PSCE_t}{CPI_t} \right) \times 100 \dots (A.1.2.1)$$

$$MG_PSCE_t = \log(rPSCE_t) - \log(rPSCE_{t-1}) \dots (A.1.2.2)$$

Spread of sovereign ten-year domestic and US bond (SPR):

$$rR10_t = R10_t - \left(\frac{CPI_t}{CPI_{t-1}} - 1 \right) \times 100 \dots (A.1.2.3)$$

$$rUS_R10_t = US_R10_t - \left(\frac{US_CPI_t}{US_CPI_{t-1}} - 1 \right) \times 100 \dots (A.1.2.4)$$

$$SPR_t = rR10_t - rUS_R10_t \dots (A.1.2.5)$$

Historical Volatility in Domestic and US ten-year government bond spread (ABS_SPR):

$$ABS_SPR_t = \left| \frac{\ln(SPR_t)}{\sigma \ln(SPR_{t,t-59})} \right| \dots (A.1.2.6)$$

Historical Volatility in Domestic ten-year government bond (ABS_R10):

$$DIFF_R10_t = rR10_t - rR10_{t-1} \dots (A.1.2.7)$$

$$ABS_SPR_t = \left| \frac{(DIFF_R10_t)}{\sigma(DIFF_R10_{t,t-59})} \right| \dots (A.1.2.8)$$

Term spreads of 10-year, 5-year, and 3-year government bonds against the 91-day treasury bill (SLOPE, SLOPE_5Y, SLOPE_3Y):

$$SLOPE_t = R10_t - TBILL_t \dots (A.1.2.9)$$

$$SLOPE_5Y_t = R5_t - TBILL_t \dots (A.1.2.10)$$

$$SLOPE_3Y_t = R3_t - TBILL_t \dots (A.1.2.11)$$

Cumulative difference of SPR. (CDIFF_SPR):

$$CDIFF_SPR_t = SPR_t - \min_{i=0}^{23} [SPR_t] \dots (A.1.2.12)$$

Increase in ten-year government bond yield compared to the minimum yield over two-year moving period (CMIN_R10):

$$CMIN_R10_t = \left(\frac{rR10_t}{\min_{i=23}^{23}[rR10_{t-i}]} \right) - 1 \dots (A.1.2.13)$$

Difference of ten-year domestic bonds and ten-year corporate bonds yield (CORP_SPR):

$$CORP_SPR_t = CORP_t - rR10_t \dots (A.1.2.14)$$

Increase in ten-year corporate bond yield compared to the minimum yield over two-year moving period (CMIN_CORP):

$$CMIN_R10_t = \left(\frac{CORP_t}{\min_{i=23}^{23}[CORP_{t-i}]} \right) - 1 \dots (A.1.2.15)$$

Historical Volatility in Domestic ten-year corporate bond (ABS_CORP):

$$\ln(CORP_t) = \log(CORP_t) - \log(CORP_{t-1}) \dots (A.1.2.16)$$

$$ABS_CORP_t = \left| \frac{\ln(CORP_t)}{\sigma \ln(CORP_{t,t-59})} \right| \dots (A.1.2.17)$$

A.3.3.Foreign Exchange Market

Cumulative change of real effective exchange rate (CUMUL_REER) – generally episodes of more severe stress are linked to longer term changes in foreign exchange rates, which is why we take the six-month cumulative change of the real effective exchange rate:

$$CUMUL_REER_t = |REER_t - REER_{t-6}| \dots (A.1.3.1)$$

Cumulative change USD/ DOMESTIC exchange rate (CUMUL_USD):

$$CUMUL_USD_t = |USD_t - USD_{t-6}| \dots (A.1.3.2)$$

Cumulative change EUR/DOMESTIC exchange rate (CUMUL_EUR):

$$CUMUL_EUR_t = |EUR_t - EUR_{t-6}| \dots (A.1.3.3)$$

Historical volatility of REER (ABS_REER):

$$DIFF_REER_t = REER_t - REER_{t-1} \dots (A.1.3.4)$$

$$ABS_REER_t = \left| \frac{(DIFF_REER_t)}{\sigma(DIFF_REER_{t,t-59})} \right| \dots (A.1.3.5)$$

Historical volatility of USD/ DOMESTIC exchange rate (ABS_USD):

$$DIFF_USD_t = USD_t - USD_{t-1} \dots (A.1.3.6)$$

$$ABS_USD_t = \left| \frac{(DIFF_USD_t)}{\sigma(DIFF_USD_{t,t-59})} \right| \dots (A.1.3.7)$$

Historical volatility of EUR/ DOMESTIC exchange rate (ABS_EUR):

$$DIFF_EUR_t = EUR_t - EUR_{t-1} \dots (A. 1.3.6)$$

$$ABS_EUR_t = \left| \frac{(DIFF_EUR_t)}{\sigma(DIFF_EUR_{t,t-59})} \right| \dots (A. 1.3.7)$$

Comparing the USD/ DOMESTIC exchange rate to its highest level (CMIN_USD):

$$CMIN_USD_t = \left(\frac{USD_t}{\min_{i=23}^{23}[USD_{t-i}]} \right) - 1 \dots (A. 1.3.8)$$

Comparing the EUR/ DOMESTIC exchange rate to its highest level (CMIN_EUR):

$$CMIN_EUR_t = \left(\frac{EUR_t}{\min_{i=23}^{23}[EUR_{t-i}]} \right) - 1 \dots (A. 1.3.8)$$

A.3.4.Money Market

Interbank and 91-day treasury bill spread (IBS):

$$IBS_t = IBS_t - TBILL_t \dots (A. 1.4.1)$$

Historical volatility of the interbank spread (ABS_IBS):

$$ABS_IBS_t = \left| \frac{(IBS_t)}{\sigma(IBS_{t,t-59})} \right| \dots (A. 1.4.2)$$

Prime rate and 91-day treasury bill spread (PRS):

$$PRS_t = PRIME_t - TBILL_t \dots (A. 1.4.3)$$

Historical volatility of the prime spread (ABS_PRS):

$$ABS_PRS_t = \left| \frac{(PRS_t)}{\sigma(PRS_{t,t-59})} \right| \dots (A. 1.4.4)$$

Cumulative difference of interbank spread in comparison to its highest level (CDIFF_IBS):

$$CDIFF_IBS_t = IBS_t - \min_{i=0}^{23}[IBS_t] \dots (A. 1.4.5)$$

Cumulative difference of the prime rate in comparison to its highest level (CDIFF_PRS):

$$CDIFF_PRS_t = PRS_t - \min_{i=0}^{23}[PRS_t] \dots (A. 1.4.5)$$

A.3.5.Resource Market

Monthly real brent crude oil price growth (MG_OIL):

$$rOIL_t = \left(\frac{OIL_t}{US_CPI_t} \right) \times 100 \dots (A. 1.5.1)$$

$$MG_OIL_t = (\log(rOIL_t) - \log(rOIL_{t-1})) \times 100 \dots (A. 1.5.2)$$

Monthly real gold price growth (MG_GOLD):

$$rGOLD_t = \left(\frac{GOLD_t}{US_CPI_t} \right) \times 100 \dots (A.1.5.3)$$

$$MG_GOLD_t = \left(\log(rGOLD_t) - \log(rGOLD_{t-1}) \right) \times 100 \dots (A.1.5.4)$$

Monthly real platinum price growth (MG_PLAT):

$$rPLAT_t = \left(\frac{PLAT_t}{US_CPI_t} \right) \times 100 \dots (A.1.5.5)$$

$$MG_PLAT_t = \left(\log(rPLAT_t) - \log(rPLAT_{t-1}) \right) \times 100 \dots (A.1.5.6)$$

Monthly real silver price growth (MG_SILVER):

$$rSILVER_t = \left(\frac{SILVER_t}{US_CPI_t} \right) \times 100 \dots (A.1.5.7)$$

$$MG_SILVER_t = \left(\log(rSILVER_t) - \log(rSILVER_{t-1}) \right) \times 100 \dots (A.1.5.8)$$

Monthly real iron price growth (MG_IRON):

$$rIRON_t = \left(\frac{IRON_t}{US_CPI_t} \right) \times 100 \dots (A.1.5.9)$$

$$MG_IRON_t = \left(\log(rIRON_t) - \log(rIRON_{t-1}) \right) \times 100 \dots (A.1.5.10)$$

Historical volatility of the real oil price (ABS_OIL), real gold price (ABS_GOLD), real platinum price (ABS_PLAT), real silver price (ABS_SILVER), and real iron price (ABS_IRON):

$$ABS_OIL_t = \left| \frac{MG_OIL_t}{\sigma MG_OIL_{t,t-59}} \right| \dots (A.1.5.11)$$

$$ABS_GOLD_t = \left| \frac{MG_GOLD_t}{\sigma MG_GOLD_{t,t-59}} \right| \dots (A.1.5.12)$$

$$ABS_PLAT_t = \left| \frac{MG_PLAT_t}{\sigma MG_PLAT_{t,t-59}} \right| \dots (A.1.5.13)$$

$$ABS_SILVER_t = \left| \frac{MG_SILVER_t}{\sigma MG_SILVER_{t,t-59}} \right| \dots (A.1.5.14)$$

$$ABS_IRON_t = \left| \frac{MG_IRON_t}{\sigma MG_IRON_{t,t-59}} \right| \dots (A.1.5.15)$$

Cumulative maximum depreciation in the real price of gold, platinum, and silver (CMAX_GOLD, CMAX_PLAT, CMAX_IRON):

$$CMAX_GOLD_t = 1 - \left(\frac{rGOLD_t}{\max_{i=0}^{23} [rGOLD_{t-i}]} \right) \dots (A.1.5.16)$$

$$CMAX_PLAT_t = 1 - \left(\frac{rPLAT_t}{\max_{i=0}^{23} [rPLAT_{t-i}]} \right) \dots (A.1.5.17)$$

$$CMAX_SILVER_t = 1 - \left(\frac{rSILVER_t}{\max_{i=0}^{23}[rSILVER_{t-i}]} \right) \dots (A. 1.5.18)$$

Increase in the real price of gold, platinum, silver, oil, and iron compared to its highest level (CMIN_GOLD, CMIN_PLAT, CMIN_SILVER, CMIN_OIL, CMIN_IRON):

$$CMIN_GOLD_t = \left(\frac{rGOLD_t}{\min_{i=0}^{23}[rGOLD_{t-i}]} \right) - 1 \dots (A. 1.5.19)$$

$$CMIN_PLAT_t = \left(\frac{rPLAT_t}{\min_{i=0}^{23}[rPLAT_{t-i}]} \right) - 1 \dots (A. 1.5.20)$$

$$CMIN_SILVER_t = \left(\frac{rSILVER_t}{\min_{i=0}^{23}[rSILVER_{t-i}]} \right) - 1 \dots (A. 1.5.21)$$

$$CMIN_OIL_t = \left(\frac{rOIL_t}{\min_{i=0}^{23}[rOIL_{t-i}]} \right) - 1 \dots (A. 1.5.22)$$

$$CMIN_IRON_t = \left(\frac{rIRON_t}{\min_{i=0}^{23}[rIRON_{t-i}]} \right) - 1 \dots (A. 1.5.23)$$

A.3.6. Property Market

Monthly growth of real property prices (MG_PROPERTY):

$$rPROPERTY_t = \left(\frac{PROPERTY_t}{CPI_t} \right) \times 100 \dots (A. 1.6.1)$$

$$MG_PROPERTY_t = (\ln(rPROPERTY_t) - \ln(rPROPERTY_{t-1})) \times 100 \dots (A. 1.6.2)$$

Cumulative maximum loss in real property prices (CMAX_PROPERTY):

$$CMAX_PROPERTY_t = 1 - \left(\frac{rPROPERTY_t}{\max_{i=0}^{23}[rPROPERTY_{t-i}]} \right) \dots (A. 1.6.3)$$

A.4. GARCH estimation

Louzis and Vouldis (2012) find that a multivariate GARCH approach is preferred due to the fact its data-driven, can capture sudden differences in the correlations structure, and minimises omitted variable bias risk.

This study employs the diagonal Baba, Engle, Kraft, and Kroner (BEKK) multivariate GARCH model instituted by Engle and Kroner (1995), which helps deal with the dimensionality problem associated with the large number of parameters which are estimated. Furthermore, the model is specified as a BEKK GARCH (1,1) as this specification performs the best in terms of AIC criterion compared to longer lag structures. The model is defined:

$$H_t = CC' + A'r_{t-1}r'_{t-1}A + G'H_{t-1}G \dots (A. 2.1)$$

Where C is a 6×6 lower triangular matrix, A and G are 6×6 diagonal matrices, r_{t-1} is a vector of lagged demeaned and normalised market segment sub-indices where $r_t = SI_t - 0.5$. Due to the properties of the ECDF function used to normalise the indicators within each sub-index, demeaning the sub-index is achieved by simply subtracting 0.5 from it. H_t is the 6×6 variance-covariance matrix of the sub-indices. Figure 11 depicts the cross correlations of each segment for South Africa, while Figure 12 depicts for Nigeria.

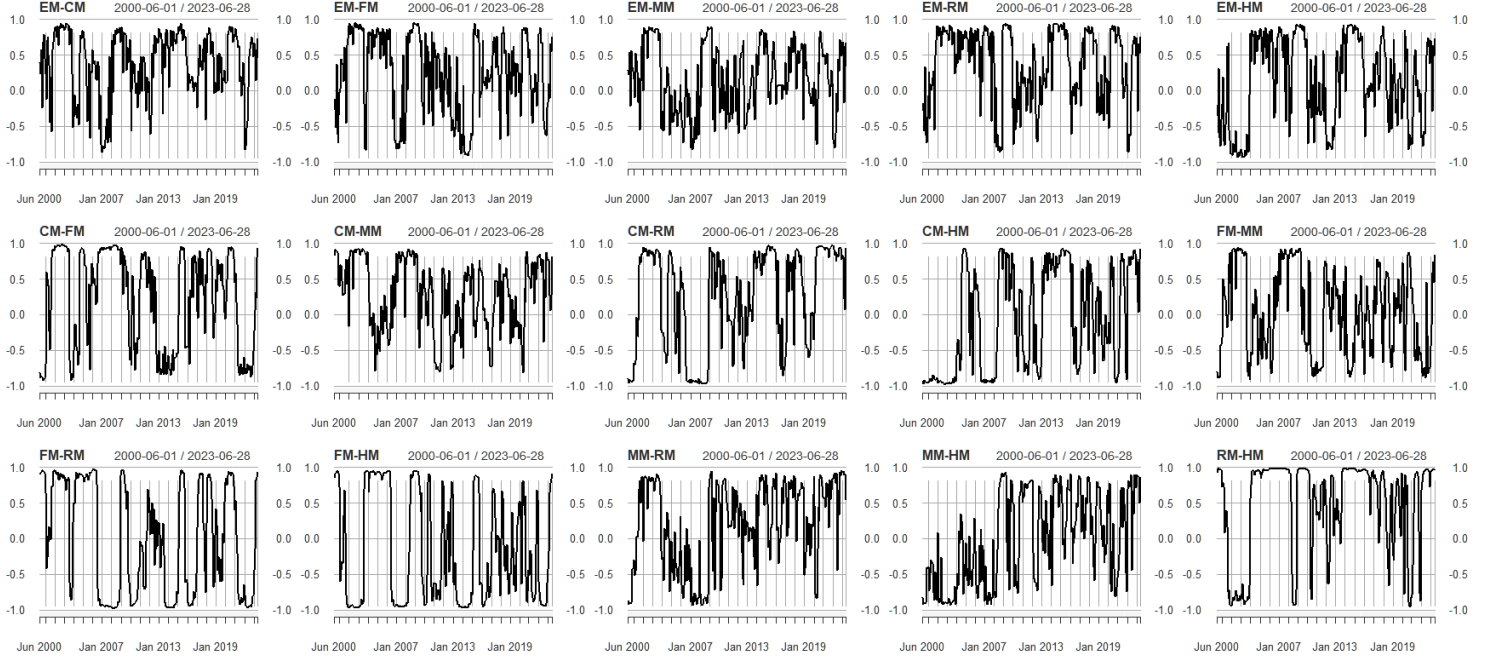


Figure 11: Cross-Correlations of SA

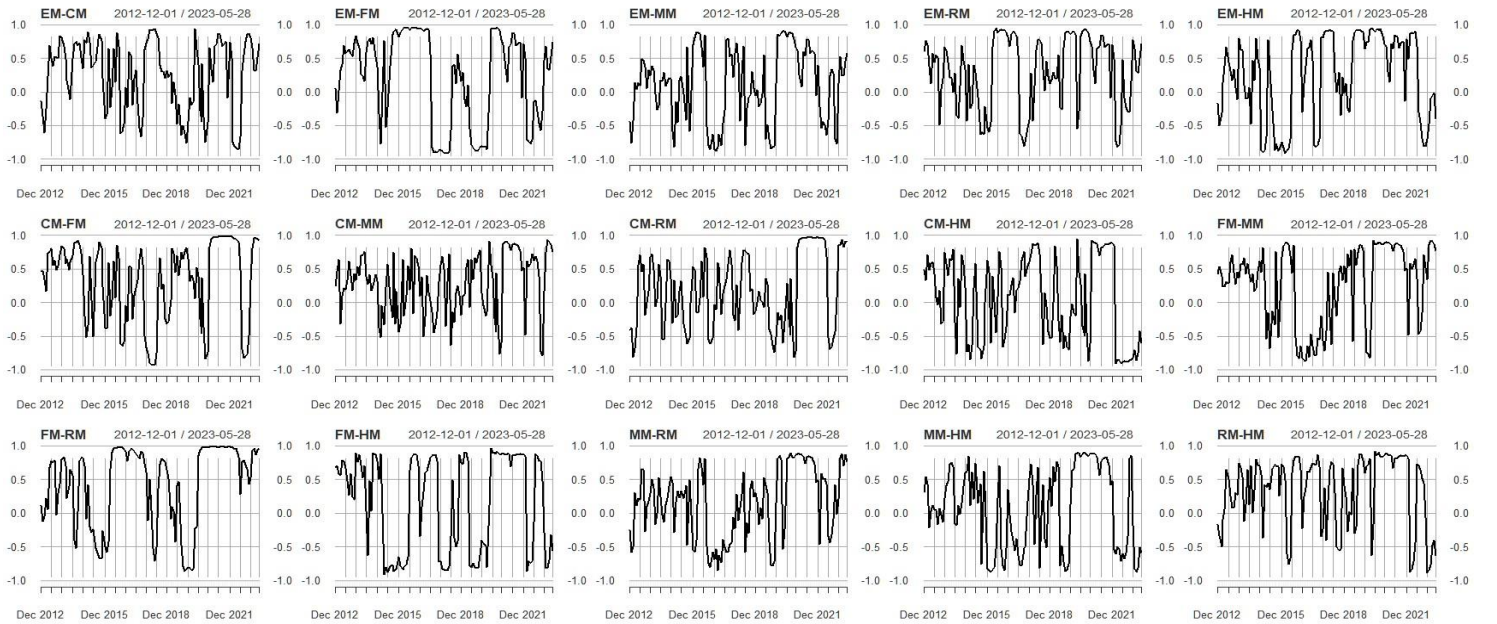


Figure 12: Cross-Correlations of Nigeria

B. Impulse Responses

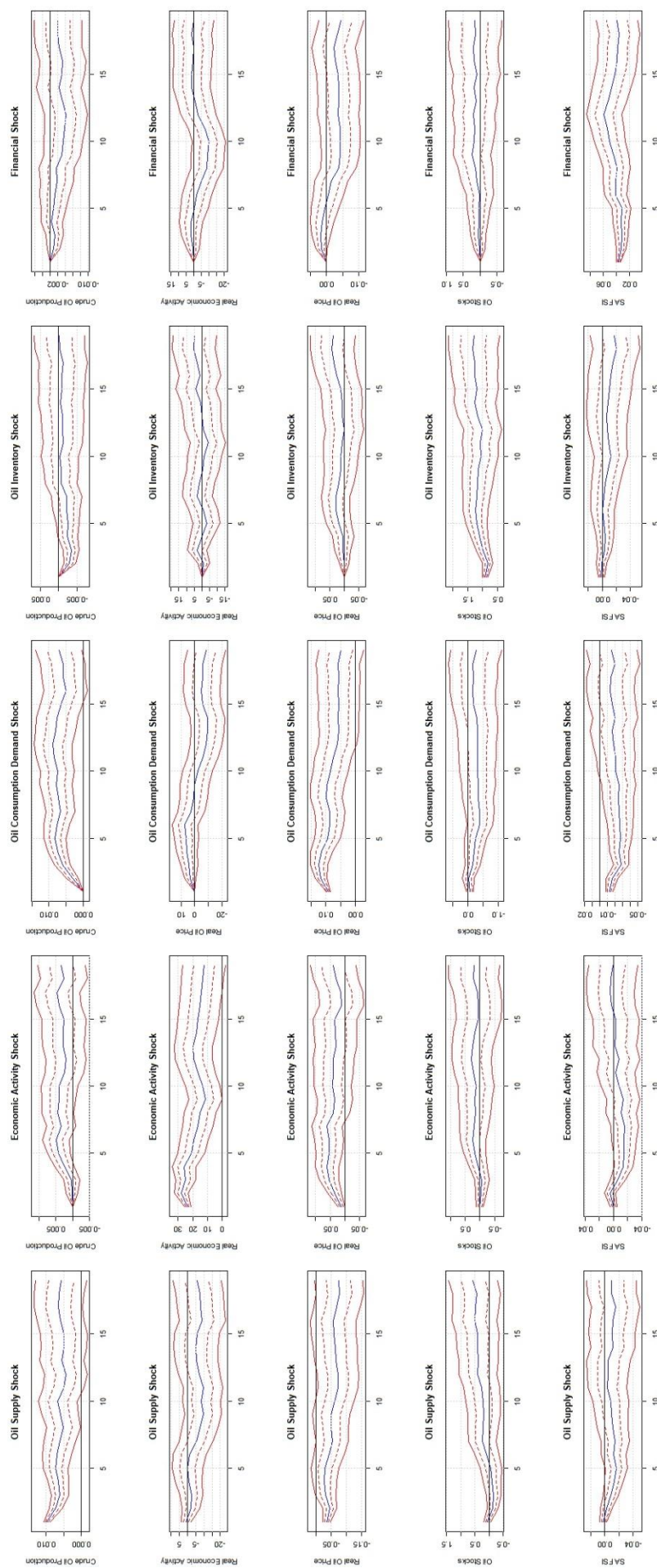


Figure 13: IRF for SA

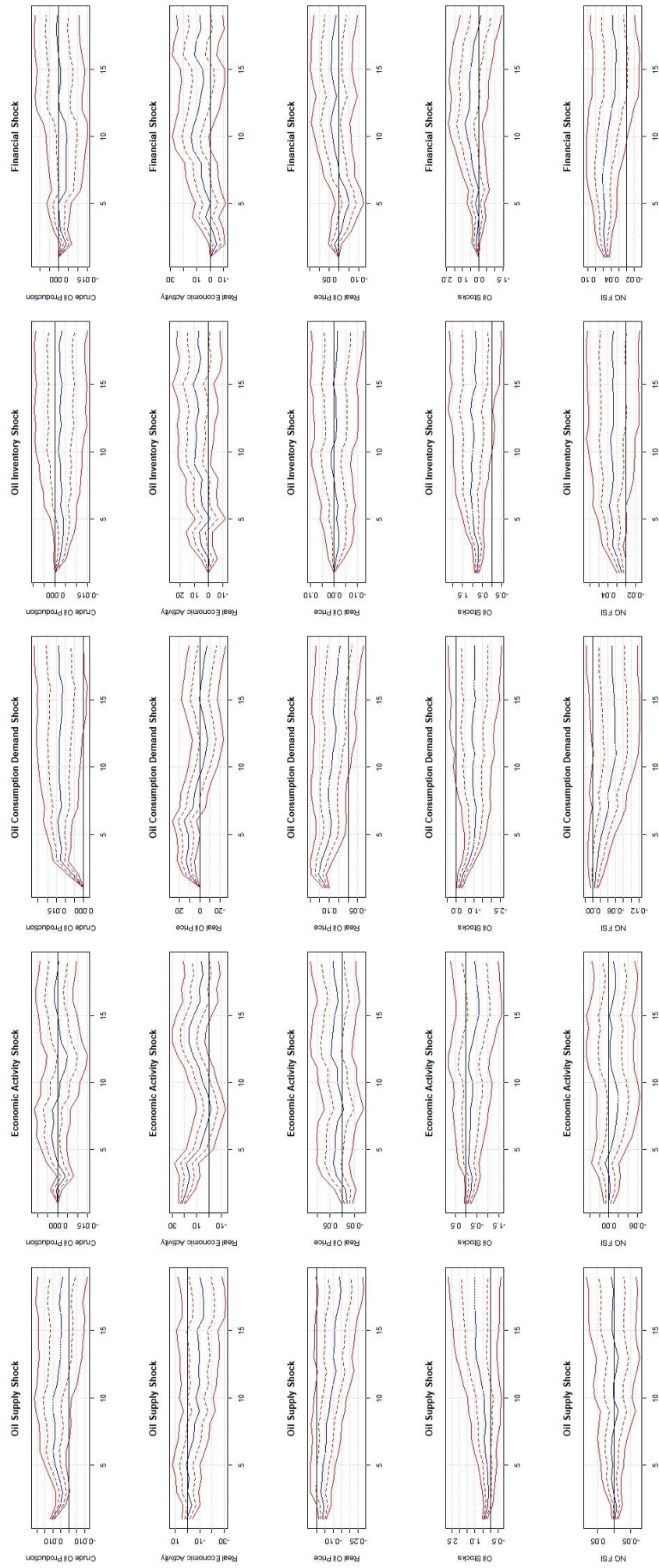


Figure 14: IRF for Nigeria