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This write-up is submitted in partial fulfilment of the Master of Management Degree in Finance and Investments Degree.

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TABLE OF DEFINITIONS AND ACRONYMS

ACRONYM	DEFINITION
AIC	Akaike Information Criterion
ACF	Autocorrelation Function
ARMA	Autoregressive Moving Average
ARCH	Autoregressive Conditional Heteroscedasticity
CPI	Consumer Price Inflation
DCF	Discounted cash flow
GARCH	Generalised Autoregressive Conditional Heteroscedasticity
GDP	Gross Domestic Product
GS	Gibson -Schwartz
GSC	Gibson –Schwartz with Cointegration
MPRDA	Mineral Resource Development Act of South Africa
RBCT	Richard Bay Coal Terminal
SAA	South African Airways
VAR	Vector Autoregressive
VECM	Vector Error Correction Model
VIRF	Volatility Impulse Response Function
WACC	Weighted Average Cost of Capital

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- **My friends:** I hope that this dissertation and degree inspires you all. I hope it shows you that you can become whomever and achieve whatever you desire. The pertinent question is: *"How badly do you want it?"* Always remember that: *"the harder you work, the luckier you get"* (Gary Player). Never stop chasing your dream.

"To God be the glory, great things he hath done"

ABSTRACT

Growth in commodity exporting economies, such as South Africa, is highly dependent on the revenue generated from exports. It is thus evident that as commodity prices fluctuate, income and the balance of payments will be accordingly impacted. This is further exacerbated by strong dependence on the imports of certain commodities. Oil is one such commodity on whose imports South Africa is highly dependent. Although natural gas is also imported, it is in lower quantities and is as such expected to impact South Africa to a lower extent. Coal, on the other hand, is among the main commodity exports and was expected to have an impact on (and be impacted by) South African macroeconomic fundamentals.

In this study, we use a VECM and MGARCH model to test the interaction between South African macroeconomic variables and these three commodities. Our VECM findings indicate that oil and exchange rates are inflationary. This implies that an increase in oil prices and/or exchange rates (indicating a depreciation of the Rand against the U.S. Dollar) results in an increase in inflation. Inflation, on the other hand, propagates higher coal prices and to a lesser extent, higher interest rates. We account the latter to South Africa's inflation targeting regime and the former to demand and supply dynamics which occur at RBCT as production costs increase (short-term coal export contracts and spot market sales). Natural gas is found to have weak impacts on interest rates and exchange rates. Our MGARCH model shows that only the innovations in natural gas and oil prices spillover into interest rates and exchange rate. There is no direct spillover captured. However, there is strong direct spillover from oil to inflation. Lastly, interest rates are found to have a strong direct volatility spillover to both oil and natural gas. We attribute this to the exchange rate impact that interest rates have and is supported by the exchange rate impact on commodity price volatility. We conclude that an in-depth understanding of triggers is pertinent for monetary and fiscal policy decisions in South Africa. Although the South African economy is relatively diversified compared to other developing countries, commodity price fluctuations do have a significant impact on economic performance.

1. CHAPTER 1: INTRODUCTION

Creamer (2014) quoted Ivan Glasenberg, Chief Executive of Glencore PLC, when he associated plummeting commodity prices to oversupply in the market and capital misallocation. Other market analysts associate the plummet with a slowdown in global growth. Notwithstanding, the era of low commodity prices has dawned and has had a dire impact on commodity markets and most, if not all commodity producers. Cortazar and Eterovic (2010) acknowledge the challenges that arise in valuing natural resource investments using the discounted cash flow method. The dependence of valuation cash flows on forecasted commodity prices is so high that a drastic change can debilitate previously profitable investments (Cortazar & Eterovic, 2010).

As primarily commodity exporters, African countries are susceptible to the effect of the global economic slowdown and fluctuations in commodity prices. Hegerty (2016) associates such fluctuation with a slowdown in Chinese consumption, triggered by their transition from growth-led to consumption-led economics. Biligin (2015) shows that energy prices are a pertinent variable in the industrial production process, suggesting that a slowdown in the latter (as seen in China – a major commodity consumer) will have a detrimental impact on the former. This study aims to study the impact of energy sector volatility on South African macroeconomic variables. Three energy commodities will be studied to this effect, namely, oil, natural gas and coal. The latter is the most locally produced of the three commodities. The South African macroeconomic variables selected are interest rates, inflation and exchange rates (Rand/U.S. Dollar).

1.1. Background and Context of the Study

The South African Chamber of Mines (2014) notes that South Africa hosts 3.5% of the world's coal resources, produces 3.3% of the world's annual total production, produces 6% of the world's total exports, and is the world's 6th largest coal exporting country. Figure 1.1 below shows the contribution of different South African mining sectors to the total annual production.

From this, it is evident that coal has a significant impact on mineral production in South Africa, while oil and gas have minor (if any) impact.

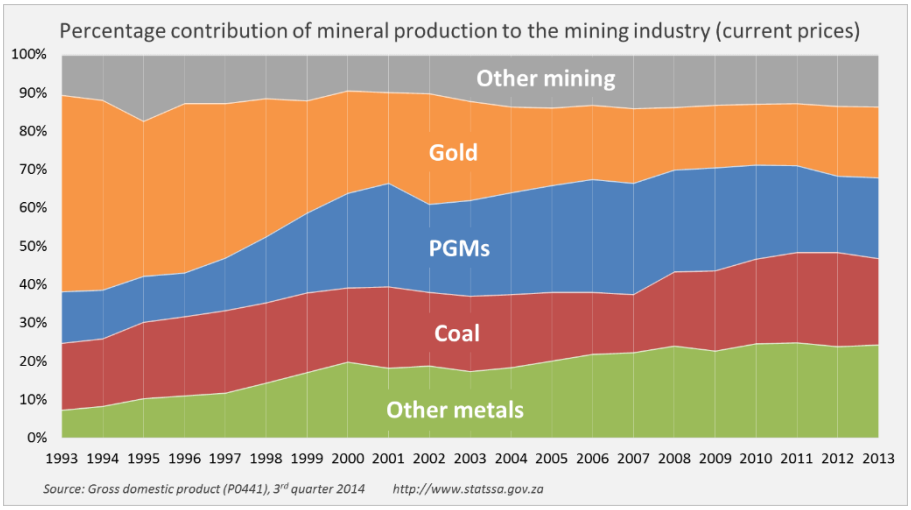


Figure 1. 1: Percentage contribution of mineral production to the mining industry at 2014 prices - **Source: Statistics South Africa**

The Chamber of Mines (2014) also shows that 46% of the total revenue generated from coal sales in 2014 was generated from the 28% which was exported in that year. This portrays the amount of value and impact the global economy and energy sector has on South African revenue generation from coal production. Trading Economics shows that coal accounts for 6% of South Africa's total exports (Trading Economics, 2016), which similarly alludes to the importance of the commodity to the local economy.

Fuel, on the other hand, accounts for up to 24% of total South African imports (Trading Economics, 2016). Over the recent past, a plethora of articles have shown South Africa's growing dependence on fuel and crude oil imports (Financial 24, 2014). This is further exacerbated by the country's steadily declining oil production (Figure 1.2) (Trading Economics, 2016) and increasing oil imports (Figure 1.3) (Index Mundi, 2015c). From this we can posit a likely impact on the balance of payments, monetary policy and fiscal policy.



Figure 1. 2: South African crude oil production from 1998 to present **(Source: Trading economics)**

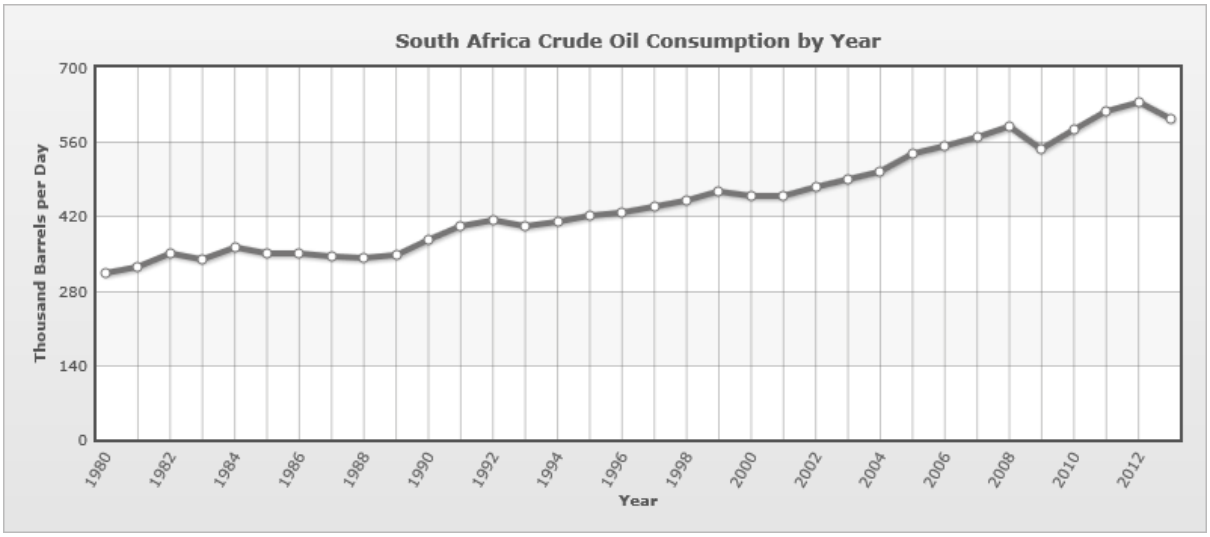


Figure 1. 3: South African oil imports from 1980 to present **(Source: Index Mundi, 2015c)**

Furthermore, a report by the United States Energy Information Administration (EIA) shows that South Africa was the primary destination for Mozambican gas exports while the South Africa itself is not a gas exporter (EIA, 2013). Tables 1.1 shows South Africa's natural gas imports and production respectively. From these tables, it is evident that imports are substantially higher than production, suggesting that local demand is higher than local supply.

Similar to both coal and oil, fluctuations in gas market can thus be expected to be transferred into the South African economy.

Table 1. 1: South African natural gas imports and production

Country	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Imports	0	0	0	0	0	0	0	3,200M	3,500M	3,040M	3,300M
Production	1,800M	N/A	2,350M	2,230M	N/A	2,900M	N/A	3,250M	1,900M	970M	1,280M

Source: Index Mundi (2015 a & b)

The 2009 production decline shown in Table 1.1 has been attributed to declining natural gas prices during this period (shown in Figure 1.4 below). As depicted in the Table, this production decline was accompanied by an increase in natural gas imports. The importance of energy in an economy propels us to the question: "Do fluctuations in energy commodity prices spillover to South African macro-economic variables?" Hegerty (2016) shows that, should such spillovers occur, they should be both when commodity prices increase and decrease. Studying commodity price volatility spillover to exchange rates, inflation, interest rates, and output, Hegerty (2016) found that exchange and inflation rates are more susceptible to commodity price volatility than the other economic variables. This leads them to the conclusion that some emerging markets countries are "commodity currencies" (Hegerty, 2016). They similarly posit feedback from economic activity of particular countries to commodity prices and call these commodity economies (Hegerty, 2016).

Figure 1.4 shows monthly time series price data for the aforementioned commodities (2007 to 2016). The volatility and fluctuation in price is evident. Economies which produce and consume these commodities are expected to be impacted. This is in line with Collier and Goderis (2012) who state that natural resources are either a "blessing" or a "curse" to those emerging markets that produce them.

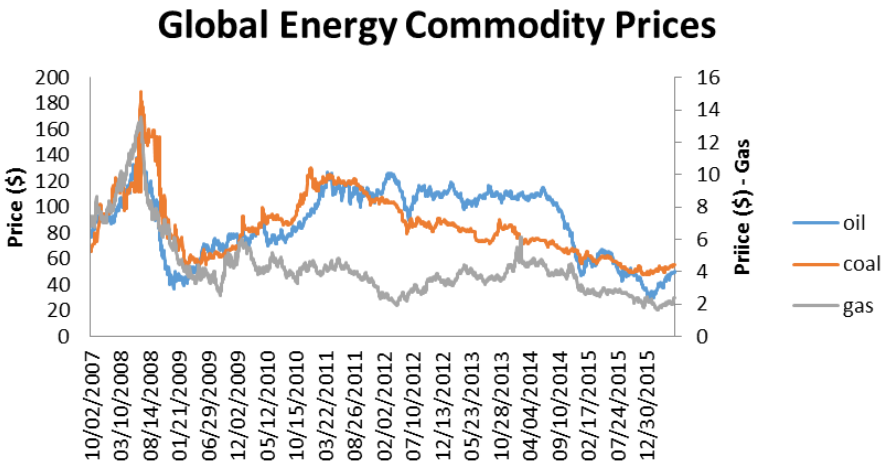


Figure 1. 4: Global energy commodity prices - **Source: Author (Bloomberg)**

1.2. Significance of the study

Jacks, O'Rourke and Williamson (2011) show that volatility in poor countries is higher than that in rich countries as a result of commodity prices. They also posit that world market integration reduces commodity price volatility. Hegerty (2016) found that commodity price volatility destabilizes emerging market economies. This is supported by Arezki, Dumitrescu, Freytag and Quintyn (2014) who also find a reversal in the causal relationship between gold price and the exchange rate in South Africa due to capital account liberalisation post 1994. In this they argue that causality was initially from the Rand to the gold price but post-1994 it reverses (from the gold price to the Rand). From this point of view and the understanding that South Africa is also an importer of goods, it can be concluded that volatility in the gold price can have an impact on the cost of importing goods. Moreira (2014) found that an increase in commodities price volatility resulted in an increase in inflation and lowered GDP. Wang and Zhu (2015) come to a similar conclusion while studying energy price shocks and China's economic fluctuations.

Fuel and diesel are oil products and as such are impacted by the market price of the commodity (see Figure 1.5a). These products in turn impact the price of goods sold in South Africa as goods need to be transported from production points to consumption centres. The actual

production of such goods similarly involves the consumption of these oil products. From these the impact of oil products on the cost of goods sold is shown. This culminates in inflationary pressures on the economy. South Africa's electricity supply is mainly from coal fired power stations. Analysis of Figures 1.5b and 1.4 shows no clear relation between the export coal prices and electricity prices. This is most evident in 2008/2009 where all energy commodity prices reduced drastically but the cost of electricity increased substantially. Figures 1.6 (a) and (b) show that coal is and has been the dominant source of energy in South Africa, accounting for ~69% of consumption (Enerdata, 2013). It is followed by oil at ~16%, biomass (~10%), primary electricity (~3%) and natural gas (~2%) - (Enerdata, 2013). The industrial, transport and non-energy (industrial) sectors are the largest consumers of the energy in South Africa (Figure 1.7) - (Enerdata, 2013). Combined these sectors account for ~67% of the total energy consumption, with households only accounting for ~33% (Enerdata, 2013).

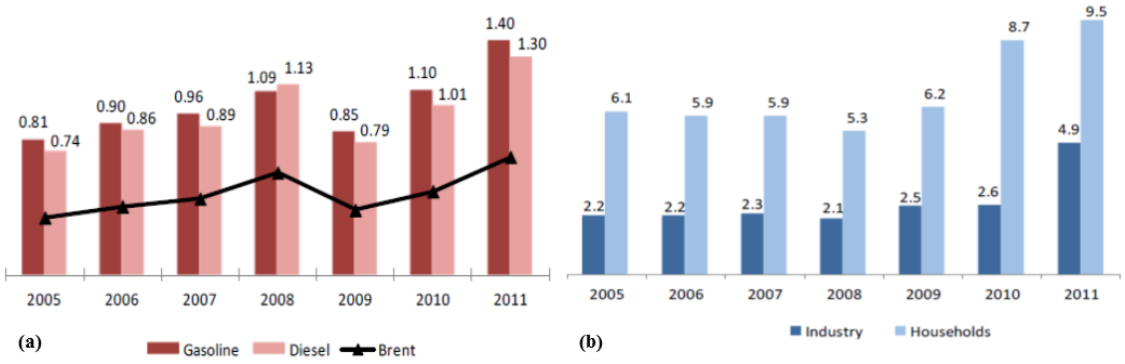


Figure 1. 5: (a) South African Fuel and Diesel prices (USD per litre) and (b) South African electricity prices for household and industry (USD per KWh) - **Source: Enerdata, (2013)**

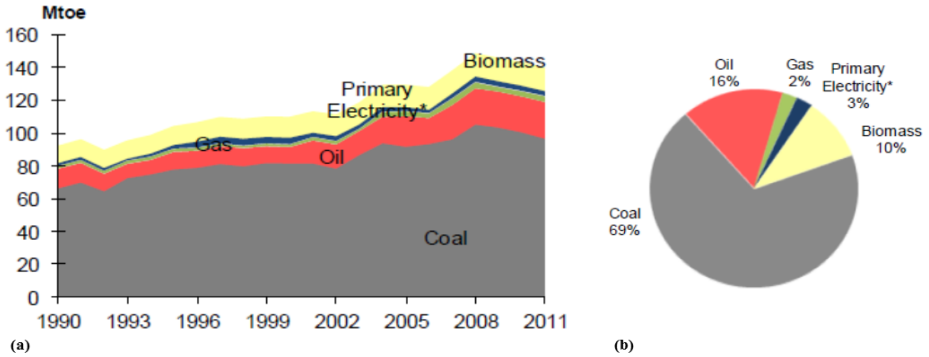


Figure 1. 6: (a) Total South African energy consumption by source and (b) Market share of energy source - **Source: Enerdata, (2013)**

From Figure 1.7 we can conclude that the transport and industry sectors are the largest energy cosumers. They account for more than 60% of the electricity consumption (Enerdata, 2013). Furthermore, they dominate oil consumtpition (over 80%) and consume the fuel produced from natural gas (Enerdata, 2013).

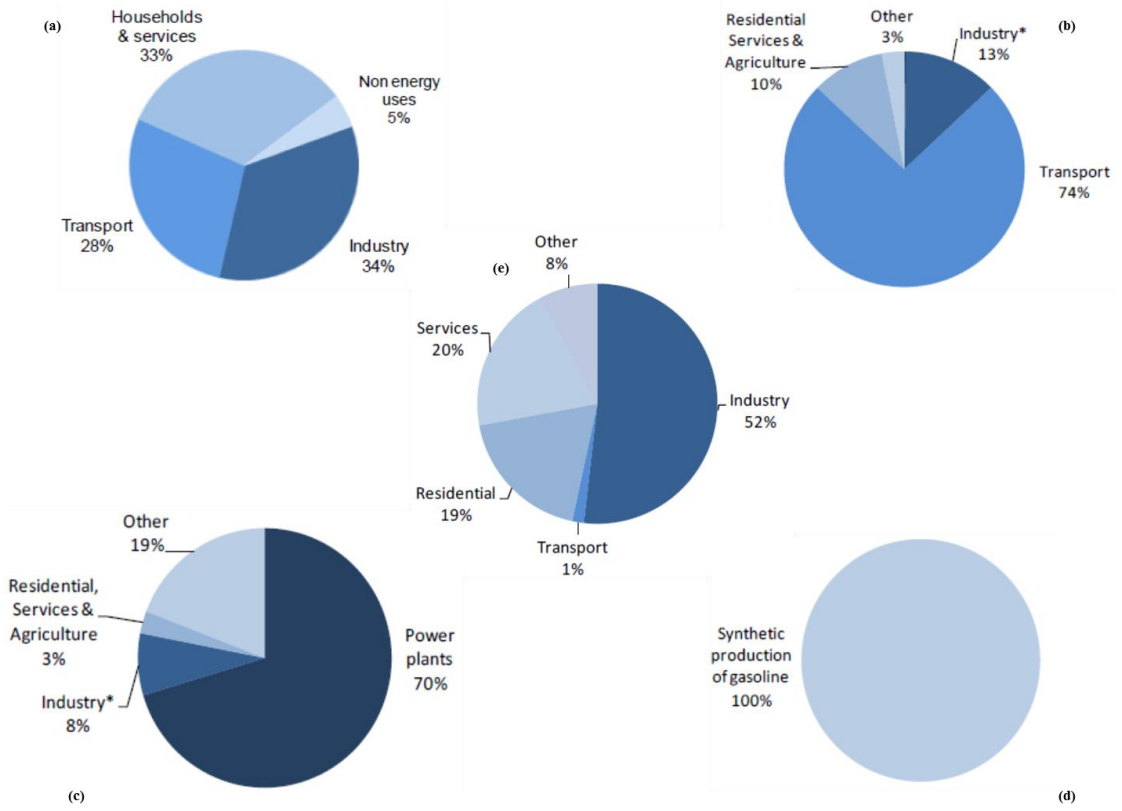


Figure 1. 7: (a) South African energy consumption by sector; (b) Oil consumption by sector; (c) Coal consumption by sector; (d) Gas consumption by sector; and (e) Electricity consumption by sector - **Source: Enerdata, (2013)**

The above begins to clarify the importance of energy commodities to the South African economy. This study aims to contextualise, determine, and quantify the impact of these energy commodities on the South African economy. This will aid policy makers in their monetary and fiscal policy reactions to changes in macroeconomic fundamentals (as they understand the triggers). The literature surveyed focuses more on oil and metal commodities volatility. To our knowledge, none have studied the relationship between energy commodity prices and an emerging market economy's macroeconomic fundamentals.

1.3. Problem Statement and Objectives of the study

1.3.1. Main Problem

Owing to an increase in coal production; and oil and natural gas consumption, South Africa is increasing its exposure to volatility in the energy sector. A stark finding by Deaton (1999), while studying commodity prices and growth in Africa; showed that commodity prices accounted for almost half the GDP of these countries which are mainly commodity exporters. From this finding, it is evident that any volatility in commodity prices would have an impact on African foreign exchange earnings with ramifications for public finances. South Africa, with its diversified mining industry, is no exception with Figure 1.1 showing that certain commodities have a major role in the sector.

Literature has shown that price volatility can impact exchange rates and inflation of some emerging market economies (Hegerty, 2016; Volkov & Yuhn, 2016). This transmission to the macro-economy is detrimental to growth and activity in such countries. Magnowski (2014) shows this in Nigeria where government spending had to be reduced in 2014/2015 due to falling oil prices. Angola, another major African oil producer, was similarly poised during the same period (Engebretsen, 2015). The current downturn in the commodities market has resulted in increased employee retrenchments and company liquidations (especially for high cost commodity producers). This follows the commodity up cycle which was wrought by exorbitant bonuses, salaries and higher employment rates. Share prices, of most commodity producing companies, which rallied during this period have since plummeted. Creamer (2014) identifies over indebtedness of commodity producing corporations as a cause. This over indebtedness is as a result of acquiring debt during the up-cycle to increase production capacity. A government's main form of income is tax. Liquidated and non-profitable corporations cannot be taxed thus the more of these in a country the lower the revenue which can be collected. This could force that particular government to increase its debt in order to meet its responsibilities (which include repaying domestic and foreign debt). This becomes a spiral that debilitates countries.

Kilian (2009) shows the importance of supply and demand on prices. Creamer (2014) shows the impact of the current commodity oversupply on the current commodity prices downturn. Jacks et al. (2011) also attest to the importance of global demand and supply dynamics in commodity pricing. Therefore, diversified export commodity economies are preferred over single export commodity economies due to the risk. Although a diversified commodity exporter, South Africa's growing dependence on oil, fuel and natural gas imports (Financial 24, 2014) and revenue from coal exports leaves the country vulnerable to global energy markets fluctuations.

1.3.2. Objectives of study

The objectives of this study are:

a. To analyse the time series properties of energy commodity prices, namely, oil, natural gas and coal
b. To model volatility in the three energy commodity prices and macroeconomic fundamentals
c. To understand the volatility spillovers between the system variables
d. To test for Granger causality and spillover between energy prices and macroeconomic variables in South Africa.

Hypothesis 1: Energy commodity prices have an impact on South African macroeconomic fundamentals.

Hypothesis 2: There is volatility spillover from energy commodity prices to South African macroeconomic fundamentals.

2. CHAPTER 2: LITERATURE REVIEW

2.1. Introduction

2.1.1. Global Commodities

Commodity price volatility has been studied for decades as some commodities are mediums of international exchange as shown by Collier and Goderis (2012). Narayan and Liu (2011) state that commodity prices literature is divided into two general components. First, commodities have a value and are generally used as mediums of international exchange and second, commodity prices are volatile due to macroeconomic factors, business cycles such as recession and expansions, and political cycles. Jacks et al. (2011) found that, although global integration may reduce commodity price volatility, commodity exporting countries are exposed to global demand instability as recessions and expansions occur. During recessions demand for some commodities reduces which creates a situation of oversupply therefore applying downward pressure on commodity prices. Similarly during expansions, demand outstrips supply resulting in prices increasing. This is argument supported by Ghoshray (2012) who show that some (if not most) developing countries depend on either a single or suite of commodities for revenue generation. From this it is evident that the stronger this dependence the more heightened the impact of commodity price volatility on macroeconomic fundamentals of such countries is expected to be. Commodity pricing literature characterisation by Narayan and Liu (2011) affirms this posit.

Jacks et al. (2011) indicate that poor commodity exporting countries experience reduced growth due to changes in commodity prices. The most recent example to this effect is Venezuela which has borne the brunt of plummeting oil prices and finds itself experiencing growing political unrest, hyperinflation and economic contraction. Hegerty (2016) found such a strong relationship between commodity prices and all studied macroeconomic variables that they labelled Chile a commodity currency. This study found an inextricable relationship between copper the Chilean macroeconomic environment. That is, changes in copper prices have a strong impact and spill over to the Chilean economy and to an extent Chilean economic activity has an impact on copper prices (as the country is a primary producer). South Africa is no exception to the aforementioned being both an exporter and importer of commodities. Although diversified in its minerals exports, it has been shown that coal is a significant portion

of total exports and oil being an important production input. Industrial and economic activity around natural gas remains low and is expected to change as energy demand dynamics change.

Van der Ploeg and Poelhekker (2009) distinguishes between two types of commodities, namely volatile and stable commodities. The former is characterised by stark, usually large, price changes while the latter has minor price changes. Countries which trade in volatile commodities experience slower growth rates than those trading in more stable commodities. To explain this Ghoshray, Kerriwal and Wohar (2014) suggest that economic policies (fiscal and monetary) can be driven by trends in commodity prices resulting in procyclical, rather than countercyclical, policy. Ghoshray (2012) suggests buffer funds as a possible mitigation for global commodity price volatility. That is funds which are stored during commodity booms and utilised during downturns in order to maintain growth. However, Ghoshray (2012) also identified the opportunity cost risk that may arise from this decision. D'Ecclesia (2016) identified the growing role of fossil fuels; the impact of renewable energy; technological and institutional interventions; energy commodity market integration; and general markets dynamics (such as price volatility, financialization, speculation, the role of derivative contracts and energy companies' performance) as recent transformations in the energy commodity market which could impact on commodity price volatility.

2.1.2. Energy Commodities in South Africa

A detailed analysis into the activities of the local oil and gas industry in South Africa has shown that demand barely increased between 2011 and 2015 (Narayan, 2014). Furthermore, Marketline (2014) reports that the industry's market value has deteriorated due to recent and persistent energy commodities' price slumps. The fundamental reason given for this is the stark decrease in Brent crude oil prices without substantial increases in demand. The report shows that crude oil accounts for more than 95% of the local oil and gas industry and is as such expected to have a more substantial impact on the macroeconomic fundamentals. Current economic forecast shows an average industry market value growth forecast of ~7% per annum (Marketline, 2014). This is driven primarily by a forecasted 1.5% average per annum growth rate in the market size and increases in energy commodity prices (Marketline, 2014).

2.2. Discussion

2.2.1. Commodity prices: Cycles, volatility and uncertainty

2.2.1.1. Cycles, Super-cycles, Booms and Busts

Commodity prices are cyclical and driven by global economic activity and idiosyncratic shocks (Brooks, Prokopczuk, & Wu, 2015; Reinhart, Reinhart, & Trebesch, 2016; and Chevallier, Gatumel, & Ielpo, 2014). Erten and Ocampo (2012) found evidence for four super-cycles (of between 30 and 40 years in length and 20 to 40 percent price movements) between 1865 and 2009. The aforementioned price movements were measured as positive and/or negative deviations from the long run commodity price trend (Erten & Ocampo, 2012). Buyuksahin, Mo and Zmitrowicz (2016) show this sustained deviation from a long run commodity price trend as an empirical definition of a commodity price super-cycle. This deviation is caused by changes in global demand and supply dynamics. During upswings, demand exceeds supply and similarly, downturns are characterised by supply exceeding demand. The slow supply response during super-cycles is usually driven by production and capital costs. That is, a wide disparity between the costs of increasing production and the sustainability of higher commodity prices (Buyuksahin et al., 2016). Those corporations which acquired debt in order to maximise during upswings usually suffer dire consequences during downturns. The most recent evidence is the post 2008 global plummet in commodity producers share prices and their increased insolvency.

There is also substantial reaction of commodity prices to surprise shocks in monetary policy in the United States (US) (Scrimgeour, 2014). From this we can deduce that unstable US monetary policy can promote commodity price cyclicality. Added to these, Hamilton (2009) and Chevallier et al. (2014) posit speculative behaviour in financial markets as pertinent drivers of the 2005 to 2008 commodity super-cycle. For example, an increase in futures prices can result in an increase in the spot price through the futures formula ($F_t = S_t * e^{(r+u-y)*(T-t)}$. Holding all things constant it is evident that the spot price (S_t) will increase as futures prices (F_t) increase. Positive speculation in the futures markets can thus perpetuate growth in spot prices, culminating in high spot prices. Furthermore, Erten and Ocampo (2012) support the demand argument and show how rapid industrialisation and urbanisation propelled metals and energy prices. They continue to support the speculative behaviour by showing the impact of

commodity indexes (on Wall Street) on promulgating speculative behaviour and thus affecting real commodity prices (Erten & Ocampo, 2012). Brooks et al. (2015) explain that speculation in commodity prices entails, but is not limited to, the market sentiment generated by favourable returns attained by early entrants (early 2000's) into the commodity space. The argument is that this would have created increased demand for commodities and perpetuated the price rally (Brooks et al., 2015). These authors (Brooks et al., 2015) continue to acknowledge the lack of evidence to substantiate speculation as a cause for extreme price movements in commodity prices from the late 1960's to 2015. On the other hand, Chevallier et al. (2014) support the impact of speculation by studying correlation between commodities and their macroeconomic environment pre-and post-2008. They posit the observed increase in the inclusion of commodities in hedge fund portfolios as an indication of increasing speculation.

Commodity cycles and super-cycles are associated with capital inflows and outflows into commodity producing countries (Reinhart et al., 2016). This is shown by the high capital inflows into commodity producing emerging market countries during the 1999 to 2011 rally in commodity prices (Reinhart et al., 2016). Brooks et al. (2015) argue that such was driven by commodities such as gold which saw increases as high as 500% in their price levels during this period. Similarly, commodity busts are accompanied by reduced investments and capital outflows. Rising unemployment, poverty, reduced government spending, increased taxes and increased government debt (local and foreign) are some of the indications of capital outflows. South Africa is amongst those emerging market economies who experienced some of these during the recent commodity downturn. Brooks et al. (2015) and Reinhart et al. (2016) estimate that about one-third attenuation in value, resulted in increased capital outflows from commodity producing economies.

A working paper by Ocampo (2015), studying Argentina, shows that commodity price booms can result in an increase in populism and populist behaviour. This in turn results in dubious monetary policy that could be detrimental in developed countries whose monetary policy has an impact on commodity prices. Barsky and Kilian (2001) and Taylor (2009) attest to this. Scrimgeour (2014) shows that a direct result of the US dollar being used as a currency measure by most commodity producing countries is the transmission of US monetary policy effects into

those countries through commodity prices effects, interest rate channels and exchange rate channels.

2.2.1.2. Commodity Price Volatility

Fernandez (2014) shows that the approximation of information flow rate characteristic of volatility is pertinent to market participants as it shows which variables affect the volatility of the underlying asset. This knowledge can influence decision making parameters such as policy determination, portfolio formation and hedging strategies (Fernandez, 2014). Jacks et al. (2011) studied price volatility from 1700 and found that although commodity price volatility is consistently higher than that of manufactured goods, their idiosyncratic volatility had seemingly not increased over time. This was partly credited to world market integrations, which they postulate as a constrictor of commodity price volatility (Jacks et al., 2011). They, (Jacks et al. 2011) argue that the economic volatility in emerging market economies is a direct consequence of commodity price volatility. This is what this paper will attempt to uncover in South Africa. A later study by Arezki, Lederman and Zhao (2013) argues against commodity price volatility being consistently more than that of manufactured goods. Furthermore, they argue that most literature has been based on commodity indices rather than idiosyncratic primary commodity price time series data – as used in their study (Arezki et al., 2013). This study will follow their study in that actual commodity prices will be analysed. Karali and Power (2013) refute the assertion by Jacks et al. (2011) by showing increased commodity price volatility during 2006 – 2009 bull and bear cycle. Fernandez (2014) shows that commodity price volatility does not only drive macroeconomic fundamentals, but also can itself be driven by macroeconomic fundamentals and industrial production levels of the underlying commodity. This macroeconomic spillover is, similar to industrial production, dependent on the underlying commodity (Fernandez, 2014).

Ghoshray (2012) found temporal variance in commodity prices' persistence, which will influence volatility and thus impact on macroeconomic variables. Similarly, Baskaya, Hulagu and Kucuk (2013) had the same findings while studying the impact of oil price volatility on a small open economy. They found that time varying volatility can amplify the response of an

oil-importing economy (Baskaya et al., 2013). South Africa's strong dependence on oil imports renders the country a good candidate to study the above. Deaton (1999) found that commodity price volatility has a negative impact on growth, similarly indicating causality and spillover effects. Volatility entails high instability in cash flows, production and inflation (see section 2.2.2 below). This is expected to cause similar volatility in interest rates in inflation targeting regimes. Similarly, through the inverse relationship between the U.S. Dollar and commodity prices, it is expected that volatility in commodity prices will manifest as volatility in exchange rates in emerging markets who use the dollar as a base. Several studies show that market dynamics such as convenience yields and stock-outs are pertinent in commodity pricing models (Heaney, 2006; Schwartz 1997; Gibson & Schwartz 1990; Schwartz and Smith 2000; Cortazar, Kovacevic & Schwartz, 2015). These dynamics affect demand and supply dynamics and therefore affect price changes and volatility. Schwartz and Smith (2000) show that short-term fluctuations and long-term equilibrium are equally important aspects of commodity price volatility.

Although Autoregressive Conditional Heteroscedasticity (ARCH) models by Engle (1982) have been used to model volatility of energy prices, Oberndorfer (2009) posits that the Generalised Autoregressive Conditional Heteroscedasticity (GARCH) models, developed by Bollerslev (1986), respond quicker to shocks than other volatility models. Chan and Grant (2016), Pop et al. (2013) and Jacks et al. (2011) support this notion. Jacks et al. (2011) attribute this to a differentiation between conditional and unconditional variances, long memory incorporation and a flexible lag structure. Poon and Granger (2003) critique and show scepticism over the out-of-sample forecast accuracy of GARCH type models. Although in agreement with GARCH models being good for modelling volatility, Byun and Cho (2013) iterate the importance of selecting the correct GARCH type. This is done by comparing the performance of several alternative models (Byun & Cho, 2013; Poon & Granger, 2003). Byun and Cho (2013) describe two general variants to GARCH models, namely, Historical Volatility, which is based on lagged information and Implied Volatility, which is based on the Black Scholes option pricing formula.

Lama, Jha, Paul and Gurung (2015) show that ARCH/GARCH models more appropriate for modelling volatility because they can classify the predictable and unpredictable components of

the time series easily; and the variance is to be modelled rather than being seen as an undesired effect. The ARCH model has a zero mean, is serially uncorrelated and has non-constant variances (Wolff, 1988). Continuing in his argument, Wolff (1988) shows that random coefficient models can be used in place of ARCH models. This is because such models can imply the same conditional variance pattern. Karali and Power (2013) opted for a spline-GARCH model in their study of short and long run determinants of commodity price volatility. They argue that, after the work of Engle and Rangel (2008), a slowly changing unconditional variance results in a better model fit and Persistence of volatility shocks is not as strong as shown in standard GARCH models. Engle and Rangel (2008) explain that this model does not only achieve the above but also gives a link between high and low frequency data; and relaxes the fundamental assumption that volatility is mean revering to some long run constant level. The authors still iterate the "attractiveness" of the GARCH framework in their conclusion, alluding to the importance of GARCH models in modelling volatility (Engle & Rangel, 2008).

Hegerty (2016) followed the GARCH process by applying a multivariate GARCH process to determine spillover effects of volatility to macroeconomic variables. Although Poloni and Sbrana (2014) and Brooks (2014) noted the complexity of multivariate GARCH models, Poloni and Sbrana (2014) still found that traditional multivariate models remain efficient predictors. Brooks (2014) identified three popular multivariate GARCH models, namely, the VECH model, the diagonal VECH model and the BEKK model. He continues to show that the numerous variations to univariate GARCH models can and are carried over to multivariate GARCH models resulting in a similar plethora of possible models for application (Brooks, 2014).

2.2.2. Commodity Prices and the macroeconomic environment

Literature has shown that commodity price shocks are pertinent drivers of macroeconomic fluctuations in developed economies such as the USA (Gubler and Hertweck, 2013). Hegerty (2016) and Zhang, Dufour and Galbraith (2016) show that commodity price volatility can affects small open economies through their dependence on exports. This can in turn be transmitted to such an economy's macroeconomic variables which include exchange rates,

interest rates and inflation (Hegerty, 2016). The aforementioned authors and Ocran and Biekpe (2007) show that there is ongoing debate pertaining the directionality and causality between commodity prices and macroeconomic fundamentals. Zhang et al. (2016) finds evidence for both exchange rate causality of commodity prices and commodity price causality of exchange rates and concludes that the debate is still open. Using work by Garner (1995), Bloomberg and Harris (1995); Furlong and Ingenito (1996) and Ocran and Biekpe (2007) show the empirical decline in the strength of commodity prices as a monetary policy determinant (from 1970s and 1980s onwards). Ocran and Biekpe (2007) also state that rising commodity prices are a sign of an economy "Heating up" (suggesting an undesired rapid growth). This is due to the expected resultant increase in inflation for commodity consuming countries (Ocran & Biekpe, 2007). Their finding, using Toda and Yamamoto (1995)'s approach to testing Granger causality, is that commodity prices can be used as macroeconomic determinants in South Africa (Ocran & Biekpe, 2007). Moreover, Chevallier et al. (2014) posit that commodity markets are themselves affected by macroeconomic fundamentals in certain countries. This is due to the increased integration of commodities into financial markets via portfolios of hedge funds. They measure this through the reaction of commodity markets to economic news (Chevallier et al., 2014). Their findings indicate stronger reactions of commodity markets to economic news during global economic downturns as opposed to global economic rallies (Chevallier et al., 2014). Brooks et al. (2015) argue that the rudimentary characteristics of commodities, either as inputs into production processes and/or as direct consumption goods, result in their increased impact on the economy through their price cyclicality and volatility. Although Cespedes and Velasco (2012) are also in agreement with the impact of commodity price volatility on macroeconomic fundamentals, they argue that the idiosyncratic structural design of each economy determines the extent to which that country's macroeconomic fundamentals will respond to commodity price volatility. To this effect, they use an open-economy model to show the impact of commodity price shocks on output and investment. Proceeding with an economy of less rigid exchange rate regimes, Cespedes and Velasco (2012) then show a reduced impact (of the same commodity price shock) on output and investment.

2.2.2.1. Commodity price volatility and Exchange rates

Two reason have been posited for the interaction between exchange rates and commodity prices (Zhang et al., 2016 and Hegerty 2016). These are mainly the commodity currency effect and speculation in foreign exchange markets. According to the latter, because a country is a producer of the underlying commodity it gains considerable revenue as its price increases. This results in its currency appreciating as a result of an upward demand pressure on the domestic currency. Similarly, such a country's currency will depreciate as the underlying commodity price reduces (due to a downward demand pressure). Zhang et al. (2016) shows that this is most prevalent in small open economies with exports which are greatly dependent on certain commodities. The second reason argues the opposite. That is, exchange rates Granger-cause commodity prices (Zhang et al., 2016). Hegerty (2016) argues that exchange rates are a pertinent transmission channel into emerging market economies. This is primarily due to the costs of importing when the local currency is weak relative to trading partners and the reduced impact a debilitated currency has in reducing foreign denominated debt. From this we can see that it is pertinent to understand the impact of commodity price volatility on a developing economy's exchange rates. This is in order to identify and quantify the correct mitigation initiatives. Studying exchange rate channels, Cespedes and Velasco (2012) found that flexible exchange rate regimes (like South Africa) absorb commodity price shocks more efficiently than fixed exchange rate regimes (like Namibia). In support, Buyuksahin et al. (2016) show that Canada can absorb commodity price shocks owing to their floating (unfixed) exchange rate and inflation targeting strategy. Van der Merwe (1996) and Van der Merwe (2004) show that South Africa has a similar approach. That is, the country has a floating exchange rate and is inflation targeting. This leads to the expectation that the country should be similarly poised to absorb commodity price fluctuations. Hegerty (2016) details a twofold impact of commodity price fluctuations on emerging market economies. Firstly, the currency of commodity producing economies is expected to appreciate as commodity prices increase. The recent (quarter 1 - 2017) strengthening of the Rand against the U.S. Dollar is an example of such an impact. Secondly, a deterioration in the balance of payments is expected when commodity prices reduce. This is caused by resultant capital outflows and reduced investments (Hegerty, 2016; Reinhart et al. 2016).

2.2.2.2. Commodity price volatility and Inflation rates

Gubler and Hertweck (2013) show that commodity prices shocks form an integral proportion and trigger of cyclical inflation movements in the US. Due to their rapid response to economic shocks (demand fluctuation) and their rapid response to idiosyncratic supply shocks (supply fluctuation), commodity prices are expected to be indicators of inflation (Furlong & Ingenito, 1996). Gelos and Ustyugova (2017) show that the composition of the consumption basket has a high bearing on the impact of commodity price shocks. They also iterate the importance of the independence and governance of the central bank (Gelos and Ustyugova, 2017). Generally commodity price shocks are transmitted through the consumption channel where an increase in oil prices results in increased production input costs and thus causes inflation within the importing economy. Gelos and Ustyugova (2017) show that this is less pronounced in recent periods due to reduced oil intensities and reduced exchange rate pass-through. Idiosyncratic economic make-up will determine the extent to which commodity price volatility will be passed through the economy. Tang, Wang and Wang (2014) show that only upstream Chinese industries benefit from increases in commodity prices. Downstream industries experience reduction in profits as inflation is seldom passed on to customers.

Using the Commodity Research Bureau Index for all commodities, the Commodity Research Bureau Raw Materials Index and the Consumer Price Index, Furlong and Ingenito (1996) empirically show the deteriorating relationship between non-oil commodity prices and inflation over time. For oil price transmission to inflation (which is extensively studied in literature), Misati, Nyamongo and Mwangi (2013) show three transmission mechanism, namely, supply side (increased production costs); demand side (reduced purchasing power); and terms of trade (import costs). Scrimgeour (2014) posits three pertinent questions which should be considered when analysing the interaction between commodity prices and macro-economy. These are the impact of booms on inflation, their role in triggering recessions and their role in triggering stagflation. From these it is shown that there is an intricate relationship between commodity prices and the macro-economy, particularly inflation. Ajmera, Kook and Crilley (2012) find that between oil; gas; animal slaughter and processing; and dairy, only oil and gas prices have notable inflationary impacts. Van der Merwe (2004) shows that should this spillover persist (an inflation continue to increase), it is expected to result in monetary policy (interest rate)

response (Gubler & Hertweck, 2013). The result is spillover effects into economic output and per capita hours. The aforementioned impact of commodity prices on inflation is therefore posited to be transmitted on to consumers, especially in emerging markets where primary consumption is on food and/or energy (Brooks et al., 2015). Further transmission into interest rates is expected for those countries following an inflation targeting regime (Van der Merwe, 2004).

2.2.2.3. Commodity price volatility and Interest rates

Literature shows two relationships between interest rates and commodity prices. First, low interest rates increase demand for commodities and there buy increase commodity prices. Second, high commodity prices induce monetary policy (interest rate) reaction to increased inflation (especially in inflation targeting regimes). Moreira (2014) substantiates the latter by arguing "the commodity prices are an integral part in the determination of consumer inflation in developed and emerging markets alike". Here, Moreira (2014) defines commodity price fluctuations as supply shocks that can be transmitted through inflation (in inflation targeting countries) to interest rates (monetary policy reaction to inflation changes). Ji, Liu and Fan (2015) support this in their analysis of the impact of oil supply shocks on the BRICS countries.

Alternatively, Lo (2008) shows that, through the efficient market hypothesis, commodity markets will react to monetary policy announcements such as interest rates movements. According to Malikane (2016) and Clare and Thomas (2011) monetary policy has an impact on money supply through three mechanism, namely the reserve ratio, interest rates and open market activities. A change in these will result in an increase or decrease in money supply and therefore affecting demand and supply dynamics of a country. Such demand and supply dynamics filter into commodity markets. Akram (2008) describes Hotelling's rule as the no-arbitrage condition where commodity prices are inversely related to interest rates. That is they increase as interest rates decrease. Akram (2008) also finds that the causality relationship is unidirectional from interest rates to commodity prices. Frankel (2014) supports the hypothesis that the increase in commodity prices with a reduction in interest rates is due to increased demand for the commodity. This is called easy monetary policy and is explained by the impact

that a change in interest rates will have on the inventory demand for goods (via the cost of carrying the good) and thereby total demand for the good. Gruber and Vigfusson (2016) theorise that low interest rates reduce volatility of commodity prices by inducing an upward demand driven pressure on prices. They find that, holding all else constant, low interest rates also increases correlations between commodities (and their prices). This finding coincides and supports that of Frankel (2014). In support of the above Frankel (2014) shows that the 2008 – 2011 period was characterised by negative correlation between commodity prices and interest rates.

2.2.2.4. Commodity price volatility and Fiscal spending

Other transmission channels for commodity price volatility in emerging markets include fiscal policy (Cespedes and Velasco, 2012). That is, fiscal spending increases during booms and decreases during busts. There is a proportional relationship between fiscal spending and a country's economic activity. This shows that commodity booms and busts will be accompanied by economic booms and busts in such countries. Using commodity producing nations, Cespedes & Velasco (2012) show the presence of fiscal procyclicality in such nations. That is fiscal policy follows commodity cycles as described above. Bloomberg and Harris (1995) also support the former.

2.3. Conclusion

Commodity cycles, super-cycles, booms, and busts are determined by short-and long-term deviations from the long run commodity price trend. Literature has shown that fundamental triggers such as Global GDP changes (demand fluctuations) and idiosyncratic shocks such as the impact of weather changes on the supply of agricultural products induce these deviations. Commodity price fluctuation is shown to have significant impact on inflation before the 1970's and 1980's. Although this impact has lessened over time, it is shown to induce short-term monetary policy reactions which impact economies. In determining monetary policy reaction

to commodity price shocks, it is important to understand the causes and sustainability of the commodity price shocks.

Similarly, literature has shown that in developed economies (such as the US), monetary policies can be transmitted into the commodity markets further exacerbating the commodity price shocks into emerging markets. This is very important for those emerging markets which are depend on commodity exports for revenue and commodity imports for production. South Africa is one such country and has to be attentive to the impacts of the U.S. economy on energy commodity prices as the country imports oil (production) and exports thermal coal (revenue). Furthermore, monetary policy change in prominent markets is transmitted to certain emerging markets through the foreign exchange rate, especially if those countries use the US dollar as base to value their own currency. Literature has shown that those countries with a floating exchange rate will therefore absorb commodity price shocks better than those with a fixed rate. This is due to the inverse relationship between commodity prices and the U.S. Dollar. To that extent, some authors have termed countries commodity currencies, iterating their inextricable relationship to the commodities in which they trade. A wide spectrum of VAR models (including SVAR and VECM) are used to determine the spillover effects of commodity price volatility on macroeconomic fundamentals. GARCH models are shown to be the most appropriate for modelling volatility. Many variants of the GARCH model can be used to model volatility with their multivariate forms used to model spillover effects.

3. CHAPTER 3: DATA AND METHODOLOGY

3.1. Data required and frequency to be analysed

Based on the surveyed literature, the following data will be required for this study:

a. Daily closing price for commodities:

i. Oil Price (Brent Crude)

We use Brent crude oil as it is a highly sought after ("sweet") crude comprising low sulphur and density and thus preferred by refineries for their petroleum production processes (Kurt, 2015). Kurt (2015) argues that this type of oil accounts for almost two-thirds of the world's crude contracts. It is US Dollar denominated. South Africa's import and use of Brent crude render the country vulnerable to price volatility, especially through inflationary impacts.

ii. Coal Price (API 4)

This Argus/McCloskey's Coal Price Index is calculated for coal which is exported from South Africa's Richards Bay Terminal (The largest export terminal in the country). It is calculated on an FOB (Free on Board) basis and is US Dollar denominated. The Argus media website (www.argusmedia.com) argues that API 4 and API 2 prices account for 90% of the world's coal derivative contracts. The oldest available API 4 data on previously mentioned databases is 2007M10. This is the furthest we can do our analyses as there is no data available beyond this point. Any changes on dates will be discussed as and when they apply in sections which follow.

iii. Natural Gas Price (NG1)

NG1 is the Natural Gas Price and will be used as a marker for the US Dollar denominated prices which South African corporations will pay to attain natural gas imports. As previously shown, imports are substantially higher than production (which is also decreasing). Data availability is not a limitation in respect of natural gas prices.

b. South African macroeconomic variables:

i. Interest rates

Interest rates are a monetary policy, primarily driven by changes in inflation as South Africa follows an inflation targeting regime (van der Merwe, 2004). These interest rates play a fundamental role for corporations raising debt locally as an increase will affect debt repayment, interest cover, working capital, current ratio, and WACC (used in company valuations). They are also used in fixed income (Bond) valuation and will result in a movement in bond prices thus affecting investments and divestment in fixed income securities. Due to South Africa's growing role as an oil consumer, it is expected that interest rates will be affected by oil prices through the inflation and inflation targeting channel. API 4 and NG 1 prices are not expected to have an impact on the interest rate. It is rather expected that changing interest rates could have an impact on the prices of these two commodities through demand and supply dynamics.

ii. Exchange rates (Rand/US Dollar)

Due to most trades being conducted in US Dollar, it was decided that the Rand/Dollar exchange rate be used to determine the influence of commodity prices locally. A depreciating Rand/Dollar exchange rate generally has inflationary results as it increases the Rand cost/s of acquiring production input raw materials and equipment from abroad. Inversely, an appreciating Rand/Dollar exchange rate has a disinflationary effect. The US Dollar denomination of oil prices expected to affect the Rand/Dollar exchange through demand and supply channels as the Dollar is inversely related to oil prices. API 4 and NG 1 prices are not expected to have an impact on the Dollar and as such are not expected to have an impact on the exchange rate.

iii. Inflation (Consumer Price Index)

The Consumer Price Index (CPI) gives the year-on-year change on the cost of a predetermined basket of goods over time. As the cost of these goods increases, inflation will increase. This increase usually triggers a monetary policy reaction in interest rates in inflation targeting regimes such as South Africa. The target inflation band in South Africa is 3% - 6%. Taylor rule defines the interest rate as $r = r^* + i + \beta_1 (i-i^*) + \beta_2 (g-g^*)$ where r is the nominal interest

rate; r^* is the real interest rate; i is the inflation rate; i^* is the inflation target; g is the real output and g^* is the output target (Malikane, 2016). From this, it is evident that inflation is positively correlated to the nominal interest rate. That is, as inflation increases, monetary policy reaction to interest rates will be in the same direction in order to reduce inflation. Brent crude and natural gas are imports and as such their prices are expected to have an impact on inflation. This is due to their strong use in the production (energy) and transportation sectors of the country. API 4 prices are for exported coal (from Richards Bay Coal Terminal) and as such are not expected to have a substantial impact on inflation.

3.1.1. Data Sources

Sources that were used to collect these data included the World Bank, International Monetary Fund (IMF) (monthly South African macroeconomic fundamentals), Bloomberg (monthly commodity prices) and iNet BFA (monthly commodity prices). Literature survey on emerging markets stipulates the need to corroborate statistics found by those economies' local authorities. To correct for the misalignment in high frequency commodity prices data and the lower frequency macroeconomic data, monthly data (lower frequency) is used in this study.

3.2. Methodology

3.2.1. Descriptive Statistics

Brooks (2014) shows that descriptive statistics such as the mean, median, mode, standard deviation, skewness, and kurtosis are important in describing time series data. Kim (2015) further argues that unit root tests are more important as they reveal the stationarity or non-stationarity of the time series. Kim (2015), Brooks (2014) and Lama et al. (2015) used the Augmented Dickey Fuller Test to determine stationarity. We will commence with the detailed analysis of the time series properties of all the data. Brooks (2014) and Lama et al. (2015) show the importance of separating the data into in-sample period (used to specify the models) and an out-of-sample period (used for forecasting and validating the specified model's accuracy).

3.2.2. Modelling the impact of commodity prices on South African macroeconomic fundamentals (VAR/VECM approach) – Hypothesis 1 testing

VAR and VECM models can be used to model the relationship between multiple variables over a given period of time. The choice of which of these models is to be used depends solely on the presence and/or absence of cointegration (long-run relationship) between the variables. Given the presence of cointegration, the VECM approach is used. This will be discussed in detail below. Following Brooks (2014) and Hegerty (2016), our VAR/VECM process will follow the specification below (equation 3.1)

$$\begin{bmatrix} \Delta\, p_t^o \\ \Delta p_t^{ng} \\ \Delta\, p_t^c \\ \Delta\, e_t \\ \Delta\, p_t \\ \Delta\, r_t \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ c_3 \\ c_4 \\ c_5 \\ c_6 \end{bmatrix} + \begin{bmatrix} \rho_{11}\rho_{12}\rho_{13}\rho_{14}\rho_{15}\rho_{16} \\ \rho_{21}\rho_{22}\rho_{23}\rho_{24}\rho_{25}\rho_{26} \\ \rho_{31}\rho_{32}\rho_{33}\rho_{34}\rho_{35}\rho_{36} \\ \rho_{41}\rho_{42}\rho_{43}\rho_{44}\rho_{45}\rho_{46} \\ \rho_{51}\rho_{52}\rho_{53}\rho_{54}\rho_{55}\rho_{56} \\ \rho_{61}\rho_{62}\rho_{63}\rho_{64}\rho_{65}\rho_{66} \end{bmatrix} \begin{bmatrix} \Delta p_{t-n}^o \\ \Delta p_{t-n}^{ng} \\ \Delta p_{t-n}^c \\ \Delta e_{t-n} \\ \Delta p_{t-n} \\ \Delta r_{t-n} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \end{bmatrix}$$

(3.1)

Where p_t^o; p_t^{ng}; p_t^c; e_t; p_t; and r_t are the monthly log returns for oil prices; natural gas prices; coal prices; exchange rates; inflation; and interest rates respectively. From equation 3.1 above, the macroeconomic systems equations for the chosen macroeconomic fundamentals is given by variants of equation 3.2 below. Here *mev* is any of the macroeconomic variables, ij is the location on the matrix of coefficients, n is the lag term, and N is the order of the VAR model.

$$\Delta mev_t = c_{ijn} + \sum_{n=1}^{N} \rho_{ijn} p_{t-n}^o + \sum_{n=1}^{N} \rho_{ijn} p_{t-n}^{ng} + \sum_{n=1}^{N} \rho_{ijn} p_{t-n}^c + \sum_{n=1}^{N} \rho_{ijn} e_{t-n} + \sum_{n=1}^{N} \rho_{ijn} p_{t-n} + \sum_{n=1}^{N} \rho_{ijn} r_{t-n} + \varepsilon_{ij}$$

(3.2)

Similarly, equation 3.3 (below) is a representation of the system equation for any of the commodity prices in question. Here *cp* is the commodity price.

$$\Delta cp_t = c_{ijn} + \sum_{n=1}^{N} \rho_{ijn} p_{t-n}^{o} + \sum_{n=1}^{N} \rho_{ijn} p_{t-n}^{ng} + \sum_{n=1}^{N} \rho_{ijn} p_{t-n}^{c} + \sum_{n=1}^{N} \rho_{ijn} e_{t-n} + \sum_{n=1}^{N} \rho_{ijn} p_{t-n} + \sum_{n=1}^{N} \rho_{ijn} r_{t-n} + \varepsilon_{ij} \quad (3.3)$$

In the VAR equations specified above (equation 3.2 and 3.3), the coefficients (and the statistical significance thereof) for each variable on the right hand side of each equation show the level to which that variable affects the dependent variable. Brooks (2014) shows that VAR models are applicable only if the system variables are not cointegrated. Cointegration entails the existence of a long run linear relationship between variables. That is, in the long run, a movement in one variable is bound to the movement in another variable within the series. This can be determined through various tests such as the Johansen Test for Cointegration (Brooks, 2014). Another test entails testing the errors of each VAR equation for stationarity using the Augmented Dickey Fuller Test (Brooks, 2014). Here the variables in the VAR equation should be level data rather than the log return data. This yields equations 3.4 and 3.5 for all macroeconomic variables and commodity prices in the system respectively. Brooks (2014) demonstrates that these error terms are stationary (integrated of order zero – *I (0)*) only when the regression variables are cointegrated. This test is conducted on level data which is integrated of order one – *I (1)* or non-stationary. Logic would dictate that the error terms should similarly be non-stationary. Therefore, their stationarity indicates cointegration in the variables (Brooks, 2014; Rezitis & Ahammad, 2015). Brooks (2014) shows that standard econometric methods cannot be used in cointegrated series and thus error correction models are estimated.

$$\Delta mev_t - c_{ijn} - \sum_{n=1}^{N} \rho_{ijn} p_{t-n}^{o} - \sum_{n=1}^{N} \rho_{ijn} p_{t-n}^{ng} - \sum_{n=1}^{N} \rho_{ijn} p_{t-n}^{c} - \sum_{n=1}^{N} \rho_{ijn} e_{t-n} - \sum_{n=1}^{N} \rho_{ijn} p_{t-n} - \sum_{n=1}^{N} \rho_{ijn} r_{t-n} = \varepsilon_{ij} \quad (3.4)$$

$$\Delta cp_t - c_{ijn} - \sum_{n=1}^{N} \rho_{ijn} p^{o}_{t-n} - \sum_{n=1}^{N} \rho_{ijn} p^{ng}_{t-n} - \sum_{n=1}^{N} \rho_{ijn} p^{c}_{t-n} - \sum_{n=1}^{N} \rho_{ijn} e_{t-n} - \sum_{n=1}^{N} \rho_{ijn} p_{t-n} - \sum_{n=1}^{N} \rho_{ijn} r_{t-n} = \varepsilon_{ij} \quad (3.5)$$

Other cointegration tests include the Johansen Cointegration Tests (Brooks, 2014). Brooks (2014) shows that the test statistic for this type of test is given by equation 3.6 below, while the maximum eigenvalue is given by equation 3.7.

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{g} [ln(1 - \lambda_i)] \quad (3.6)$$

$$\lambda_{max}(r, r+1) = -Tln\left(1 - \hat{\lambda}_{r+1}\right) \quad (3.7)$$

Here r shows the cointegrating vectors and λ_i is the value of the eigenvalue from the matrix measuring a long-term relationship. These tests are used to test for cointegration in our VAR specification. In the case that there is cointegration between the system variables, the nonstationary series is utilised in a VECM. Brooks (2014) shows that this model avoids the no long run solution predicament of pure first difference models. Brooks (2014) and Hamilton (1994) demonstrate that the cointegrating relationship/s can be captured by the error correction term shown in equation 3.8 below. This will aid in mitigating the aforementioned dilemma (Brooks, 2014).

$$\Delta y_t = \beta_1 \Delta x_t + \beta_2 (y_{t-1} - \Upsilon x_{t-1}) + u_t \quad (3.8)$$

Where $(y_{t-1} - \Upsilon x_{t-1})$ is the error correction term and Υ is the cointegrating coefficient. Brooks (2014) and Hamilton (1994) show that the cointegrating coefficient and β_1 measure the long run and short run relationships between the variables while β_2 measures the speed of adjustment

to an equilibrium state between the cointegrating variables. The Johansen Cointegration tests mentioned above test how many cointegration equations are present in a VAR system. These can then be specified and used in the VECM. Following the VECM specification, VIRF are used to determine spillovers between financial markets and commodity price volatility. This is similar to Moreira 2014 who uses VAR (Vector Autoregressive), ARAMA-GARCH and Cointegration/VEC (Vector Error Correction) to model relationships between commodities prices and macroeconomic variables in Brazil.

3.2.3. Modelling volatility spillovers in the system variables – Hypothesis 2 testing

Poloni and Sbrana (2014) argue that the estimation of a multivariate GARCH remained a complex task even in the wake of modern technology and computers. They postulated a generalized least squares estimator for unrestricted GARCH (1, 1) models as a solution. Brooks (2014) corroborates the complexity of multivariate GARCH models and identifies the need to specify the temporal movement of the covariance as the main impediment. Poloni and Sbrana (2014) still found that the traditional multivariate GARCH is still the best predictor. Hegerty (2016) suggests a two-step approach to achieving his aim of determining the spillover effects of commodity price volatility to macroeconomic variables.

The first step entails using GARCH processes to model the univariate volatility process of commodity prices. Hegerty (2016), Kim (2015) and Brooks (2014) show that this process requires the specification of mean and variance equations. To this end, we use monthly log return data and the Box-Jenkins procedure to determine an appropriate ARMA (p, q) order for each commodity price time series (Brooks, 2014). Our mean equation follows the ARMA process shown in equation 3.9.

$$\Delta p_t^c = c + \sum_{i=1}^{p} \rho_i \Delta p_{t-i}^c + \sum_{j=0}^{q} \theta_j \varepsilon_{t-j} \qquad (3.9)$$

Here p^c is the monthly log commodity price; ρ and θ are the coefficients in the ARMA (p,q) mean equation; c is the constant; and ε is the error term. The order of the ARMA model is one which minimises the Akaike Information Criteria (Brooks, 2014). Hegerty (2016); Brooks (2014) and Lama et al. (2015) show that this step will be followed by a test for ARCH effects which, if found, will warrant the specification of a variance equation (this is the GARCH process). Brooks (2014) indicates that ARCH and GARCH type models show higher efficacy with high frequency data rather than low frequency further substantiating our use of monthly data. Our variance equation is a GARCH (3.10).

$$h_t = k + \sum_{j=1}^{q} \alpha_j \Delta\varepsilon_{t-j}^2 + \sum_{j=0}^{p} \delta_i h_{t-i} \tag{3.10}$$

Here *k* is a constant; α and δ are coefficients; ε^2_{t-j} is the lag of the ARCH term (the squared errors from the mean equation (3.9); and h_{t-i} is the lag of the GARCH term. For the purpose of this study, only the historical volatility variants of the GARCH processes defined by Byun and Cho (2013) will be applied. Chan and Grant (2016) identified seven generally used GARCH models (equation 3.11 – 3.17).

a. GARCH (1, 1)

$$y_t = \mu + \varepsilon_t, \qquad \varepsilon_t \sim N(0, \sigma_t^2),$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 \tag{3.11}$$

b. GARCH (2, 1)

$$y_t = \mu + \varepsilon_t, \qquad \varepsilon_t \sim N(0, \sigma_t^2),$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2 + \beta_2 \sigma_{t-2}^2 \tag{3.12}$$

c. GARCH WITH JUMPS (GARCH – J)

$$y_t = \mu + k_t q_t + \varepsilon_t, \qquad \varepsilon_t \sim N(0, \sigma_t^2), \qquad k_t \sim N(\mu_t, \sigma_k^2),$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 (y_{t-1} - \mu)^2 + \beta_1 \sigma_{t-1}^2$$

(3.13)

d. GARCH IN MEAN (GARCH – M)

$$y_t = \mu + \lambda \sigma_t^2 + \varepsilon_t \qquad \varepsilon_t \sim N(0, \sigma_t^2)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 (y_{t-1} - \mu - \lambda \sigma_{t-1}^2)^2 + \beta_1 \sigma_{t-1}^2$$

(3.14)

e. GARCH WITH A FIRST ORDER MOVING AVERAGE (GARCH – MA)

$$y_t = \mu + \varepsilon_t,$$

$$\varepsilon_t = u_t + \psi u_{t-1} \qquad u_t \sim N(0, \sigma_t^2)$$

(3.15)

f. GARCH – t

$$y_t = \mu + \varepsilon_t, \qquad \varepsilon_t \sim t_v(0, \sigma_t^2)$$

(3.16)

g. GARCH – GJR

$$\sigma_t^2 = \alpha_0 + \left(\alpha_1 + \delta_1 \mathbb{Y}(\varepsilon_{t-1} < 0)\right) \varepsilon_{t-1}^2 + \beta_1 \sigma_{t-1}^2$$

(3.17)

The GARCH (1, 1) model is the most widely used process (Hegerty, 2016; Lama et al., 2015). Although we will test the suitability of the other models to describe each data series, we use the GARCH (1, 1) process in our multivariate GARCH model (for spillover analysis). As shown by Lama et al. (2015) and Brooks (2014), the performance of these models will be compared using the AIC and RMSE (root mean square error). While comparing the predictive

ability of univariate and multivariate GARCH models in the energy market, Wang and Wu (2012) found that multivariate GARCH models are better predictors than univariate models. However, Poloni and Sbrana (2014) and Brooks (2014) iterate the complexity of multivariate GARCH models as shown in the second step of Hegerty's (2016) approach.

The second step entails applying multivariate GARCH process to determine spillover effects of volatility to the macroeconomic variables of each country in their study (Hegerty, 2016). Kim (2015) argues that multivariate models are appropriate in explaining the relationship between multiple series. In addition, Kim (2015) shows that, similar to standard GARCH models, multivariate models also have two processes, namely, the mean processes (explained by vector autoregressive model - VAR) and the variance process (explained by two or more residual series of the VAR process. Brooks (2014) identified that the BEKK, VECH and diagonal VECH models are the most popular multivariate GARCH models in literature. Of the three, Brooks (2014) and Kim (2015) agree that the BEKK model is the most convenient as it ensures that the variance matrix is always positive definite. Kim (2015) specifies the following mean (3.18) and variance (3.19) equations for the BEKK GARCH Model:

$$X_t = c + \sum_{i=1}^{r} \Phi_i X_{t-i} + u_t \tag{3.18}$$

$$u_t = H_t^{1/2} v_t, \qquad v_t \sim \mathrm{N}(0,1) \tag{3.19}$$

Kim (2015) specifies the following conditional variance equation (3.20) for H_t, which we adopt and augment for our multivariate GARCH model.

$$H_t = C_0 C_0' + A\varepsilon_{t-1}\varepsilon_{t-1}' A' + \beta H_{t-1}\beta' \tag{3.20}$$

Here H_t is a 5x5 conditional variance covariance matrix where the diagonal terms capture the variance and the off diagonal terms capture the covariance between the variables under study. C is a lower triangular 5x5 matrix which is used to ensure the semi-positive definiteness of H_t. Matrix A is a 5x5 matrix of coefficients capturing the relation of past error terms to H_t. Lastly, matrix B (a 5x5 matrix) captures the relation of past conditional variances on H_t. Engle and Kroner (1995) define the lagged error terms as the arch terms (also innovation) and the lagged conditional variance term as the GARCH term. From the above, equation 3.21, which is a matrix formula of the conditional variance, is derived.

$$\begin{bmatrix} h_{11} & \dots & h_{15} \\ \vdots & \ddots & \vdots \\ h_{51} & \dots & h_{55} \end{bmatrix}$$

$$= \begin{bmatrix} c_{11} & \dots & c_{15} \\ \vdots & \ddots & \vdots \\ c_{51} & \dots & c_{55} \end{bmatrix} \begin{bmatrix} c_{11} & \dots & c_{15} \\ \vdots & \ddots & \vdots \\ c_{51} & \dots & c_{55} \end{bmatrix}'$$

$$+ \begin{bmatrix} a_{11} & \dots & a_{15} \\ \vdots & \ddots & \vdots \\ a_{51} & \cdots & a_{55} \end{bmatrix} \begin{bmatrix} \varepsilon_{1t-1} \\ \vdots \\ \varepsilon_{5t-1} \end{bmatrix} \begin{bmatrix} \varepsilon_{1t-1} & \dots & \varepsilon_{5t-1} \end{bmatrix} \begin{bmatrix} a_{11} & \dots & a_{15} \\ \vdots & \ddots & \vdots \\ a_{51} & \dots & a_{55} \end{bmatrix}'$$

$$+ \begin{bmatrix} b_{11} & \dots & b_{15} \\ \vdots & \ddots & \vdots \\ b_{51} & \dots & b_{55} \end{bmatrix} \begin{bmatrix} h_{11} & \dots & h_{12} \\ \vdots & \ddots & \vdots \\ h_{51} & \dots & h_{55} \end{bmatrix} \begin{bmatrix} b_{11} & \dots & b_{15} \\ \vdots & \ddots & \vdots \\ b_{51} & \dots & b_{55} \end{bmatrix}'$$

(3.21)

Through matrix algebra, equation 3.21 is decomposed to a series of conditional variance and covariance equations as shown below (equation 3.22 and 3.23) and in Appendix 2. The coefficients which measure the $\varepsilon^2_{nt\text{-}l}$ and the $h_{nt\text{-}1}$ variables in the variance equations are pertinent in measuring spillovers and direct impact of volatility in one variable (RHS) on the variance equation of the dependent variable (LHS). In our MGARCH model, the variables $h_{11;}$ h_{12}; h_{13}; h_{14} and h_{15} represent the conditional variance for oil, natural gas, inflation, interest rate, and exchange rates respectively. This study focuses on the coefficients of the above-mentioned variance equations and the significance levels. We employ the maximum likelihood method (equation 3.24 and 3.25) to determine the most likely coefficients and their significance.

$$h_{11} = c_{11}^2 + a_{11}^2\varepsilon_{1t-1}^2 + 2a_{11}a_{12}\varepsilon_{2t-1}\varepsilon_{1t-1} + 2a_{11}a_{13}\varepsilon_{3t-1}\varepsilon_{1t-1} + 2a_{11}a_{14}\varepsilon_{4t-1}\varepsilon_{1t-1} + 2a_{11}a_{15}\varepsilon_{5t-1}\varepsilon_{1t-1} + a_{12}^2\varepsilon_{2t-1}^2 + 2a_{12}a_{13}\varepsilon_{3t-1}\varepsilon_{2t-1} + 2a_{12}a_{14}\varepsilon_{4t-1}\varepsilon_{2t-1} + 2a_{12}a_{15}\varepsilon_{5t-1}\varepsilon_{2t-1} + a_{13}^2\varepsilon_{3t-1}^2 + 2a_{13}a_{14}\varepsilon_{4t-1}\varepsilon_{3t-1} + 2a_{13}a_{15}\varepsilon_{5t-1}\varepsilon_{3t-1} + a_{14}^2\varepsilon_{4t-1}^2 + 2a_{14}a_{15}\varepsilon_{5t-1}\varepsilon_{4t-1} + a_{15}^2\varepsilon_{5t-1}^2 + b_{11}^2h_{11t-1} + 2b_{11}b_{12}h_{12t-1} + 2b_{11}b_{13}h_{13t-1} + 2b_{11}b_{14}h_{14t-1} + 2b_{11}b_{15}h_{15t-1} + b_{12}^2h_{22t-1} + 2b_{12}b_{13}h_{32t-1} + 2b_{12}b_{14}h_{42t-1} + 2b_{12}b_{15}h_{52t-1} + b_{13}^2h_{33t-1} + 2b_{13}b_{14}h_{43t-1} + 2b_{13}b_{15}h_{53t-1} + b_{14}^2h_{44t-1} + 2b_{14}b_{15}h_{54t-1} + b_{15}^2h_{55t-1}$$

(3.22)

⋮

$$h_{55} = c_{51}^2 + c_{52}^2 + c_{53}^2 + c_{54}^2 + c_{55}^2 + a_{51}^2\varepsilon_{1t-1}^2 + 2a_{51}a_{52}\varepsilon_{2t-1}\varepsilon_{1t-1} + 2a_{51}a_{53}\varepsilon_{3t-1}\varepsilon_{1t-1} + 2a_{51}a_{54}\varepsilon_{4t-1}\varepsilon_{1t-1} + 2a_{51}a_{55}\varepsilon_{5t-1}\varepsilon_{1t-1} + a_{52}^2\varepsilon_{2t-1}^2 + 2a_{52}a_{53}\varepsilon_{3t-1}\varepsilon_{2t-1} + 2a_{52}a_{54}\varepsilon_{4t-1}\varepsilon_{2t-1} + 2a_{52}a_{55}\varepsilon_{5t-1}\varepsilon_{2t-1} + a_{53}^2\varepsilon_{3t-1}^2 + 2a_{53}a_{54}\varepsilon_{4t-1}\varepsilon_{3t-1} + 2a_{53}a_{55}\varepsilon_{5t-1}\varepsilon_{3t-1} + a_{54}^2\varepsilon_{4t-1}^2 + 2a_{54}a_{55}\varepsilon_{5t-1}\varepsilon_{4t-1} + a_{55}^2\varepsilon_{5t-1}^2 + b_{51}^2h_{11t-1} + 2b_{51}b_{52}h_{12t-1} + 2b_{51}b_{53}h_{13t-1} + 2b_{51}b_{54}h_{14t-1} + 2b_{51}b_{55}h_{15t-1} + b_{52}^2h_{22t-1} + 2b_{52}b_{53}h_{32t-1} + 2b_{52}b_{54}h_{42t-1} + 2b_{52}b_{55}h_{52t-1} + b_{53}^2h_{33t-1} + 2b_{53}b_{54}h_{43t-1} + 2b_{53}b_{55}h_{53t-1} + b_{54}^2h_{44t-1} + 2b_{54}b_{55}h_{54t-1} + b_{55}^2h_{55t-1}$$

(3.23)

$$L(\Theta) = \sum_{t=1}^{p} l_t\,(\Theta)$$

(3.24)

Where

$$l_t(\Theta) = -\frac{n}{2}log(2\Pi) - \frac{1}{2}log|\mathrm{H}_t| - \frac{1}{2}\varepsilon_t'\mathrm{H}_t^{-1}\varepsilon_t$$

(3.25)

4. CHAPTER 4: RESULTS AND ANALYSIS

4.1. Data Descriptive Statistics

Figure 4.1 shows the evolution of monthly energy commodity prices from January 1992 to December 2016. From this figure, it is evident that there is a generic co-movement between these commodity prices. This is expected as they are for the same and/or similar target clients who utilise them in similar approaches (such as to generate energy for downstream productive purposes). Brooks (2014) calls this co-movement "cointegration of the vectors" and describes it as the presence of a long run relationship between the series'. In this section, we analyse and understand these commodity prices and their dynamics; South African macroeconomic fundamentals and their dynamics; and the causal relationships which may exist across all the pairs in our system. We conclude the section with the Johansen Test for Cointegration to determine the amount of cointegrating equations in the system. From the results, we use the AIC and SBIC to determine the order of the VECM model to be specified. Following work by Hegerty (2016), the Census X-12 approach was used to de-seasonalize series data which showed seasonality.

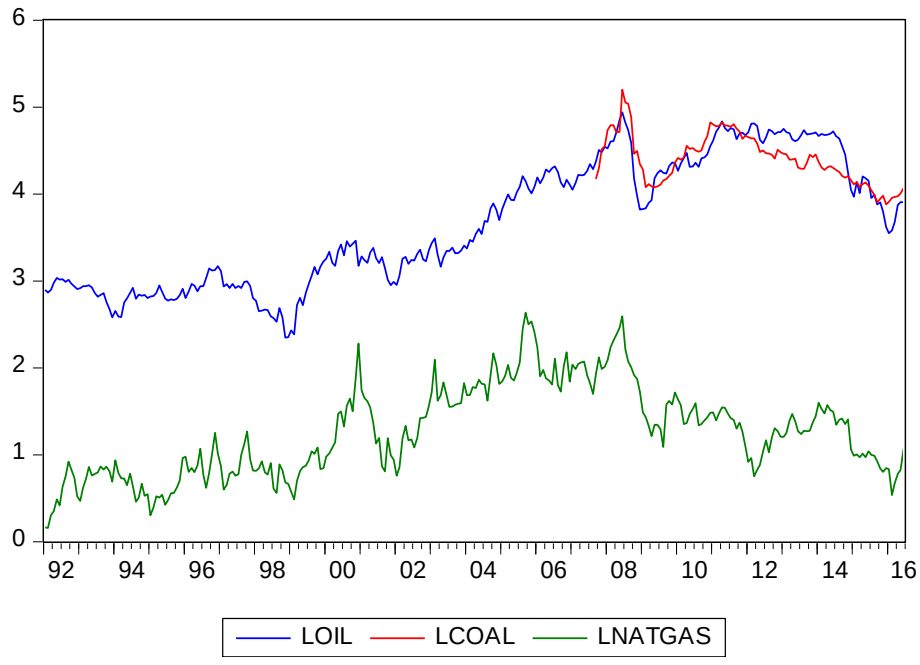


Figure 4. 1: Logged Level energy commodity prices

Kim (2015) and Ismail, Luan and Ee. (2015) argue that the log of level data reduces the volatility of level data. We therefore use both the log of level data and the log returns from these series in this study.

4.1.1. Correlation between the time series data

Analysing the correlation between energy commodity prices and the related South African macroeconomic variables yields Table 4.1 and 4.2 below. Table 4.1 shows that the coal prices (and returns) have a moderate to strong positive correlation to inflation, interest rates, natural gas prices, and oil prices. Their relationship to exchange rates is strong and negative. Natural gas prices portray the same correlation pattern as coal prices with weaker correlations to exchange rates and oil prices. Their strongest correlation is to inflation and interest rates. Lastly, oil prices seem to have a weak and negative correlation to selected macroeconomic fundamentals. Their strongest correlation is to coal prices.

Table 4. 1: Logged level data correlation for the time series' data

	Coal Price	**SA Inflation**	**SA Exchange Rate**	**SA Interest Rate**	**Natural Gas Price**	**Oil Price**
Coal Price	1.000	0.266	-0.533	0.250	0.486	0.566
SA Inflation	0.266	1.000	0.078	0.869	0.753	-0.072
SA Exchange Rate	-0.533	0.078	1.000	-0.169	-0.226	-0.130
SA Interest Rate	0.250	0.869	-0.169	1.000	0.794	-0.343
Natural Gas Price	0.486	0.753	-0.226	0.794	1.000	0.104
Oil Price	0.566	-0.072	-0.130	-0.343	0.104	1.000

The returns correlation in Table 4.2 show the expected correlation between commodity price returns and the South African macroeconomic fundamentals returns. First, they are positively correlated to inflation suggesting that an increase in the commodity price (or their returns) yields an increase in inflation for commodity importing and exporting countries. Second, they are negatively correlated to exchange rates suggesting that an increase in commodity prices results in the currency strengthening. Oil price returns show the strongest (and negative) impact on the South African currency. This suggests that a positive move in the oil price results

in the local currency strengthening substantially. Natural gas and oil price returns are negatively correlated to interest rates. This implies that a positive move in either of these prices results in a reduction in interest rates. Coal price returns, on the other hand, are positively correlated to interest rates. All the commodity price returns are strongly positively correlated to each other. The same holds for the correlation between the macroeconomic fundamentals in the country. Table 4.2 shows that the correlation between inflation and interest rate is the strongest at 0.191. This is expected as the country follows an inflation targeting regime.

Table 4. 2: Log returns data correlation for the time series data

	Coal Price	**SA Inflation**	**SA Exchange Rate**	**SA Interest Rate**	**Natural Gas Price**	**Oil Price**
Coal Price	1.000	0.217	-0.283	0.270	0.241	0.439
SA Inflation	0.217	1.000	0.080	0.191	0.249	0.112
SA Exchange Rate	-0.283	0.080	1.000	0.121	-0.007	-0.474
SA Interest Rate	0.270	0.191	0.121	1.000	-0.007	-0.096
Natural Gas Price	0.241	0.249	-0.007	-0.007	1.000	0.268
Oil Price	0.439	0.112	-0.474	-0.096	0.268	1.000

4.1.2. Returns data

From the logged series data, Figures 4.2 (a) and (b) are derived. These figures show the log returns for all the series which will be used in this study. Both these and the logged level data series are tested for stationarity and cointegration. The results are given below. Due to the existence of cointegrating vectors, a VECM will be utilised to model the linear relationship between and the impact of all the variables on the each other (system equation approach). The log returns data is used to estimate and test the predictive ability of the aforementioned GARCH models (including the multivariate GARCH model to determine spillover effects between variables).

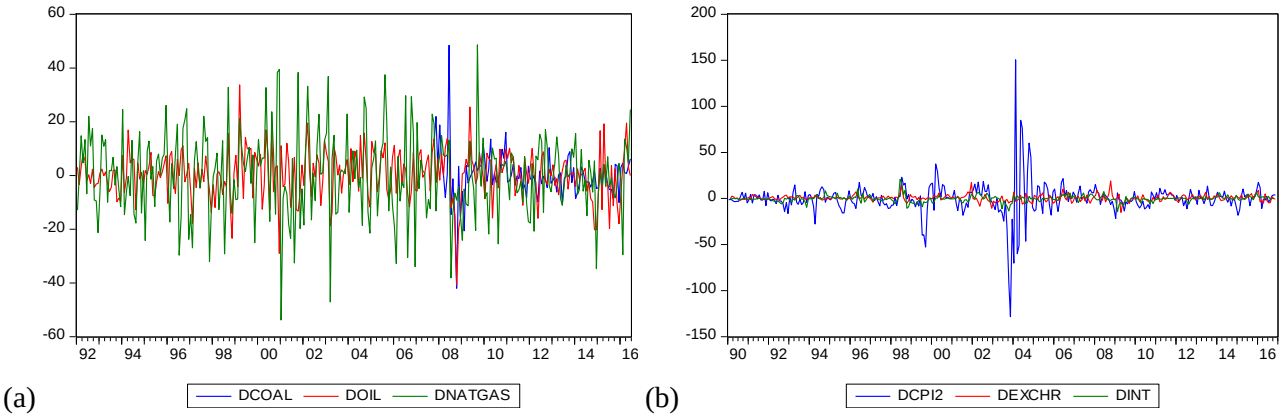


Figure 4. 2: (a) Monthly log returns for energy commodity prices. (b) Monthly log returns of macroeconomic indicators of South Africa

4.1.3. Normality of the time series data

Brooks (2014) shows the importance of data normality in least squares analysis. To this effect, Brooks (2014) describes a series of descriptive data statistics such as mean, median, mode, kurtosis, variance, and standard deviation. The kurtosis and skewness of a normal distribution should be 3 and 0 respectively (Brooks, 2014). Tables 4.3 and 4.4 below show the descriptive statistics for the logged level and log return data respectively. From these tables, it is evident that both series are not normally distributed. According to Brooks (2014), the high kurtosis (and excess kurtosis – calculated as kurtosis – 3) denote are that the returns data are more leptokurtic for the macroeconomic returns as compared to the commodity price returns. Skewness figures reveal both positive and negative skewness for the data respectively. The deviation from normality is supported by the strong rejection of the Jarque-Bera null hypothesis which states that data are normally distributed in its null hypothesis (P-value shows statistical significance at the 1% level). Brooks (2014) argues that deviation from normality is inconsequential for large data sets and states that the real estate and economic data (and their respective residuals in regression analyses) are generally characterised by leptokurtic distributions. For this purpose, we proceed with the data in its leptokurtic form.

Table 4. 3: Descriptive Statistics for level data (Oil, Coal and Natural gas prices; and South African Macroeconomic fundamentals - Inflation, Interest Rates and Exchange Rates)

	Obs	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	JB-Stat	JB-Prob
Coal Price	113	84.649	82.100	181.000	48.450	24.737	1.042	4.422	29.958	0.000
SA Inflation	707	7.973	6.908	20.942	0.164	4.806	0.348	2.031	41.938	0.000
SA Exchange Rate	323	6.904	6.868	16.365	2.524	3.039	0.644	3.186	22.780	0.000
SA Interest Rates	322	10.247	10.155	21.620	4.930	3.923	0.493	2.220	21.201	0.000
Natural Gas Price	322	3.908	3.231	13.921	1.171	2.344	1.538	5.611	218.365	0.000
Oil Price	344	46.389	28.555	139.830	10.460	34.151	0.912	2.476	51.661	0.000

Table 4. 4: Descriptive Statistics for returns data (Oil, Coal and Natural gas prices; and South African Macroeconomic fundamentals - Inflation, Interest Rates and Exchange Rates)

	Obs	Mean	Median	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	JB-Stat	JB-Prob
Coal Price	112	0.213	-0.025	48.447	-41.977	9.225	0.608	12.361	415.841	0.000
SA Inflation	706	0.072	-0.283	161.589	-128.426	18.013	0.748	27.298	17433.870	0.000
SA Exchange Rate	322	0.526	0.338	19.018	-15.179	3.430	0.688	8.706	462.187	0.000
SA Interest Rates	321	-0.279	-0.181	20.860	-14.512	3.532	0.495	9.798	631.153	0.000
Natural Gas Price	321	0.245	1.053	48.621	-53.813	15.179	-0.152	3.858	11.085	0.004
Oil Price	343	0.398	0.634	37.959	-40.740	9.305	-0.186	5.343	80.437	0.000

4.1.4. Stationarity analyses of the time series data

According to Kim (2015), Box and Jenkins (1984) and Brooks (2014), a more pertinent feature of times series data is the stationarity of the data. Brooks (2014) shows that non-stationary time series data are those without constant means, variances and autocovariances. These are characterised by unit roots and will result in spurious regressions (shown by significant coefficients and high R^2 for unrelated data series'); undying, and at times explosive, responses to shocks, and unreal results for hypotheses testing. Hamilton (1994), Brooks (2014), Kim (2015) and Moreira (2014) employ the Augmented Dickey Fuller and/or the Phillips-Perron tests in analysing stationarity of time series data. Both tests have the null hypothesis of a unit root *I (1)* and an alternative hypothesis of a stationary process *I (0).* Xu and Moon (2013) and Brooks (2014) show that differencing a nonstationary series results in a stationary series of returns. Tables 4.5 and 4.6 show the unit root results for both the Augmented Dickey Fuller and Phillips-Perron tests conducted on the logged level and log return data series respectively. From these tests, it is shown that all logged level data have unit roots besides natural gas prices which seem stationary at the 5% and 10% levels. The Phillips-Perron test shows the logged level CPI data to be stationary at the 5% level. Both tests show that all log returns data are stationary at the 1% level.

Table 4. 5: Probability values of Augmented Dickey Fuller unit root analysis for all the series' used in the study (Level, logged level and return data)

	P-Values		
	Level data	**Logged Level data**	**Returns**
Coal Price	0.220	0.351	0.000
SA Inflation	0.430	0.161	0.000
SA Exchange Rate	0.890	0.706	0.000
SA Interest Rate	0.203	0.374	0.000
Natural Gas Price	**0.025**	**0.070**	0.000
Oil Price	0.345	0.488	0.000

Table 4. 6: Probability values of Phillips-Perron unit root analysis for all the series' used in the study (Level, logged level and return data)

	P-Values		
	Level data	**Logged Level data**	**Returns**
Coal Price	0.184	0.202	0.000
SA Inflation	0.157	0.020	0.000
SA Exchange Rate	0.913	0.745	0.000
SA Interest Rate	0.267	0.407	0.000
Natural Gas Price	0.034	0.094	0.000
Oil Price	0.397	0.576	0.000

4.1.5. Testing for ARCH effects

After assuring the stationarity of the returns data, we proceed to tests for arch effects in the postulated mean equations. This is done in order to determine if the ARCH and GARCH family of models are relevant tools to analyse the time series data. Brooks (2014) shows that these models are efficient in analysing leptokurtosis, volatility clustering and leverage effects in time series data. Table 4.7 shows the probabilities of the LM test for ARCH effects which has the Null hypothesis that there are no ARCH effects. The results show that a random walk mean equation of each series rejects the Null hypothesis at the stated level of significance (1% level for coal prices and 10% level for oil prices). The resultant GARCH models specified showed high proportions of serial correlations which prompted the author to consider alternative approaches of removing the serial correlation. Kim (2015) suggested an ARMA model of order (p,q) as the mean equation.

Using an ARMA (p,q) approach restricted to a maximum of three autoregressive variables and three moving average variables, ARMA specifications which best fit were determined (those which give the lowest AIC). Although the SBIC yields more parsimonious models, it results in high serial correlation in the residuals of those models. The determined ARMA specifications are then used similarly tested for ARCH effects. The results are also given in Table 4.7. They show a stronger rejection of the null hypothesis of the LM test and indicate ARCH effects thus suggesting the use of ARCH and GARCH type models as efficient in describing the time series volatility. Also given in Table 4.7 are the final mean equations

specifications used in the mean equation of each series. The ARMA in mean approach is utilised and the resultant GARCH models are not serially correlated (see section 4.2).

Table 4. 7: Arch effects in mean equations of GARCH Models

	Random Walk Mean Equation	ARMA Mean Equation	
	P-Value (Random Walk)	P-Value (ARMA Mean)	RW/ARMA
Coal Price	0.0007	0.0507	(3,3)
SA Inflation	0.0000	0.0000	(3,2)
SA Exchange Rate	0.0966	0.0018	(2,3)
SA Interest Rates	0.0000	0.0000	RW
Natural Gas Price	0.0627	0.0066	(3,3)
Oil Price	0.0966	0.0966	RW

4.1.6. Granger causality tests between the time series data

Granger (1969) posited tests to determine causality between variables in a system. These are known as Granger Causality tests (Brooks, 2014) and entail the specification and simulation of bivariate regression based on predetermined lags of those variables in order to estimate the significance of one variable in the estimation of the other (Brooks, 2014; Hamilton, 1994). Table 4.8 shows the results of the Granger Causality analysis conducted for the data used in this study. From this we find that: First, inflation seems to Granger causes coal and natural gas prices, while there seems to be no Granger causality from energy commodity prices to inflation. Second, the Rand/Dollar exchange rate Granger causes only oil and coal prices while there are no impacts of these commodity prices on the Rand/Dollar exchange rates. Third, interest rates Granger cause oil prices while coal prices Granger cause interest rates. Fourth, in the long term, the Rand/Dollar exchange rate Granger causes the inflation rate. This is reduced in post-2008 data with a significance of 0.101 as shown in Table 4.8. In similitude, inflation Granger causes the Rand/Dollar exchange rate post-2008 and seemingly not in the long run. Fifth, interest rates Granger cause inflation in the long run and seemingly not post-2008. Sixth, interest rates only Granger cause exchange rates in the short run (post-2008).

Table 4. 8: Granger causality for the data set utilised in this study

Null Hypothesis:	**Natural Gas Price***			**Oil Price***			**Coal Price***		
	Obs	**F-Stat**	**Prob.**	**Obs**	**F-Stat**	**Prob.**	**Obs**	**F-Stat**	**Prob.**
DCPI2 does not Granger Cause **Commodity Price***	276	0.922	0.526	276	0.741	0.710	75	1.151	0.343
Commodity Price* does not Granger Cause DCPI2		1.690	**0.069**		1.540	0.110		2.097	**0.034**
DEXCHR does not Granger Cause **Commodity Price***	276	0.560	0.873	276	1.858	**0.040**	75	3.080	**0.003**
Commodity Price* does not Granger Cause DEXCHR		1.257	0.245		1.463	0.139		3.759	**0.000**
DINT does not Granger Cause **Commodity Price***	276	0.763	0.689	276	1.837	**0.043**	75	0.569	0.856
Commodity Price* does not Granger Cause DINT		1.232	0.261		0.700	0.751		3.232	**0.002**
DEXCHR does not Granger Cause DCPI2	276	2.274	**0.009**	276	2.274	**0.009**	84	1.656	0.101
DCPI2 does not Granger Cause DEXCHR		1.258	0.244		1.258	0.244		2.650	**0.007**
DINT does not Granger Cause DCPI2	276	4.495	**0.000**	276	4.495	**0.000**	84	0.845	0.605
DCPI2 does not Granger Cause DINT		0.862	0.587		0.862	0.587		1.641	0.105
DINT does not Granger Cause DEXCHR	276	0.445	0.944	276	0.445	0.944	84	2.457	**0.011**
DEXCHR does not Granger Cause DINT		0.695	0.756		0.695	0.756		1.442	0.173

4.1.7. Johansen Cointegration tests between the time series data

The last test conducted on the data is to establish the presence of cointegrating relationships between the times series data in the system (Johansen Cointegration tests) (Brooks, 2014). These tests are grouped into three based on trend (no trend, linear trend and quadratic trend). Within each grouping distinctions are then made on the existence of intercepts and/or trends in the cointegrating equation/s and/or the VAR/VECM regression. Table 4.9 below shows the results of the Johansen Cointegration tests conducted. From these tests, it is evident that there are at least six cointegrating relationships as shown by the trace statistic and eigenvalue estimates. These results aid us in the specification of our VECM.

Table 4. 9: A summary output for a Johansen Test for Cointegration done on a VAR system for commodity prices returns and South African macroeconomic fundamentals.

Data Trend:	None	None	Linear	Linear	Quadratic
Test Type	No Intercept	Intercept	Intercept	Intercept	Intercept
	No Trend	No Trend	No Trend	Trend	Trend
Trace	6	6	6	6	6
Max-Eig	6	6	6	6	6

4.2. Results

4.2.1. Vector Autoregressive and Vector Error Correction Models (The bidirectional relationship between energy commodity prices and South African macroeconomic fundamentals - Hypothesis 1 results)

In order to capture and model the effects of coal prices on the local economy in our VECM specification, we use the period 2008M01 to 2015M12. This is due to the limited data for coal prices (do not extend before 2008M01). Table 4.10 shows the VECM results for the energy commodity prices and South African macroeconomic fundamental system. From these results, it is evident that the coefficients of the cointegrating equations are mostly significant in the coal price equations. As shown in Figure 1.1 above, coal forms a substantial proportion of mining output in the country and should therefore be pertinent in the country's balance of payments and income. Simultaneously, the country is dependent on coal fired electricity generation. This would suggest a high correlation and strong cointegration between coal price returns and local macroeconomic variables. Alternatively, oil is a strong input into the local production. With Figure 1.2 and 1.3 showing reduction in oil production and increasing oil imports respectively, we expect that oil price changes will impact macroeconomic fundamentals. Natural gas, on the other hand, is produced, imported and used in low quantities and thus posited to have little effect of fundamentals.

From Table 4.10, it is evident that lagged coal price returns are insignificant in the system equations of all the other variables (including its own). This is a result of API 4 prices being determined at RBCT rather than in international markets. Such spot and over the counter trades are likely to be driven by local macroeconomic dynamics. This is shown in Table 4.10 where inflation rates propagate coal returns upward by 0.30 for every unit increase in inflation (significant at 5%). Alternatively, a unit change in natural gas price returns has a 0.065 (negative) impact on exchange rates (10% significance level). That is, as natural gas prices increase, the Rand tends to depreciate. On the other hand, oil prices appreciate the Rand by 0.104 (significant at the 10% level). Coudert and Mignon (2016) and Jawadi, Louhichi, Ameur, and Cheffou (2016) explain this using the correlation between oil prices and the US Dollar. Here they show a negative correlation which suggests that oil prices reduce as the Dollar appreciates and vice versa. Furthermore, oil returns are strong and positively significant on

their current prices (0.420 at the 1% level) and on inflation (0.213 at the 5% level). The latter is characteristic of economies which are dependent on oil and are themselves not a significant oil producer (such as is the case for South Africa) (Nkomo, 2006). Oil is a pertinent production input for the country and as such, an increase in its prices triggers increased production, transport and manufacturing costs. These increased costs result in an increase in prices and thus propagate inflation. Coudert and Mignon (2016) and Jawadi et al. (2016) postulate a negative correlation between oil prices and the US Dollar where a depreciation in the Dollar results in an appreciation in oil prices. Therefore, it can be deduced that an increase in oil prices inadvertently shows a depreciation in the Dollar. This is seen in Table 4.10 where an increase in oil prices is significant (at the 10% level) in reducing the exchange rate by 0.104.

The Taylor Rule is an economic-principled approach in which monetary policy (interest rate) is utilised to stabilise the economy. Beju and Ulici (2015) show that through this approach, the variance of the planned and actual targeted production output and inflation rates should be minimal. This approach can be utilised along with an inflation targeting regime to attain the desired interest rate in order to maintain inflation between desired target bands. In this regard, we find that inflation is significant (at the 10% level), attesting to the inflation targeting regime which was adopted in 2001. Van der Merwe (2004) argues that inflation targeting regimes could face a challenge of exchange rate stabilisation as fluctuating exchange rates have an impact on inflation.

Purchasing power parity which is the economic principle where a basket of goods are priced equally in two different countries when considering the exchange rate between the two countries. That is, when converting currencies between the two countries, the basket of good should cost the same. From this we see that as one currency strengthens in relation to the other, inflation in the country whose currency is weaker should increase to maintain the balance. Hegerty (2016) indicates the inflationary impact of exchange rates on the South African economy and relates these to the purchasing power parity principle. In Table 4.10, we find that the Rand/Dollar exchange rates are significant (at the 1% level) and inflationary (0.588). These exchange rates are also significant (5% level) in reducing oil prices (-0.587). Besides the aforementioned relationship between oil prices and the US Dollar, demand and supply dynamics are also expected to have a role in the oil price. A depreciating Rand increases the

Rand value of oil prices thus reducing the quantity which can be attained. More cash (Rand denominated) will be required to satisfy demand. Van der Merwe (2004) furthers this by arguing that this, combined with high indebtedness in foreign denomination currency, incentivises developing countries to target exchange rate. This is in tandem with the aim of reducing the amount of repayments due (in local currency terms) and the impact of imported inflation.

Table 4. 10: Vector error correction estimates to determine the effects of coal prices on the South African macroeconomic fundamentals

Vector Error Correction Model						
	Coal Price Eq.	**Nat. Gas Price Eq.**	**Oil Price Eq.**	**SA CPI Eq.**	**SA Fx. Rate Eq.**	**SA Int. Rate Eq.**
CointEq1	-0,287 [0,072]***	-0,267 [0,106]**	0,084 [0,075]	-0,052 [0,052]	0,017 [0,033]	0,002 [0,020]
CointEq2	0,028 [0,047]	-0,233 [0,070]***	0,101 [0,049]**	-0,034 [0,034]	-0,030 [0,022]	0,017 [0,013]
CointEq3	0,112 [0,081]	0,377 [0,121]***	-0,316 [0,085]***	0,141 [0,059]**	0,056 [0,037]	0,007 [0,023]
CointEq4	-0,120 [0,060]**	-0,176 [0,090]*	0,140 [0,063]**	-0,150 [0,044]***	-0,038 [0,028]	0,002 [0,017]
CointEq5	-0,172 [0,067]**	-0,064 [0,100]	-0,173 [0,071]**	0,059 [0,049]	0,045 [0,031]	0,042 [0,019]**
Coal (-1)	-0,095 [0,112]	0,030 [0,166]	-0,181 [0,117]	-0,032 [0,081]	-0,065 [0,051]	-0,013 [0,032]
Natgas (-1)	-0,011 [0,075]	0,089 [0,112]	-0,045 [0,079]	-0,010 [0,055]	0,065 [0,034]*	0,038 [0,021]*
Oil (-1)	0,185 [0,115]	-0,104 [0,170]	0,420 [0,120]***	0,213 [0,084]**	-0,104 [0,053]*	-0,004 [0,033]
SA Inflation (-1)	0,303 [0,125]**	0,248 [0,186]	0,056 [0,132]	0,397 [0,091]***	0,079 [0,058]	0,065 [0,036]*
SA Exch. Rate (-1)	0,039 [0,256]	-0,074 [0,380]	-0,587 [0,269]**	0,588 [0,187]***	0,040 [0,118]	0,033 [0,074]
SA Int. rate (-1)	0,380 [0,341]	-0,427 [0,506]	0,445 [0,358]	0,117 [0,249]	0,029 [0,158]	0,305 [0,099]***
C	-0,002 [0,008]	-0,008 [0,012]	0,001 [0,008]	-0,005 [0,006]	0,007 [0,003]**	-0,002 [0,002]

Notes: 1) ******* is 1% Significance level; ****** is 5% Significance level & ***** is 10% Significance level

2) In […] are Standard Error terms

3) Eq. is Equation

4) (-1) . . . (-5) are lags of that respective variable in the equation

Serial correlation analysis conducted using the Lagrange Multiplier analysis method (Table 4.11) shows that the residuals of the VECM model above are not autocorrelated. Brooks (2014) shows that the null hypothesis under these tests is that of no autocorrelation. Therefore, the high probability values show an inability to reject the null hypothesis. Brooks (2014) and Rezitis and Ahammad (2015) show that a high probability for the LM statistic is indicative of no autocorrelation.

Table 4. 11: The serial correlation for the VECM system between coal prices and South African macroeconomic fundamentals

Lags	LM-Stat	Prob
1	49.348	0.068
2	41.175	0.254
3	37.610	0.395
4	43.757	0.175

4.2.2. The volatility spillover between energy commodity prices and South African macroeconomic fundamentals: The MGARCH approach (Hypothesis 2 results)

Due to the aforementioned lack of coal price data and the requirement of large data for MGARCH type models (Brooks, 2014), we construct our MGARCH model for oil, natural gas, interest rate, exchange rates and inflation and extend the period to 1993M01 (all variables data available from this period). As previously discussed, Appendix 2 gives the variance equations derived from the conditional variance equation given by Kim (2015); Hegerty (2016) and Brooks (2014). Here the impact of the ARCH or innovation (ε^2_{nt-1}) and GARCH (h_{nt-1}) terms are of interest in measuring direct and indirect spillover. Li (2015) shows that this model tests the null hypothesis that the off diagonal terms in the matrix of coefficients are equal to zero. Therefore, a low p-value rejects the null hypothesis in favour of the alternative that the off-diagonal terms in the coefficients matrices are significantly different from zero. Hegerty (2016) acknowledges the importance of conditional correlation as an indication of relationship between the variables but argues that the coefficients in the variance calculation (Appendix 2) are stronger indications. In this section, we distinguish between positive (reducing volatility)

and negative (increasing volatility) ARCH and GARCH effects on conditional variance of the dependent variable.

Table 4.12 shows the results of our MGARCH analysis. Here we see that although all innovations or indirect spillovers (depicted by matrix a_{ij} elements) are significant in the system, they have a low amplitude and thus an overall low impact on the respective variance equations. Similarly, the direct or GARCH spillovers (depicted by matrix b_{ij} elements) generally have a higher amplitude and thus show more direct spillovers as compared to indirect. We will focus on these.

Oil's previous volatility has a strong negative impact on its present volatility (0.74***) and on natural gas price volatility (1.383***). This shows persistence in oil price volatility and its dominance in the energy commodity market. To substantiate this, the volatility in natural gas prices is found to reduce oil price volatility by -0.168(***). The lower magnitude of the latter as compared to the former shows that oil prices have a stronger impact on natural gas prices than vice versa. Also, the reduction in volatility of oil prices when naturals gas prices increase suggests a strong one directional movement in oil prices. Interest rates are shown to have a substantial impact on oil price volatility (1.082***). This can be explained by South Africa's position as an oil consumer (~28th highest consumer in the world) and the exchange rate channel. Here higher interest rates reduce money supply and increase the value of the local currency relative to the US Dollar (in which oil is denominated) (van der Merwe, 2004; Mohanty & Klau, 2004). This results in a local increase in demand for oil which in turn propagates price volatility through price discovery dynamics. The negative impact of exchange rates on oil price volatility (0.211***) is testament to this fact. Similarly, previous interest rate volatility has a strong negative impact on natural gas price volatility (2.778***). The CPI also increases oil price volatility, although to a lesser extent (0.057***). Unlike oil prices, natural gas price's previous volatility is found to reduce its present volatility (-0.36***).

Due to the currency impact defined above, interest rate volatility is found to have a significant negative impact on CPI volatility (0.135***). This is substantiated by the sign and magnitude of the exchange rate volatility impact on CPI volatility (0.163***). The strongest contributor to CPI volatility in this system is found to be previous CPI volatility (0.349***). Oil is the only commodity which impacts on CPI volatility (-0.101***). This reduction in volatility arises due to the inflationary impact of an increase in oil prices. Misati et al. (2013) found that oil prices are significant and inflationary in net oil importing economies such as South Africa.

Only the South African macroeconomic fundamentals have direct spillover to the interest rate and exchange rates. CPI volatility tends to decrease interest rate volatility (-0.173***). This is due to the country's inflation targeting regime. As CPI volatility increases, monetary policy is expected to take a position (on interest rates) that will maintain the inflation within the desired band. For similar reasons, monetary policy is expected to take a position based on the exchange rate stabilisation motif defined by van der Merwe (2004) and Mohanty and Klau (2004). This will result in exchange rate volatility having a positive impact on the interest rate volatility as shown (-0.168***). Previous interest rate volatility is shown to be persistent within the South African context (0.701***). This is found to be the same for exchange rate volatility (0.740***).

Table 4. 12: Multivariate GARCH results for a system of oil prices, natural gas prices, SA inflation, SA interest rates and SA Rand/Dollar exchange rates.

Code Element	Matrix Element	Measured Variable	Coefficient	z-Statistic
MU(1)			-10.399	[-55.13]***
MU(2)			55.332	[99.95]***
MU(3)			13.731	[137.59]***
MU(4)			17.229	[69.8]***
MU(5)			57.062	[133.29]***
OMEGA(1)	o11		1.125	[12.58]***
ALPHA(1)	a11	Oil Spillover to Oil	0.017	[53.21]***
ALPHA(2)	a12	Natgas Spillover to Oil	0.006	[31.94]***
ALPHA(3)	a13	CPI Spillover to Oil	0.004	[63.55]***
ALPHA(4)	a14	Interest Spillover to Oil	0.035	[50.98]***
ALPHA(5)	a15	Exchange Spillover to Oil	-0.013	[-33.5]***
BETA(1)	b11	Oil direct spill to Oil	0.740	[31.65]***
BETA(2)	b12	Natgas direct spill to Oil	-0.168	[-17.49]***
BETA(3)	b13	CPI direct spill to Oil	0.057	[3.23]***
BETA(4)	b14	Interest direct spill to Oil	1.082	[14.34]***
BETA(5)	b15	Exchange direct spill to Oil	0.211	[4.17]***
OMEGA(2)	o21		3.378	[17.13]***
ALPHA(6)	a21	Oil Spillover to Natgas	-0.013	[-14.48]***
ALPHA(7)	a22	Natgas Spillover to Natgas	0.034	[62.81]***
ALPHA(8)	a23	CPI Spillover to Natgas	0.012	[59.46]***
ALPHA(9)	a24	Interest Spillover to Natgas	0.161	[89.05]***
ALPHA(10)	a25	Exchange Spillover to Natgas	-0.094	[-79.62]***
BETA(6)	b21	Oil direct spill to Natgas	1.383	[23.71]***
BETA(7)	b22	Natgas direct spill to Natgas	-0.365	[-15.54]***
BETA(8)	b23	CPI direct spill to Natgas	0.112	[2.07]**
BETA(9)	b24	Interest direct spill to Natgas	2.778	[13.82]***
BETA(10)	b25	Exchange direct spill to Natgas	0.135	[1.07]
OMEGA(4)	o41		0.382	[13.27]***
ALPHA(11)	a31	Oil Spillover to CPI	-0.004	[-45.47]***
ALPHA(12)	a32	Natgas Spillover to CPI	0.008	[129.32]***
ALPHA(13)	a33	CPI Spillover to CPI	0.003	[146.62]***
ALPHA(14)	a34	Interest Spillover to CPI	-0.037	[-154.41]***
ALPHA(15)	a35	Exchange Spillover to CPI	0.003	[18.47]***
BETA(11)	b31	Oil direct spill to CPI	-0.101	[-8.59]***
BETA(12)	b32	Natgas direct spill to CPI	-0.003	[-0.86]
BETA(13)	b33	CPI direct spill to CPI	0.349	[31.54]***
BETA(14)	b34	Interest direct spill to CPI	0.135	[4]***
BETA(15)	b35	Exchange direct spill to CPI	0.163	[12.26]***
OMEGA(7)	o51		0.346	[7.83]***
ALPHA(16)	a41	Oil Spillover to Interest	0.001	[5.93]***
ALPHA(17)	a42	Natgas Spillover to Interest	0.001	[9.46]***
ALPHA(18)	a43	CPI Spillover to Interest	0.001	[11.34]***
ALPHA(19)	a44	Interest Spillover to Interest	0.028	[37.08]***
ALPHA(20)	a45	Exchange Spillover to Interest	-0.011	[-36.26]***
BETA(16)	b41	Oil direct spill to Interest	-0.001	[-0.06]
BETA(17)	b42	Natgas direct spill to Interest	-0.007	[-1.5]

BETA(18)	b43	CPI direct spill to Interest	-0.173	[-15.49]***
BETA(19)	b44	Interest direct spill to Interest	0.701	[24.75]***
BETA(20)	b45	Exchange direct spill to Interest	-0.168	[-9.93]***
OMEGA(11)	o11		-0.346	[-3.18]***
ALPHA(21)	a51	Oil Spillover to Exchange	-0.008	[-31.78]***
ALPHA(22)	a52	Natgas Spillover to Exchange	-0.004	[-29.24]***
ALPHA(23)	a53	CPI Spillover to Exchange	-0.005	[-44.47]***
ALPHA(24)	a54	Interest Spillover to Exchange	-0.012	[-14.67]***
ALPHA(25)	a55	Exchange Spillover to Exchange	0.007	[18.9]***
BETA(21)	b51	Oil direct spill to Exchange	0.000	[0.02]
BETA(22)	b52	Natgas direct spill to Exchange	0.006	[0.99]
BETA(23)	b53	CPI direct spill to Exchange	-0.102	[-6.97]***
BETA(24)	b54	Interest direct spill to Exchange	-0.149	[-3.69]***
BETA(25)	b55	Exchange direct spill to Exchange	0.740	[39.04]***
OMEGA(3)	o22		0.647	[2.35]**
OMEGA(5)	o32		-0.344	[-2.95]***
OMEGA(8)	o42		0.192	[1.75]*
OMEGA(12)	o52		-0.237	[-1.09]
OMEGA(6)	o33		0.261	[2.38]**
OMEGA(9)	o43		0.533	[2.34]**
OMEGA(13)	o53		-0.140	[-0.76]
OMEGA(10)	o44		-0.276	[-0.76]
OMEGA(14)	o54		-0.593	[-0.54]
OMEGA(15)	o55		0.364	[0.08]

Log likelihood	98 915.79
Avg. log likelihood	361.01
Number of Coefs.	70.00
Akaike info criterion	-721.50
Schwarz criterion	-720.58
Hannan-Quinn criter.	-721.13

Notes: 1) ******* is 1% Significance level; ****** is 5% Significance level & ***** is 10% Significance level

2) In […] are z-statistic terms

4.2.2.1. Serial correlation for all GARCH (1.1) models used in MGARCH analysis

We use the Ljung Box Q-statistics (equation 4.1) to measure the presence of the serial correlation using the ACF determined from each models' correlogram. Brooks (2014) shows that the null hypothesis for this statistic is one of no serial correlation. Table 4.16 shows that we cannot reject the null hypothesis at any significance level as the statistic is less than the Chi-squared distribution test statistic.

$$Q = T(T+2)\sum_{k=1}^{12}\frac{ACF^2}{(T-k)} \tag{4.1}$$

Table 4. 13: The Ljung Box Q-statistic for GARCH models used in the MGARCH model

	Ljung Box - Qstat	t-stat chi^2		
		0.1	0.05	0.01
Natgas Price	18.422	18.540	21.026	26.217
Oil Price	5.609	18.540	21.026	26.217
SA Inflation	10.031	18.540	21.026	26.217
SA Interest	2.733	18.540	21.026	26.217
SA Exchange Rate	8.325	18.540	21.026	26.217

5. CHAPTER 5: IMPLICATIONS, CONCLUSION AND LIMITATIONS OF THE STUDY

5.1. The impact of our results on stakeholders and possible strategy and/or policy reforms

5.1.1. Commodity producers

From our VECM results, we find that inflation has a strong impact on coal prices at RBCT. That is, an increase in inflation causes an increase in coal prices. All the while oil prices have an impact on inflation and exchange rates. This is supported by the innovation and direct volatility spillover from oil to CPI (found in the MGARCH model). Against this background, we conclude that coal-exporting corporations, which have long-term coal-exporting contracts, are exposed to production cost implications of higher oil prices, increased inflation and a depreciating rand. Corporations which entered into long-term contracts prior to or immediately post the 2008 super-cycle (shown in Figure 1.4) were unable to exploit the upturn in commodity prices. Similarly, the depreciating Rand and a drastically lowered demand most adversely impacted them during the commodity price down turn.

Among the plethora of examples on the impact of these conventional hedging strategies is South African Airways (SAA) which hedged oil (a pertinent input in their production process). As a result of this, they were unable to exploit plummeting oil prices but were rather further debilitated by the depreciating Rand. The hedging costs incurred were dire. These conventional hedging strategies of fixing prices for the long-term, as deployed by SAA, do not suffice in present day commodity markets. More innovative hedging strategies using derivatives (such as futures and options) contracts in the futures markets are suggested as pertinent tools for consideration by government organisations (such as SAA) and commodity producers in South Africa. These are cost effective solutions which can be sold when "out of or in the money" and avail the option to execute when in the money or when the underlying asset is required. With these, contracts losses such as those incurred by SAA and commodity producers in South Africa can be minimised and controlled by the corporations without being faced with challenges of repudiating on contracts. Added to this, commodity producers should use the spot market as a means of sales rather than entering into long-term coal contracts.

5.1.2. Government budget, the economy at large, households and welfare

The South African government's main sources of income are corporate and individual taxes and valued added tax (VAT). Although mining's contribution to the South African economy has deteriorated (with finance playing a more pertinent role), mining remains an important source of employment and foreign earnings. Volatility in energy commodity prices therefore present adverse impacts on the South African economy and can thus result in reduced growth, increase in unemployment (through Okun's law), increased poverty, increased Gini coefficient and a lowered government income (through reduced corporate and individual taxes). The fundamental impact of the latter is on fiscal policy where the government may be motivated to increase taxes such as sin tax, individual tax, and VAT. Recent debates on wealth tax and increasing VAT in South Africa are testament to the impact which commodity prices have on commodity exporting economies. Other adverse impacts include reduced government spending which usually stagnates economic activity and exacerbates the debilitated economy.

Our finding that there is a strong direct volatility spillover from oil volatility to CPI shows that production cost increases will arise as oil is a pertinent input into the production and transportation sectors. These increased costs will result in reduced taxable income (corporate taxes) as operational costs are deducted prior to taxes. Furthermore, reduced earnings can translate into increased retrenchments and therefore reduced household incomes and inadvertently adverse welfare ramifications. Through the country's inflation targeting regime, monetary policy may be tempted to counter commodity price induced inflation by increasing interest rates. This could possibly increase the value of the Rand by attracting foreign investments. Capital flight from countries such as the US to South Africa will depreciate their respective currencies (U.S. Dollar) relative to the Rand which will translate into a further increase in oil prices. Coudert and Mignon (2016) show that oil prices are inversely correlated to the US Dollar. From such an increase, local inflation is expected to further increase. This could result in a snowball effect. As an example, a stronger local currency makes imports cheaper and thus results in increased imports as compared to exports. The effect this will have on the current account and the balance of payments is dire. Monetary policy stakeholders should understand the drivers of inflation before reacting to inflation. This curing the symptoms approach may be detrimental to the economy if misused. The fine balance between

favourable exchange rates and desired inflation rates should be attained. The impact of decisions on the balance of payments, consumption dynamics, economic activity and stability should be the primary drivers of monetary policy.

Recent amendments to South Africa's Mineral Resources Act (MPRDA) allow and reduce restrictions on and promote oil and gas exploration in the country. This is expected to play an important role in attracting foreign direct investments into offshore exploration for the aforementioned commodities. The success of such exploration initiatives will increase the country's production of these commodities and further its position as a producer. This will reduce dependence on oil and gas imports. Although initiating a furore, other initiatives such as the Shell fracking (shale gas) exploration project in the Karoo (currently on hold) have potential to reduce the country's dependence on energy commodities imports. Furthermore, the employment opportunities which can be expected to arise from such mining activities will be to the benefit of the surrounding societies. We acknowledge that environmental implications have to be considered for these to be successes.

5.2. Conclusion for the study

Our study finds that Hypothesis 1 cannot be rejected in the case of oil and natural gas as found by our VECM results. Our MGARCH results prove the existence of volatility spillover between our variables. We found strong bidirectional volatility spillover between oil and inflation; oil and naturals gas; exchange rates and inflation; interest rates and inflation; and exchange rates and interest rates. The other spillovers found were unidirectional. We therefore cannot reject our Hypothesis 2.

We conclude that the energy commodity prices have impact on, and are impacted by, South African macroeconomic fundamentals. In line with van der Misati et al. (2013), van der Merwe (2004) and Mohanty and Klau (2004), it is important for monetary and fiscal policy to distinguish which triggers warrant a response and which do not. As stated in their findings, the exchange rate stabilisation which most emerging market economies find themselves adopting

could result in unnecessary interest changes which can be detrimental to the economy (van der Merwe. 2004). As shown in our findings, commodity prices, such as oil and natural gas have an impact on exchange rates and inflation. Their volatility could thus adversely affect monetary policy if leaders are unaware of which triggers require a response and which do not.

From our system of variables, only oil has direct volatility spillover into other variables (interest rates and inflation respectively). Other direct volatility spills are those of both oil and natural gas prices on themselves and each other and between all the macroeconomic fundamentals. Our findings corroborate with those of Hegerty (2016). Although South Africa, like most emerging markets economies, is dependent on the production and sale of raw materials and commodities, it is not a commodity economy (defined as a strong relationship between the commodity produced and macroeconomic fundamentals). Rather it is a diversified economy which is only affected by commodity price volatility mainly due to its position as a net importer of oil (Misati et al. 2013). An important finding that requires careful consideration by the local government is the strong influence which oil prices have on the South African economy. Misati et al. (2013) found considerable impacts of oil prices on net oil-importing economies such as South Africa.

5.3. Limitations of the study

The fundamental challenge of this study was the lack of coal data before 2008. This has made it difficult to include coal as a variable in the MGARCH analyses. Restricting the MGARCH model to the period 2008M01 to 2016M06 resulted in system coefficients which are more than the amount of data points available for analysis. A possible solution is to attain high frequency data and model with low frequency data as done by Engle and Rangel (2008). Another suggestion would be the use of multiple Bivariate GARCH models to study short term relationships.

6. APPENDICES

6.1. Appendix 1: Volatility Impulse Response Functions - VECM

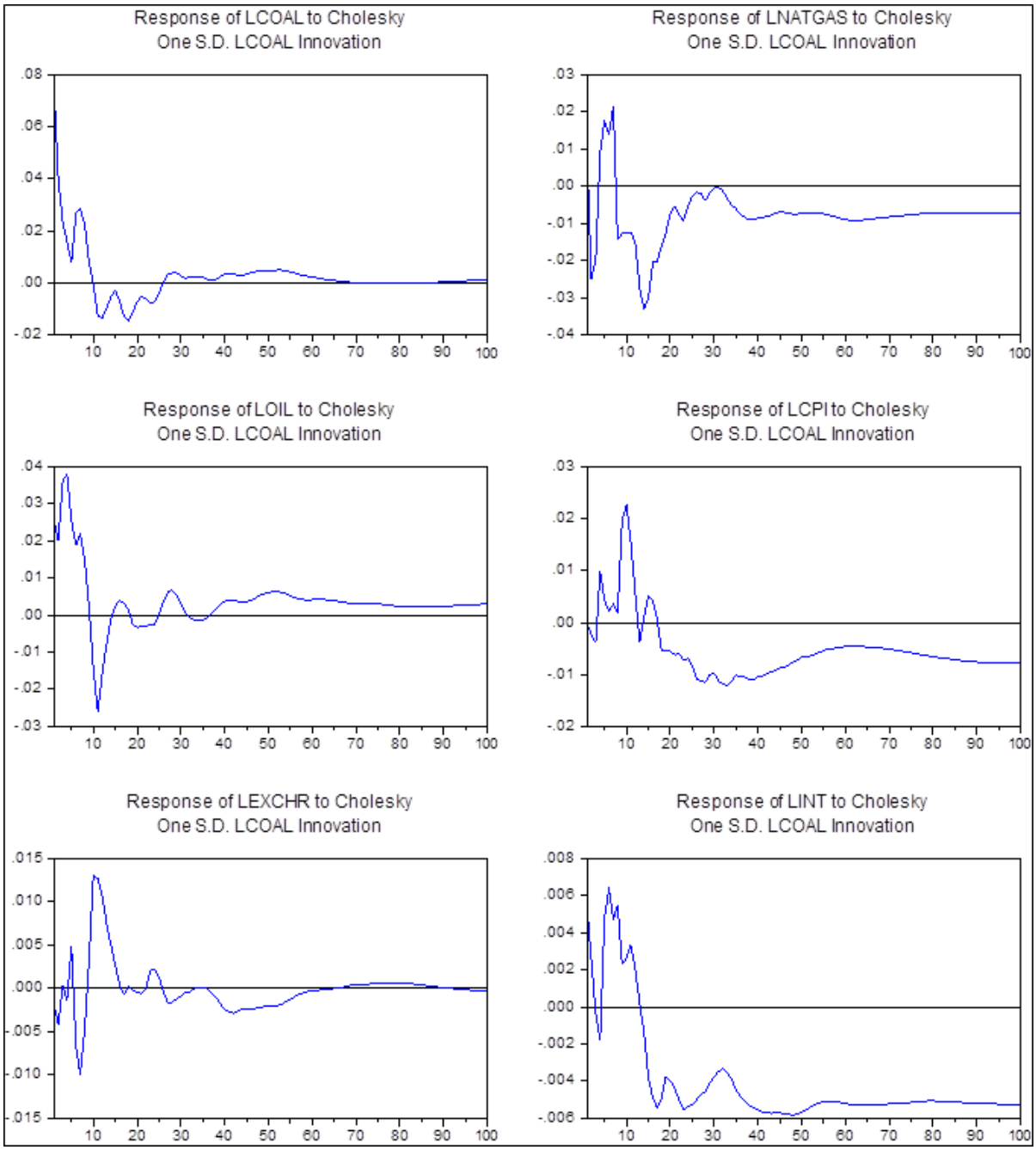


Figure 6. 1: Impulse Response Function of all variables to a coal price shock

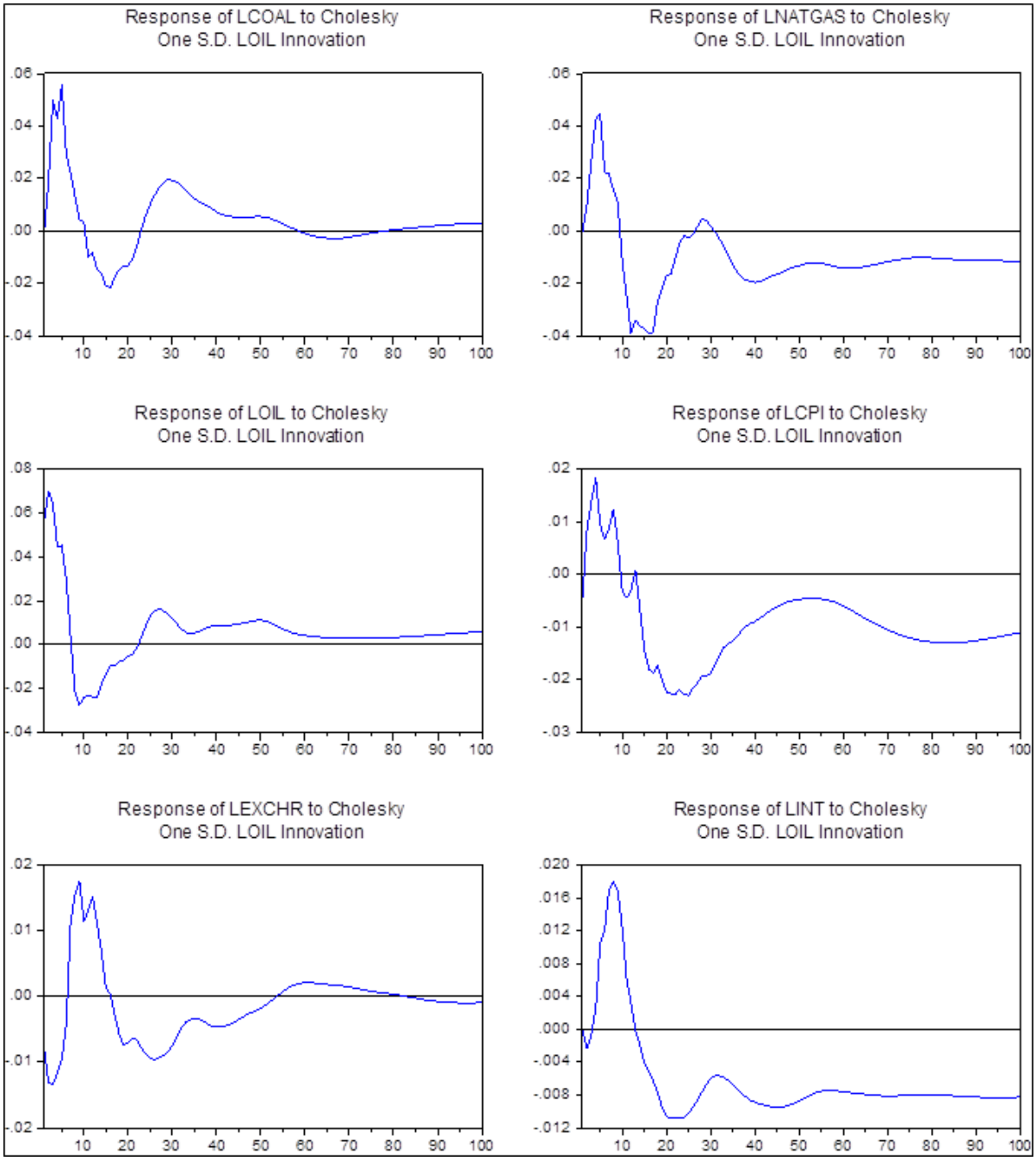


Figure 6. 2: Impulse Response Function of all variables to an oil price shock

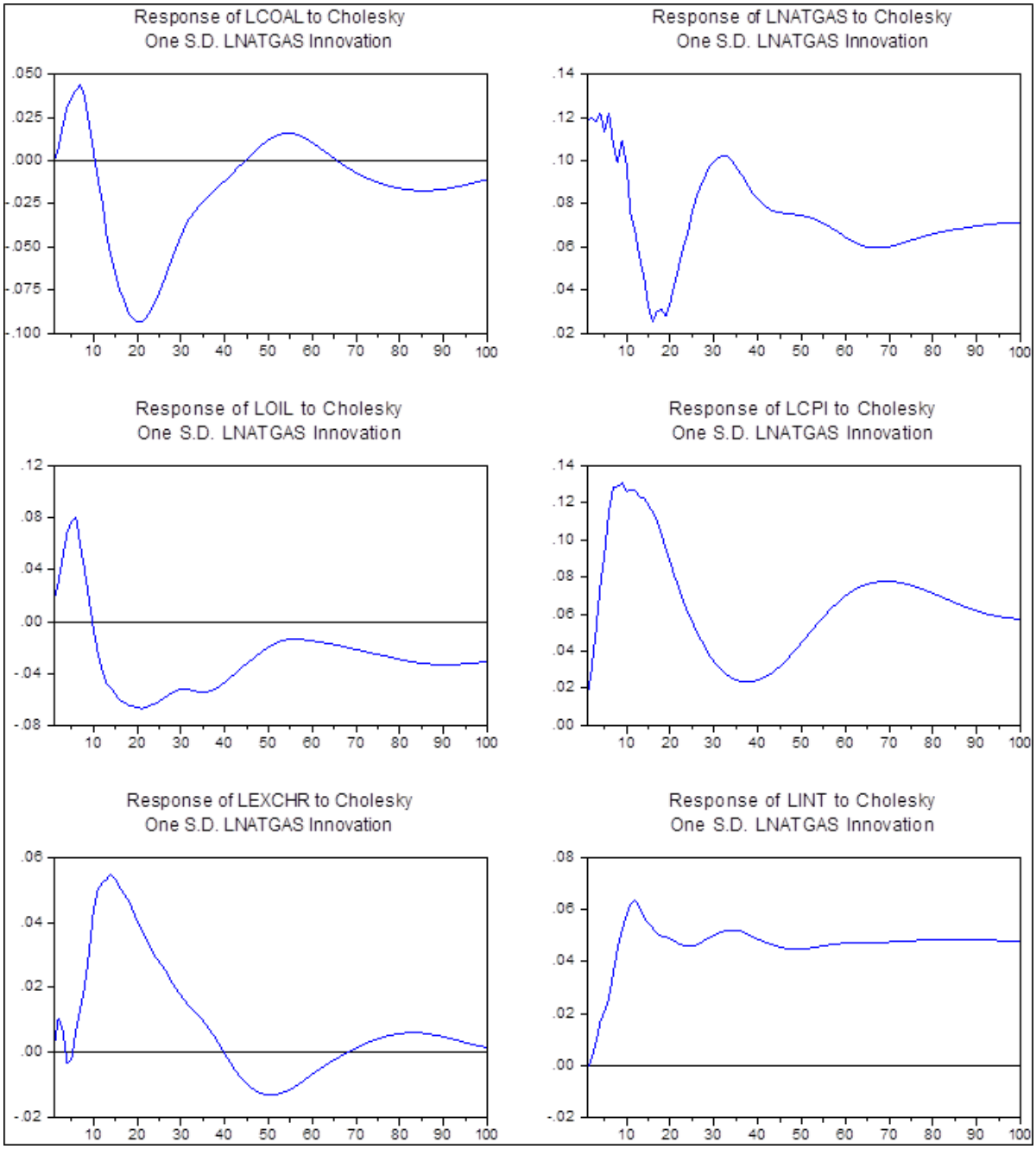


Figure 6. 3: Impulse Response Function of all variables to a natural gas price shock

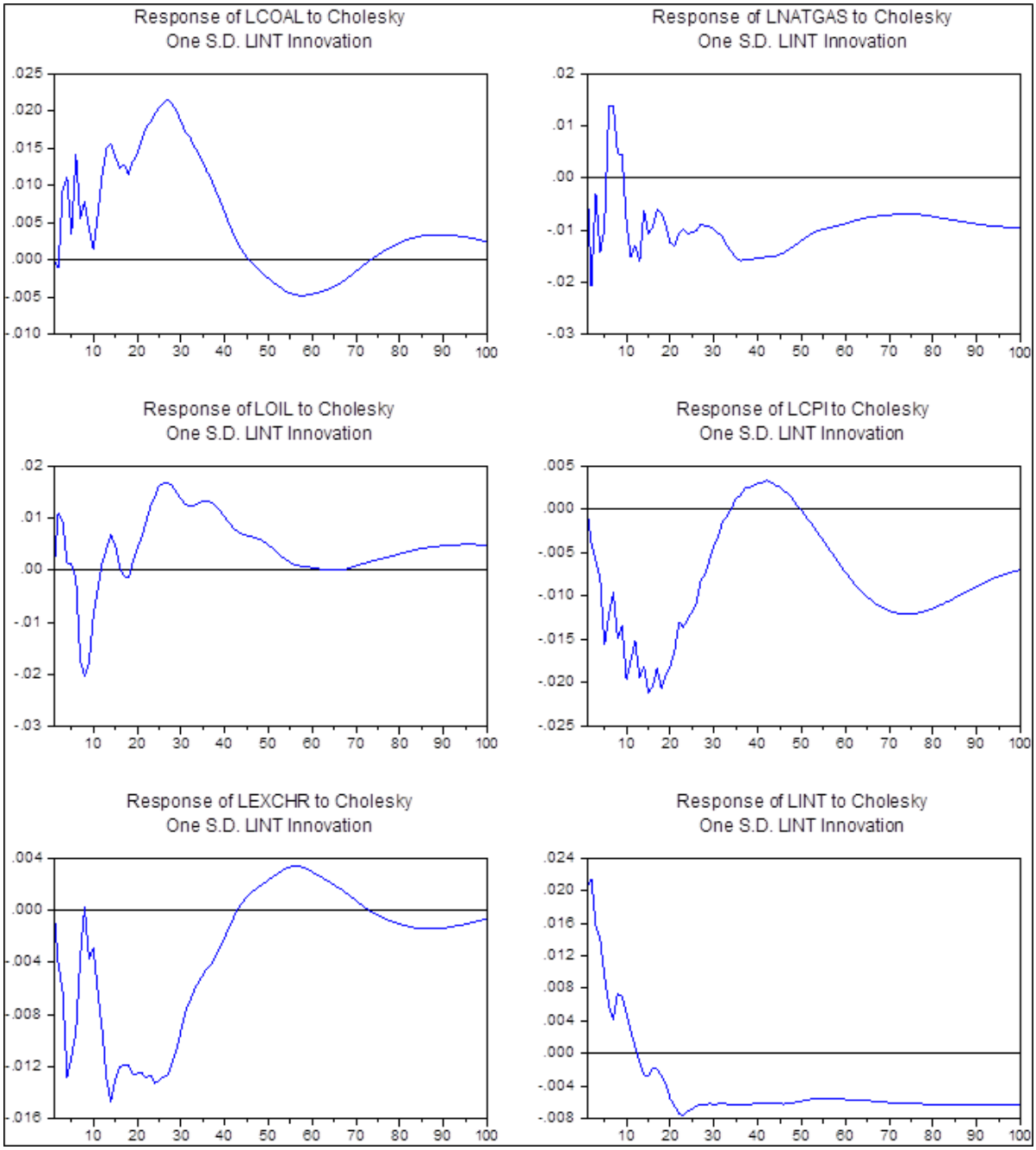


Figure 6. 4: Impulse Response Function of all variables to an interest rate shock

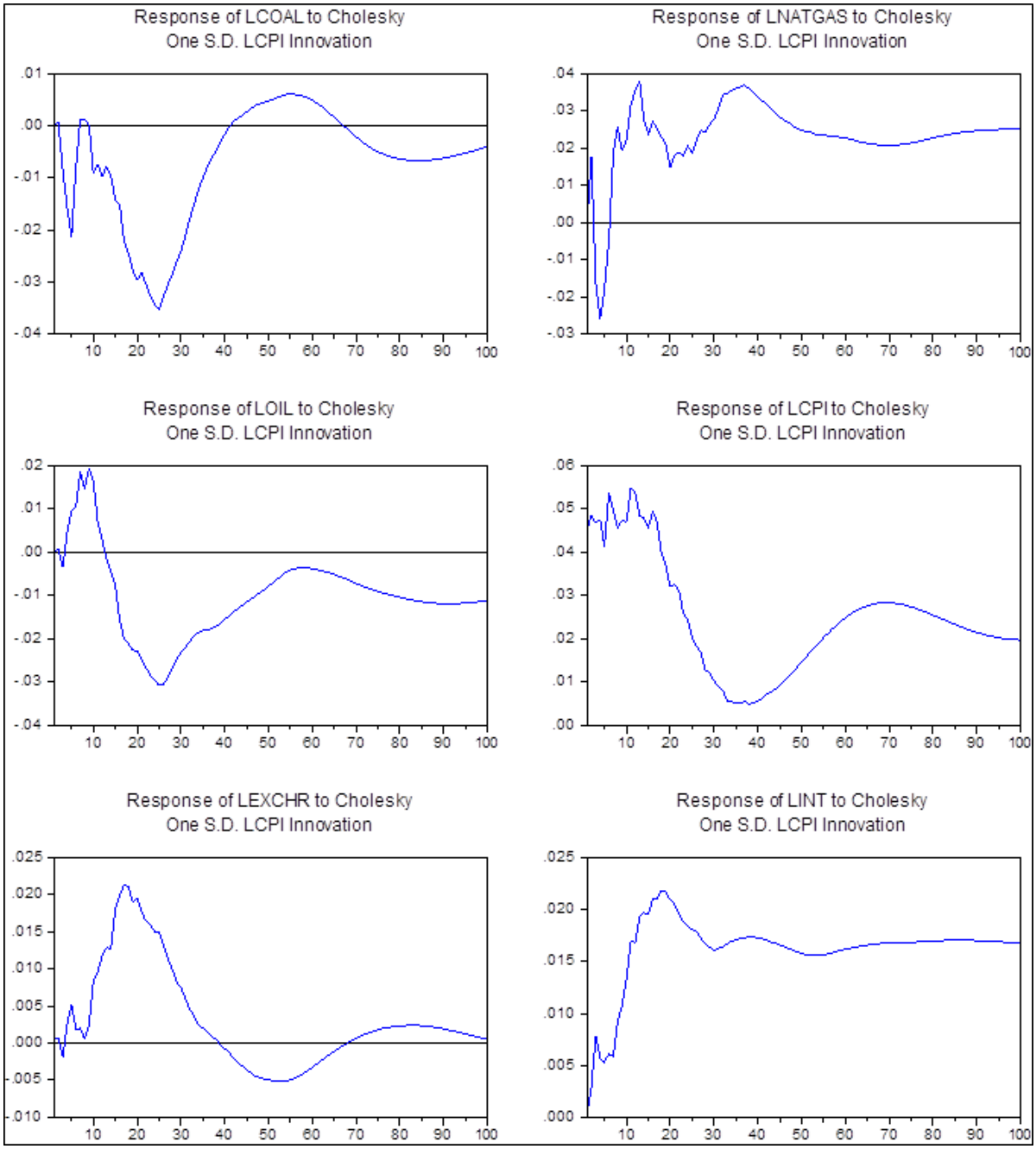


Figure 6. 5: Impulse Response Function of all variables to an inflation rate shock

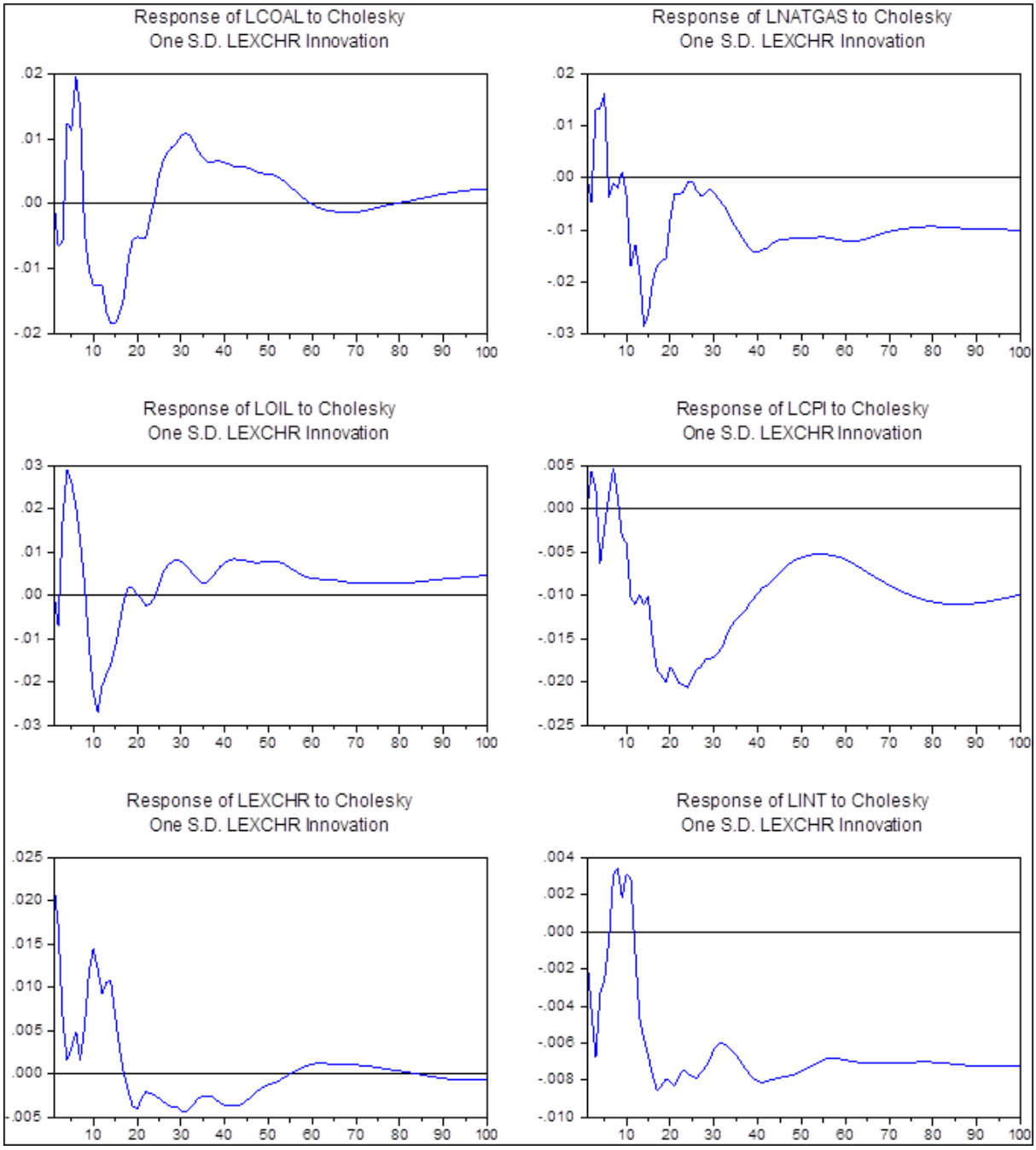


Figure 6. 6: Impulse Response Function of all variables to an exchange rate shock

6.2. Appendix 2: Variance formulas arising from HT matrix formula (equation 3.20)

$$h_{11} = c_{11}^2 + a_{11}^2\varepsilon_{1t-1}^2 + 2a_{11}a_{12}\varepsilon_{2t-1}\varepsilon_{1t-1} + 2a_{11}a_{13}\varepsilon_{3t-1}\varepsilon_{1t-1} + 2a_{11}a_{14}\varepsilon_{4t-1}\varepsilon_{1t-1} + 2a_{11}a_{15}\varepsilon_{5t-1}\varepsilon_{1t-1} + a_{12}^2\varepsilon_{2t-1}^2 + 2a_{12}a_{13}\varepsilon_{3t-1}\varepsilon_{2t-1} + 2a_{12}a_{14}\varepsilon_{4t-1}\varepsilon_{2t-1} + 2a_{12}a_{15}\varepsilon_{5t-1}\varepsilon_{2t-1} + a_{13}^2\varepsilon_{3t-1}^2 + 2a_{13}a_{14}\varepsilon_{4t-1}\varepsilon_{3t-1} + 2a_{13}a_{15}\varepsilon_{5t-1}\varepsilon_{3t-1} + a_{14}^2\varepsilon_{4t-1}^2 + 2a_{14}a_{15}\varepsilon_{5t-1}\varepsilon_{4t-1} + a_{15}^2\varepsilon_{5t-1}^2 + b_{11}^2h_{11t-1} + 2b_{11}b_{12}h_{12t-1} + 2b_{11}b_{13}h_{13t-1} + 2b_{11}b_{14}h_{14t-1} + 2b_{11}b_{15}h_{15t-1} + b_{12}^2h_{22t-1} + 2b_{12}b_{13}h_{32t-1} + 2b_{12}b_{14}h_{42t-1} + 2b_{12}b_{15}h_{52t-1} + b_{13}^2h_{33t-1} + 2b_{13}b_{14}h_{43t-1} + 2b_{13}b_{15}h_{53t-1} + b_{14}^2h_{44t-1} + 2b_{14}b_{15}h_{54t-1} + b_{15}^2h_{55t-1}$$

$$h_{22} = c_{21}^2 + c_{22}^2 + a_{21}^2\varepsilon_{1t-1}^2 + 2a_{21}a_{22}\varepsilon_{2t-1}\varepsilon_{1t-1} + 2a_{21}a_{23}\varepsilon_{3t-1}\varepsilon_{1t-1} + 2a_{21}a_{24}\varepsilon_{4t-1}\varepsilon_{1t-1} + 2a_{21}a_{25}\varepsilon_{5t-1}\varepsilon_{1t-1} + a_{22}^2\varepsilon_{2t-1}^2 + 2a_{22}a_{23}\varepsilon_{3t-1}\varepsilon_{2t-1} + 2a_{22}a_{24}\varepsilon_{4t-1}\varepsilon_{2t-1} + 2a_{22}a_{25}\varepsilon_{5t-1}\varepsilon_{2t-1} + a_{23}^2\varepsilon_{3t-1}^2 + 2a_{23}a_{24}\varepsilon_{4t-1}\varepsilon_{3t-1} + 2a_{23}a_{25}\varepsilon_{5t-1}\varepsilon_{3t-1} + a_{24}^2\varepsilon_{4t-1}^2 + 2a_{24}a_{25}\varepsilon_{5t-1}\varepsilon_{4t-1} + a_{25}^2\varepsilon_{5t-1}^2 + b_{21}^2h_{11t-1} + 2b_{21}b_{22}h_{12t-1} + 2b_{21}b_{23}h_{13t-1} + 2b_{21}b_{24}h_{14t-1} + 2b_{21}b_{25}h_{15t-1} + b_{22}^2h_{22t-1} + 2b_{22}b_{23}h_{32t-1} + 2b_{22}b_{24}h_{42t-1} + 2b_{22}b_{25}h_{52t-1} + b_{23}^2h_{33t-1} + 2b_{23}b_{24}h_{43t-1} + 2b_{23}b_{25}h_{53t-1} + b_{24}^2h_{44t-1} + 2b_{24}b_{25}h_{54t-1} + b_{25}^2h_{55t-1}$$

$$h_{33} = c_{31}^2 + c_{32}^2 + c_{33}^2 + 2a_{31}a_{32}\varepsilon_{2t-1}\varepsilon_{1t-1} + 2a_{31}a_{33}\varepsilon_{3t-1}\varepsilon_{1t-1} + 2a_{31}a_{34}\varepsilon_{4t-1}\varepsilon_{1t-1} + 2a_{31}a_{35}\varepsilon_{5t-1}\varepsilon_{1t-1} + a_{32}^2\varepsilon_{2t-1}^2 + 2a_{32}a_{33}\varepsilon_{3t-1}\varepsilon_{2t-1} + 2a_{32}a_{34}\varepsilon_{4t-1}\varepsilon_{2t-1} + 2a_{32}a_{35}\varepsilon_{5t-1}\varepsilon_{2t-1} + a_{33}^2\varepsilon_{3t-1}^2 + 2a_{33}a_{34}\varepsilon_{4t-1}\varepsilon_{3t-1} + 2a_{33}a_{35}\varepsilon_{5t-1}\varepsilon_{3t-1} + a_{34}^2\varepsilon_{4t-1}^2 + 2a_{34}a_{35}\varepsilon_{5t-1}\varepsilon_{4t-1} + a_{35}^2\varepsilon_{5t-1}^2 + b_{31}^2h_{11t-1} + 2b_{31}b_{32}h_{12t-1} + 2b_{31}b_{33}h_{13t-1} + 2b_{31}b_{34}h_{14t-1} + 2b_{31}b_{35}h_{15t-1} + b_{32}^2h_{22t-1} + 2b_{32}b_{33}h_{32t-1} + 2b_{32}b_{34}h_{42t-1} + 2b_{32}b_{35}h_{52t-1} + b_{33}^2h_{33t-1} + 2b_{33}b_{34}h_{43t-1} + 2b_{33}b_{35}h_{53t-1} + b_{34}^2h_{44t-1} + 2b_{34}b_{35}h_{54t-1} + b_{35}^2h_{55t-1}$$

$$h_{44} = c_{41}^2 + c_{42}^2 + c_{43}^2 + c_{44}^2 + a_{41}^2\varepsilon_{1t-1}^2 + 2a_{41}a_{42}\varepsilon_{2t-1}\varepsilon_{1t-1} + 2a_{41}a_{43}\varepsilon_{3t-1}\varepsilon_{1t-1}$$
$$+ 2a_{41}a_{44}\varepsilon_{4t-1}\varepsilon_{1t-1} + 2a_{41}a_{45}\varepsilon_{5t-1}\varepsilon_{1t-1} + a_{42}^2\varepsilon_{2t-1}^2 + 2a_{42}a_{53}\varepsilon_{3t-1}\varepsilon_{2t-1}$$
$$+ 2a_{42}a_{44}\varepsilon_{4t-1}\varepsilon_{2t-1} + 2a_{42}a_{55}\varepsilon_{5t-1}\varepsilon_{2t-1} + a_{53}^2\varepsilon_{3t-1}^2 + 2a_{43}a_{44}\varepsilon_{4t-1}\varepsilon_{3t-1}$$
$$+ 2a_{43}a_{45}\varepsilon_{5t-1}\varepsilon_{3t-1} + a_{44}^2\varepsilon_{4t-1}^2 + 2a_{44}a_{45}\varepsilon_{5t-1}\varepsilon_{4t-1} + a_{45}^2\varepsilon_{5t-1}^2$$
$$+ b_{51}^2h_{11t-1} + 2b_{41}b_{42}h_{12t-1} + 2b_{41}b_{43}h_{13t-1} + 2b_{41}b_{44}h_{14t-1}$$
$$+ 2b_{41}b_{45}h_{15t-1} + b_{42}^2h_{22t-1} + 2b_{42}b_{43}h_{32t-1} + 2b_{42}b_{44}h_{42t-1}$$
$$+ 2b_{42}b_{45}h_{52t-1} + b_{43}^2h_{33t-1} + 2b_{43}b_{44}h_{43t-1} + 2b_{43}b_{45}h_{53t-1}$$
$$+ b_{44}^2h_{44t-1} + 2b_{44}b_{45}h_{54t-1} + b_{45}^2h_{55t-1}$$

$$h_{55} = c_{51}^2 + c_{52}^2 + c_{53}^2 + c_{54}^2 + c_{55}^2 + a_{51}^2\varepsilon_{1t-1}^2 + 2a_{51}a_{52}\varepsilon_{2t-1}\varepsilon_{1t-1} + 2a_{51}a_{53}\varepsilon_{3t-1}\varepsilon_{1t-1}$$
$$+ 2a_{51}a_{54}\varepsilon_{4t-1}\varepsilon_{1t-1} + 2a_{51}a_{55}\varepsilon_{5t-1}\varepsilon_{1t-1} + a_{52}^2\varepsilon_{2t-1}^2 + 2a_{52}a_{53}\varepsilon_{3t-1}\varepsilon_{2t-1}$$
$$+ 2a_{52}a_{54}\varepsilon_{4t-1}\varepsilon_{2t-1} + 2a_{52}a_{55}\varepsilon_{5t-1}\varepsilon_{2t-1} + a_{53}^2\varepsilon_{3t-1}^2 + 2a_{53}a_{54}\varepsilon_{4t-1}\varepsilon_{3t-1}$$
$$+ 2a_{53}a_{55}\varepsilon_{5t-1}\varepsilon_{3t-1} + a_{54}^2\varepsilon_{4t-1}^2 + 2a_{54}a_{55}\varepsilon_{5t-1}\varepsilon_{4t-1} + a_{55}^2\varepsilon_{5t-1}^2$$
$$+ b_{51}^2h_{11t-1} + 2b_{51}b_{52}h_{12t-1} + 2b_{51}b_{53}h_{13t-1} + 2b_{51}b_{54}h_{14t-1}$$
$$+ 2b_{51}b_{55}h_{15t-1} + b_{52}^2h_{22t-1} + 2b_{52}b_{53}h_{32t-1} + 2b_{52}b_{54}h_{42t-1}$$
$$+ 2b_{52}b_{55}h_{52t-1} + b_{53}^2h_{33t-1} + 2b_{53}b_{54}h_{43t-1} + 2b_{53}b_{55}h_{53t-1}$$
$$+ b_{54}^2h_{44t-1} + 2b_{54}b_{55}h_{54t-1} + b_{55}^2h_{55t-1}$$

Although covariance formulas were also specified and utilised in the maximum likelihood model, they will not be included due to space constraints. The most pertinent equations in this study are the variance equations specified above as they portray and/or determine the existence, direction and extent of direct and indirect volatility effects from all system variables (RHS) on the dependent variable (LHS).

6.3. Appendix 3: Conditional correlation graphs for the unrestricted MGARCH model

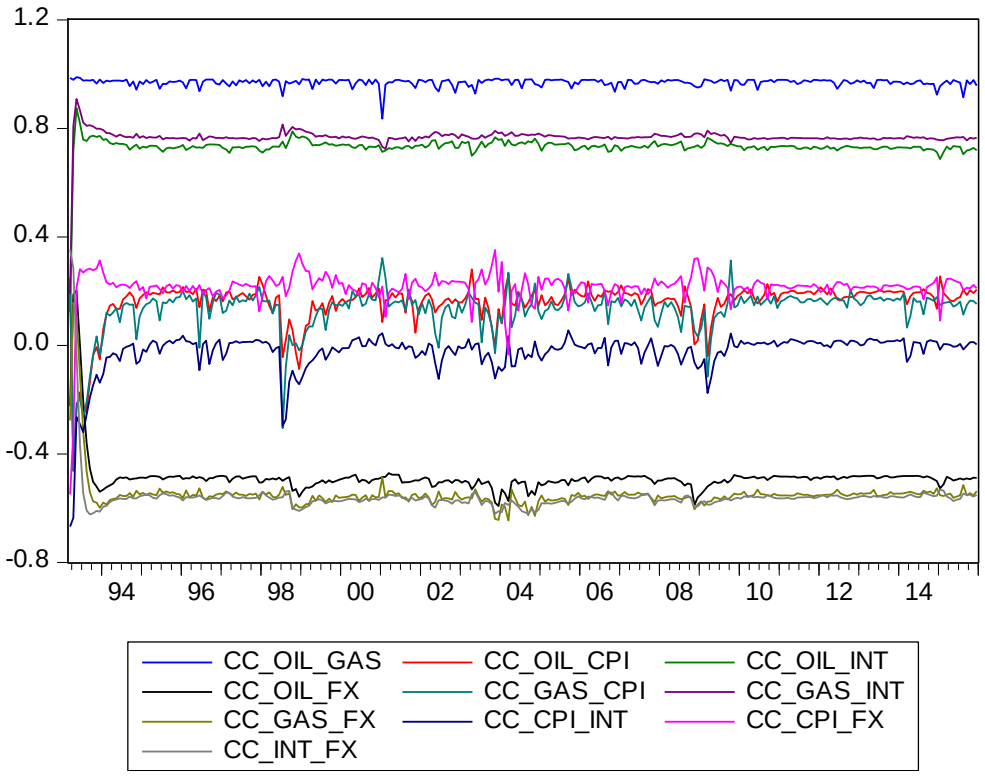


Figure 6. 7: The conditional correlation for the MGARCH model

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