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MEASURING VOLATILITY SPILL-OVER EFFECTS OF CRUDE OIL PRICES ON GHANA'S EXCHANGE RATE AND STOCK MARKET BETWEEN 1991 AND 2015

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Abstract

This paper examines the shock spill-over and volatility spill-over effects from crude oil prices to the Ghana exchange rate and the Ghana stock market index. We employ the multivariate GARCH BEKK and TBEKK models using monthly data from January 1991 to December 2015. We address two central issues. First, whether crude oil price movements affect the Ghana exchange rate and the Ghana stock market. Second, whether the crude oil price effect depends on the treatment of crude oil prices as exogenous or endogenous. Our findings indicate that world crude oil prices have significant spill-over effects on the exchange rate, and this result is unaffected by the treatment of world crude oil prices as exogenous or endogenous. However, the relationship between crude oil prices and the Ghana stock market depends on whether the crude oil price is exogenous or endogenous. The implication of these results is that internationally diversified portfolio investors in Ghana should use hedging strategies such as currency forwards, futures, and options to protect their investments from exchange rate risk emanating from oil price shocks. The government should also encourage the use of renewable energy such as solar to help reduce the country's dependence on oil.

Keywords: Ghana, exchange rate, stock markets, oil prices, exogeneity, shock and volatility spill-overs, system GARCH-TBEKK model.

JEL codes: C32, F31, F41

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1. Introduction

Our aim is to investigate the shock and volatility spill-over effects of crude oil prices on the Ghanaian currency exchange rate and stock market. This topic is important because of the financialization of the oil market in recent years (Antonakakis et al 2017). According to some researchers, the financialization of the oil market is due to increased hedging and speculative activities by investors (Hamilton and Wu 2014, Alquist and Kilian 2010, and Buyukashin et al 2010).

The traditional view argues that oil prices affect exchange rates through the terms of trade effect (Chen and Chen 2007). A rise in oil prices reduces the demand for the domestic currency of an oil-importing country, hence driving down the value of the currency. Traditional finance theory also posits that oil prices can affect stock prices directly by impacting future cash flows or indirectly through an impact on the discount rate used to discount the future cash flows (Basher and Sadorsky, 2006 and Muhtaseb and Al-Assaf, 2017). This assumes that increases in oil prices will raise the cost of production and the cost of doing business, and hence, reduces profits. Consequently, as profits decline, company share prices are expected to fall.

The relationships between oil prices and exchange rates, and oil prices and stock markets have been examined by Gosh (2011), Lizardo and Mollick (2011), Amano and Norden (2008), Masih et al (2011), Basher and Sadorsky (2006), Chen (2010), and Filis (2010). However, no previous study has investigated the exogenous crude oil price effects on exchange rates and the stock market for any small country. For small countries like Ghana, the treatment of world crude oil prices may be important since economic activities in those countries are not likely to have any significant effect on world oil prices (compared to economic activities in developed countries). However, world oil prices can influence economic activities in those countries. Hence, this paper explores the effects of oil price shocks and volatilities on Ghana's exchange rate and stock market treating crude oil prices as exogenous. This will be compared to the common approach of treating crude oil prices as endogenous. To the best of our knowledge, no paper has used this approach in the existing literature to examine the link between crude oil prices and financial markets for any small country. Hence, the treatment of crude oil prices as exogenous to study a small country like Ghana represents a contribution of this paper.

The paper is organised as follows. Section 2 discusses relevant economic features of Ghana while section 3 provides a brief review of the literature. Section 4 discusses the data with some preliminary analysis. Section 5 presents the research methodology and Section 6 discusses the results. Section 7 concludes the paper.

2. Ghana's economy and oil

Ghana's dependence on oil has been rising for several years. Oil accounted for 28% of Ghana's total energy consumption in 2000, and this substantially increased to 52% in 2014 (Energy Commission of Ghana, 2015). Further, important sectors such as transport, agriculture, and to some extent industry (manufacturing and mining) depend solely on oil. In particular, petroleum products account for 100% of the energy used by the transport and agricultural sectors (Energy Commission of Ghana, 2015). Between 2004 and 2014, Ghana's oil consumption increased by about 54% - oil consumption increased from 45 barrels a day in 2004 to 83 barrels a day in 2014 (Indexmundi). Despite becoming an oil producer in 2011, significant amounts of petroleum products consumed in Ghana are still imported, and the quantities of refined petroleum products imported continue to rise – petroleum product imports increased from 1,589.9 kilo tonnes in 2010 to 3,393.8 kilo tonnes in 2014 (Energy Commission of Ghana, 2015). This highlights the extreme importance of oil and petroleum products to Ghana's developing economy.

Given the importance of oil and petroleum product imports to the Ghanaian economy, the price of oil could influence financial markets, such as the stock market and especially the exchange rate, in Ghana. Since Ghana adopted a flexible exchange rate[1] in the mid-1980s, the Ghanaian currency subsequently witnessed remarkable depreciation and volatility. The government has attempted, without success, to manage a stable exchange rate. This is largely due to balance of trade deficits because of a continuous rise in imports, which oil is part of. The value of Ghana's oil imports increased from US$0.511 billion in 2002 to US$3.693 billion in 2014 (Bank of Ghana statistical bulletin, 2015). In 2014, the import of oil products constituted 33.8% of total imports.

As is well known, the price of imported commodities can affect movements in the domestic currency. Considering the volume of Ghana's oil imports, and the volatility in oil prices over the last five decades, the Ghanaian currency could be susceptible to oil price changes. Since the US dollar is the main invoicing and settlement currency in the world oil market, Ghanaian oil importers must sell their domestic currency (the Ghana cedi) in the foreign exchange market in order to obtain liquidity in US dollars to

[1] In 1982, the bilateral exchange rate of the Ghanaian currency against the US dollar was ȼ2.75 per US$1. Ghana agreed to reform its exchange rate policy, to implement a flexible exchange rate regime and devalue the local currency. By 1990, the cedi declined in value to ȼ345 per US$1, and further to ȼ1754 per US$1 in 1996. The cedi continued to depreciate at an alarming rate for the rest of the 1990s. By December 2000, the cedi suffered its highest annual depreciation, exchanging for the US dollar at ȼ7047 per US$1 representing a depreciation of 99% from the previous year. In 2007, the government redenominated the currency and a new currency called the Ghana cedi (GHȼ) replaced the oil currency. The new currency was trading at GHȼ0.9704 per US$1 at the time of the redenomination. However, the new Ghana cedi fell steadily against the US dollar over the years. By 2015, the cedi fell to about GHȼ3.795 per US$1.

pay for their oil imports. As a result, movements in oil prices can have a destabilizing effect on the local currency.

The price of oil and petroleum products could also be important determinants of movements of the Ghana stock market. Three possible reasons why oil prices and Ghana's stock market could be related are as follows. First, the mining and manufacturing industries which rely heavily on oil for their operations constitute the second largest in terms of the number of listed companies on the Ghana stock market. Second, there are oil companies listed on the Ghana stock market, such as, Tullow Oil, Total Petroleum Ghana, and Ghana Oil, and some of these companies are foreign owned. As a result, oil price movements can have a direct effect on their share prices which may have some impact on the Ghana stock exchange index. Third, as oil plays an important role in Ghana's production activities, oil price movements are expected to impact Ghana's stock market if oil prices affect macroeconomic variables such as output and inflation. Inflationary pressures and economic downturns deteriorate consumer sentiment and slow down overall consumption and investment spending which can affect the stock market.

3. Literature review

Hamilton (1983) first explored the relationship between oil prices and macroeconomic variables when he examined the role of oil price shocks on US business cycles. Since then, research has expanded to include the link between oil prices and other macroeconomic variables and the financial sector. In the last two decades there has been considerable research on the effects of oil price shocks on exchange rates and stock markets.

The nature of oil price effects on exchange rates remains inconclusive. Some literature suggests that increases in oil prices depreciate exchange rates (Beckmann and Czudaj, 2013, Ghosh, 2010, Dogan et al, 2012, Selmi et al, 2012, Chen and Chen, 2007, Lizardo and Mollick, 2010, and Kin and Courage (2014)). For example, Beckmann and Czudaj (2013) using Markov-switching and the vector error correction models, suggest that a real depreciation of the US dollar triggers an increase in oil prices whereas increases in oil prices lead to a depreciation of the US dollar. Employing GARCH and EGARCH models, Ghosh (2010) finds that an increase in the oil price return leads to a depreciation of the Indian currency against the US dollar. Dogan et al (2012), Selmi et al (2012), and Kin and Courage (2014) found similar results for the currencies of Turkey, Morocco, Tunisia, and South Africa. However, Amano and Norden (1998) and Benassy-Quere et al (2007) demonstrate that oil price increases lead to exchange rate appreciation.

Other studies distinguish between oil-exporting and oil-importing countries to assess whether the crude oil price effects on their currencies differ. Aziz and Bakar (2011) found that real oil price increases lead to a depreciation of oil-importing countries' exchange rates, whilst oil prices and exchange rates of oil-exporting countries have no relationship. Contrary to these findings, Yang et al (2017) found that the degree of interdependence between oil prices and exchange rates is greater for oil-exporting countries than for oil-importing countries. Similarly, Reboredo (2012) suggests that the co-movement between oil prices and exchange rates is more intense for oil-exporting countries and less intense for oil-importing countries. While the findings of Jiang and Gu (2016) suggest that the oil price-exchange rate relationship is not dependent on whether a country is an oil exporter or oil importer. Their study used the multifractal detrended-cross correlation analysis (MF-DCCA) and found some evidence that the cross-correlations between oil prices and exchange rates are significantly asymmetric; cross-correlation persistence is greater when there is a negative shock to the oil market than when there is a positive shock. This result, however, does not differ for oil-exporting countries and oil-importing countries.

Other papers use a time-varying approach to examine the oil price-exchange rate relationship. Using wavelet analysis, Reboredo and Rivera-Castro (2013) examined the time-varying correlations between crude oil prices and the US dollar between 2000 and 2011 using daily data. Their study reveals that oil prices had no effect on the dollar and vice versa before the 2008 financial crisis. However, the oil price effect on the exchange rate became apparent from the onset of the 2008 crisis, with evidence of negative interdependence between the two. This result was confirmed by Reboredo (2012). Using the DCC model, Turhan et al (2014) showed that correlations between oil prices and the exchange rates of G20 countries were stronger during the 2003 Iraq invasion. During the 2008 financial crisis, correlations between oil prices and exchange rates also became stronger for all currencies in the G20 countries.

The pioneering work of Jones and Kaul (1996) considered the relationship between oil prices and stock markets. They used quarterly data over the post-war period of 1970 to 1991 to test the rational reaction of stock prices to oil price shocks using the dividend valuation model in four developed countries: the US, Canada, the UK and Japan. For all four countries, they showed that stock prices react to oil price shocks. They further demonstrate that US and Canadian stock markets rationally react to oil price shocks, whereas UK and Japanese stocks overreact to oil price shocks.

The literature following Jones and Kaul (1996), is inconclusive on how oil prices affect stock market prices. For example, Evangelia (2001), Papatetrou (2001), Filis (2010), Driesprong et al (2008), Al-rjoub and Am (2005), Lee and Zeng (2011), and Masih et al (2011) suggest that oil price movements have a significant negative effect on stock market prices. Apergies and Miller (2009) and Al-Fayoumi (2009) find the link between oil markets and stock markets to be very weak. In contrast, Basher and Sadorsky (2006) found a positive relationship between oil prices and 21 emerging stock market returns.

Some papers also distinguish between the oil price effects on the stock markets of net oil-exporting countries and net oil-importing countries. Filis et al (2011) suggest that correlations between oil prices and stock market prices do not differ for oil-exporting countries and oil-importing countries. In contrast, Talukdar and Sunyaeva (2012) showed that oil price shocks have a negative effect on the real stock market returns of net oil-importing countries compared to positive effects for net oil-exporting countries. Conversely, Boldanov et al (2015) suggest that correlations between oil prices and stock markets are positive for oil-importing counties and negative for oil-exporting countries during crises periods, such as wars in the Middle East. Wang et al (2013) noted that oil price shocks have a stronger explanatory power on the variability of stock returns in oil-exporting countries than oil-importing countries.

Other papers also examined the oil price-stock market relationship within time-varying frameworks (Filis et al, 2011, Ciner et al, 2013, Antonakakis and Filis, 2013, Boldanov et al, 2015, and Antonakakis et al, 2017). All these papers conclude that the relation between oil prices and stock market prices of a range of countries change over time.

This review shows that the linkages between oil prices and exchange rates, and oil prices and stock markets have been examined extensively with varying conclusions. These different conclusions could be due to the use of different methodologies, types of data, and national and regional characteristics. However, there has been no previous literature that examines exogenous crude oil price effects for small countries. This study, therefore, intends to build on the existing literature by examining the shock and volatility spill-over effects of international crude oil prices on the exchange rate and the stock market in Ghana using models that treat crude oil prices as, first, endogenous and, second, exogenous. The aim is to determine whether the crude oil price effect in Ghana is related to the treatment of the crude oil price. To the best of our knowledge, this will be the first examination of this issue for Ghana.

4. Data

This study uses data on Ghana's stock exchange composite index (GSECI), the US S&P 500 index, the Ghanaian cedi exchange rate vis-à-vis the US dollar, and world Brent crude oil prices. The data are monthly over the period January 1991 to December 2015, yielding 300 observations. The period was chosen, first, because data was available for all the series during this period. Second, this period witnessed sharp movements in oil prices caused by both supply-led and demand-led factors such as conflicts in the Middle East, the actions of OPEC, and increases in global demand propelled by China's economic growth. Third, this period captures the global financial crisis of 2008 which led to the crash of stock markets.

The GSECI is a capitalization-weighted index that tracks the performance of all companies traded on Ghana's stock exchange (GSE). It is the only stock exchange in Ghana and the criteria for listings on the exchange include profitability, capital adequacy, years of existence, spread of shares, and management efficiency. In 2015 there were 37 listings and 2 corporate bonds on the GSE. The closing prices of listed equities are calculated using the volume weighted average price of each equity for every given trading day. The Ghana stock exchange introduced the GSECI in 2011 to replace the previous GSE All-Share index. This means two indices existed for the Ghana stock exchange at different times within our sample period; the GSE All-Share index covering the period from January 1991 to December 2010, and the GSECI covering the period from January 2011 to December 2015. The method of calculating the closing prices of shares since the GSECI was introduced is different from the method that was used during the regime of the GSE All-Share index. To link the two indices, we used a three-period moving average extrapolating method to forecast the GSE All-Share index one period ahead into January 2011. We then used this forecast value and the actual value of the GSECI for January 2011 to splice both indices into a single consistent series (see Appendix). The S&P 500 index is included in this study to capture the role of a global financial centre such as the US in transmitting macroeconomic news. All variables are defined in Table 1.

Figure 1 shows that all four-variables have trended upward over the sample and appear to decline sharply in late 2008. The latter reflects the 2008 global financial crisis which affected oil prices and stock markets across the world. The S&P 500 also experienced structural shocks around 1997 (Asian financial crisis) and 1998 (the dot com bubble). The Ghana stock exchange index experienced a spike in 2012. The exchange rate also rose sharply in 2001 and 2007 and witnessed declines in 2005 and 2008. There was also a considerable drop in the price of crude oil in late 2014.

Table 1: Variable definitions and sources

Variable	**Description**	**Source**
GSECI	Ghana stock exchange index	Ghana Stock Exchange head office, Accra
EXR	Ghana cedi exchange rate against the US dollar	Oanda website (www.oanda.com)
SP500	US stock market index	Yahoo Finance
COP	International Crude Oil Price (UK Brent)	Energy Information Administration website

Figure 1: Market price graphs

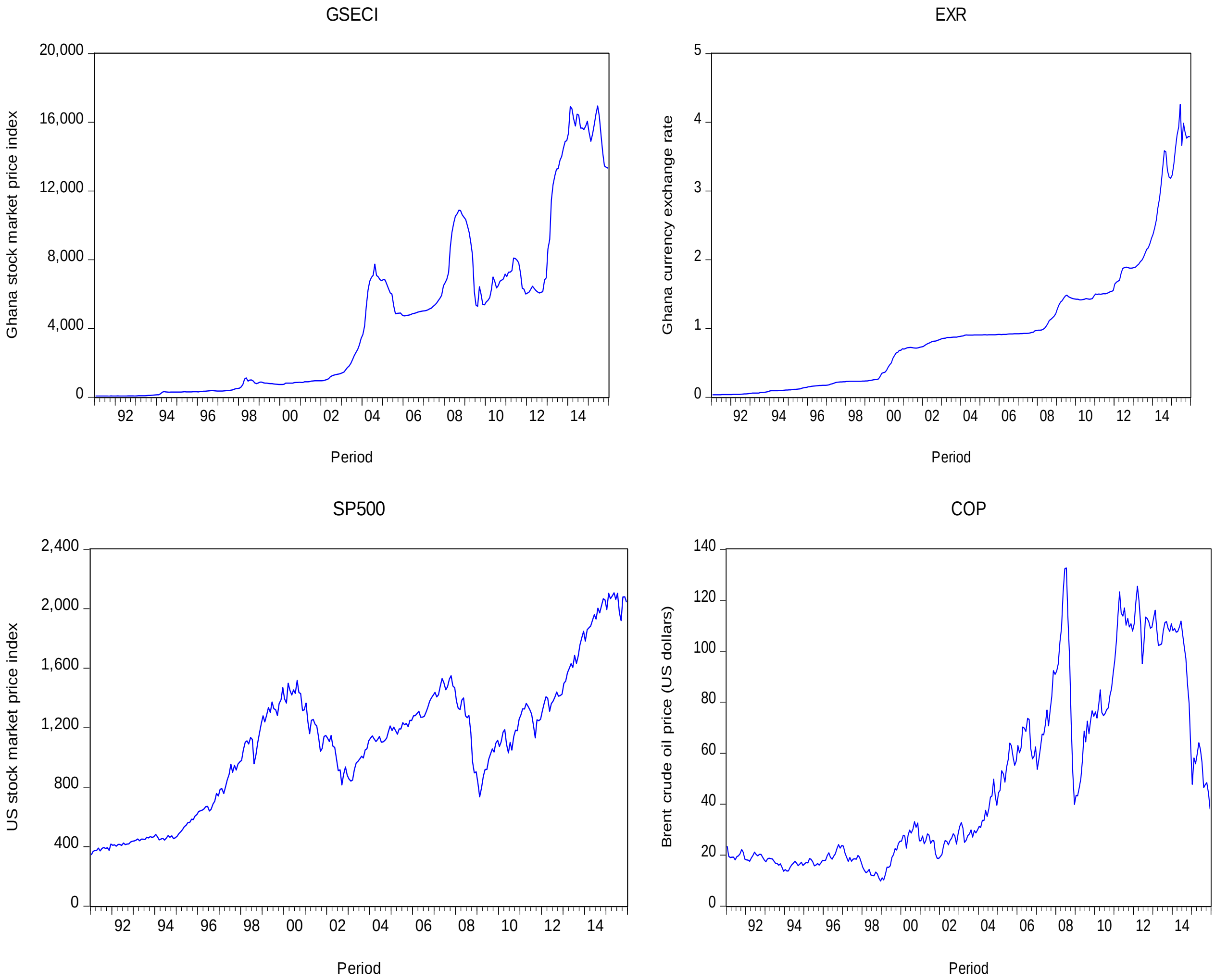

Figure 2 shows the growth rates (returns) of variables given by the first differences of the natural logarithms of the price series (variable names are prefixed with “DL”). All series exhibit volatility clustering typically associated with financial data. This suggests the use of a GARCH specification is appropriate. Note that taking the differences of the logs of each series removes the trend leaving data with broadly constant means that are, therefore, likely to be stationary. The differencing also removes the structural breaks (mean shifts) observed in the levels data, transforming them into pulse outliers. Hence, we do not consider modelling structural breaks.

Figure 2: Price return graphs

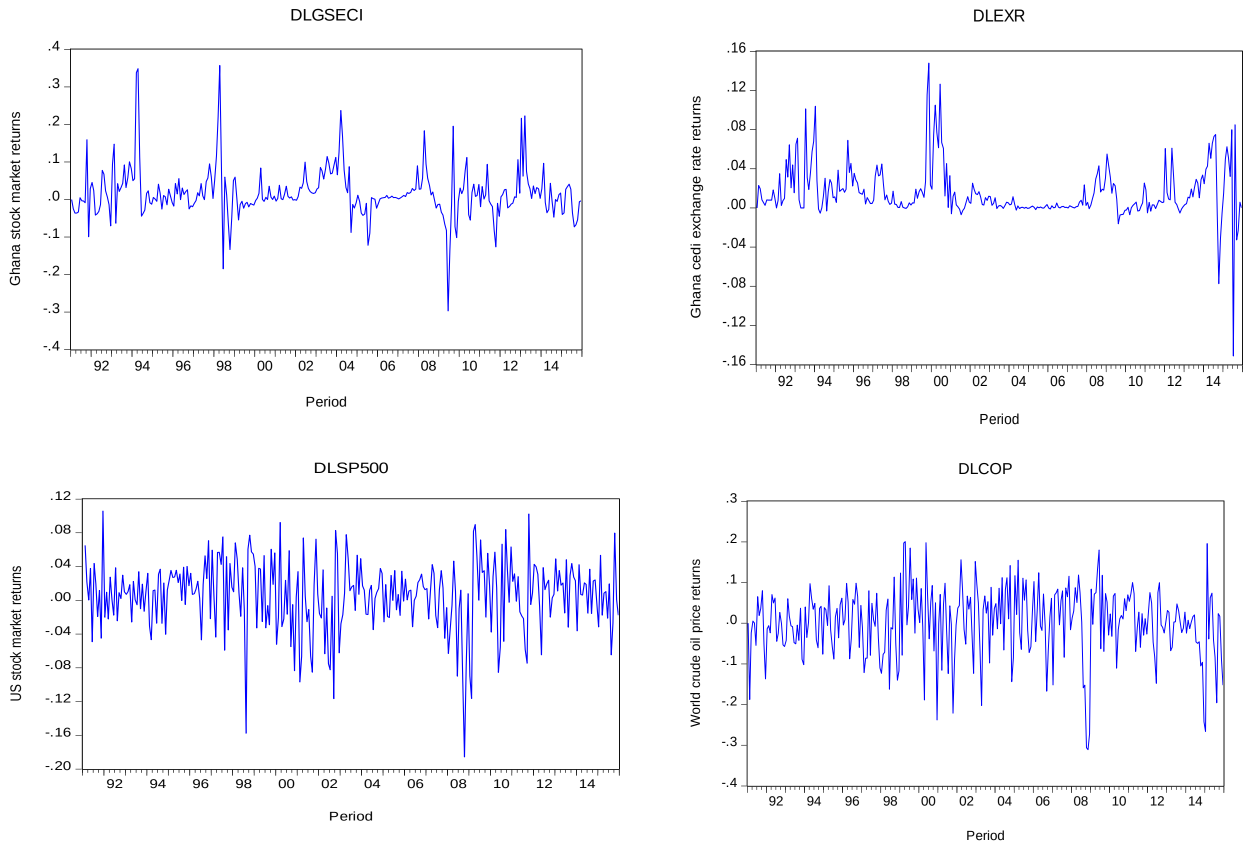

Table 2: Return series summary statistics

	Ghana Stock Exchange	Ghana Cedi Exchange rate	SP500	Crude Oil Price
Mean	0.0176	0.0157	0.0059	0.0016
Median	0.0079	0.0077	0.0106	0.0074
Maximum	0.3575	0.1479	0.1058	0.2007
Minimum	-0.2972	-0.1513	-0.1856	-0.3109
Std. Dev	0.0669	0.0269	0.0420	0.0859
CV	3.8011	1.7134	7.1186	53.6875
Skewness	1.1992	0.7040	-0.8033	-0.7082
Kurtosis	10.485	11.493	4.8187	4.1993
Jarque-Bera	772.15*** (0.000)	926.47*** (0.000)	73.36*** (0.000)	43.06*** (0.000)
LB-Q(12)	115.23*** (0.000)	156.40*** (0.000)	11.07 (0.520)	30.77*** (0.000)
LB-Q(24)	153.69*** (0.000)	164.98*** (0.000)	17.70 (0.820)	44.92** (0.010)
LB-Qs(12)	54.52*** (0.000)	148.83*** (0.000)	55.01*** (0.000)	84.47*** (0.000)
LB-Qs(24)	63.06*** (0.000)	154.08*** (0.000)	72.97*** (0.000)	89.77*** (0.000)
ARCH LM(1)	38.46*** (0.000)	31.05*** (0.000)	17.93*** (0.000)	59.30*** (0.000)
ARCH LM(12)	38.20*** (0.000)	49.29*** (0.000)	35.32*** (0.000)	80.53*** (0.000)
ARCH LM(24)	38.72*** (0.030)	50.19*** (0.000)	46.72*** (0.000)	89.44*** (0.000)

Note: LB-Q(12) and (24) denote the Ljung-Box Q-statistics for return series up to 12 and 24 lags whilst LB-Qs(12) and (24) represent the Ljung-Box Q-statistics for the squared return series. ARCH LM is the Lagrange multiplier test of autoregressive conditional heteroscedasticity for ARCH orders 1, 12, and 24. ***, **, and * denotes significance at the 1%, 5%, and 10% levels respectively.

Table 2 reports descriptive statistics of the return series. The mean monthly returns of all variables are positive. The Ghana stock exchange index has the highest mean return (0.0176), followed by the Ghana cedi exchange rate (0.0157), while the crude oil price has the lowest mean return (0.0016). In general, the mean returns of the domestic variables are higher than the mean returns of the global oil price and the S&P 500. In terms of volatility, the coefficient of variation (denoted as CV) and the standard deviation (Std. Dev) suggest that the Ghana cedi exchange rate is the least volatile since it has the smallest CV (1.7134) and standard deviation (0.0269). On the other hand, the crude oil price is most volatile with the highest CV (53.6875) and standard deviation (0.0859).

According to the estimated skewness, the Ghana stock exchange index and (especially) the Ghana cedi exchange rate are positively skewed, indicating that large positive returns are more common than large negative returns. In contrast, the S&P 500 and crude oil prices have negative skewness. Furthermore, all the return series are leptokurtic (kurtosis is greater than 3) indicating significantly fatter tails and higher peaks that tend to produce more outliers than the normal distribution. This is expected and is common with many financial return series. Finally, the Jarque-Bera statistics reject the normally distributed null for all series.

Table 2 also gives the Ljung-Box (1979) Q-statistics and corresponding p-values (in parentheses) for 12th and 24th order autocorrelation for both return series (LB-Q(12) and LB-Q(24)) and squared return series (LB-Qs(12) and LB-Qs(24)) following Li and Giles (2015). We strongly reject the no autocorrelation null for all return (except for the S&P 500) and squared return series. Evident autocorrelation in the squared series indicate the existence of ARCH effects in all series. The ARCH LM test (proposed by Engle (1982)) for 1st (ARCH LM(1)), 12th (ARCH LM(12)), and 24th (ARCH LM(24)) order ARCH effects confirms the presence of significant ARCH effects for all return series. Hence, the application of multivariate GARCH models (which we use) is appropriate.

We report the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests for nonstationarity in Table 3. The results unambiguously indicate that all log-level series are I(1) - an “L” prefix indicates a variable in logarithmic form. Hence, it is appropriate to model the growth rates of these variables (as we do) because they are stationary.

Table 3: ADF and PP unit root tests

Panel (a): ADF test								
	Intercept only				**Intercept and trend**			
	Data in levels		Data in first differences		Data in levels		Data in first differences	
	t-statistic	Lag	t-statistic	Lag	t-statistic	Lag	t-statistic	Lag
LGSECI	-1.55	1	-10.05***	0	-1.90	1	-10.11***	0
LEXR	-1.83	2	-7.38***	1	-1.77	2	-7.52***	1
LSP500	-1.69	0	-16.53***	0	-1.85	0	-16.53***	0
LCOP	-1.41	1	-14.11***	0	-1.77	1	-14.01***	0

Panel (b): PP test				
	Intercept only		**Intercept and trend**	
	Data in levels	Data in first differences	Data in levels	Data in first differences
	t-statistic	t-statistic	t-statistic	t-statistic
LGSECI	-1.45	-10.21***	-1.87	-10.24***
LEXR	-1.87	-12.43**	-1.73	-12.55***
LSP500	-1.69	-16.61***	-2.00	-16.61**
LCOP	-1.27	-14.11***	-2.00	-14.10***

Note: ***, **, and * denotes significance at the 1%, 5%, and 10% levels respectively.

5. Methodology

As our aim is to examine the interdependence or spill-over effects across different variables and given the observed ARCH effects of the series, a multivariate GARCH model is appropriate. We therefore use variants of the standard multivariate GARCH BEKK model proposed by Engle and Kroner (1995) that is widely used in modelling volatility/shock spill-overs in simultaneous equations systems. The model requires specification of both mean and variance-covariance equations. The mean equation employs a standard vector autoregressive (VAR) specification. The (conditional) variance-covariance (volatility) equation, $\boldsymbol{H}_t$, uses a BEKK(1,1) form, given by:

$$\boldsymbol{H}_t = \boldsymbol{C}'\boldsymbol{C} + \boldsymbol{A}'\boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}'_{t-1}\boldsymbol{A} + \boldsymbol{G}'\boldsymbol{H}_{t-1}\boldsymbol{G} \tag{1}$$

where $\boldsymbol{C}$ is an $(n \times n)$ lower triangular matrix of constants, while the $(n \times n)$ parameter matrices $\boldsymbol{A}$ and $\boldsymbol{G}$ are:

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{34} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix};\ \boldsymbol{G} = \begin{bmatrix} g_{11} & g_{12} & g_{13} & g_{14} \\ g_{21} & g_{22} & g_{23} & g_{24} \\ g_{31} & g_{32} & g_{33} & g_{34} \\ g_{41} & g_{42} & g_{43} & g_{44} \end{bmatrix}. \tag{2}$$

The variance-covariance matrix of shocks, $\boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}'_{t-1}$, is given by:

$$\boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}'_{t-1} = \begin{bmatrix} \varepsilon^2_{1,t-1} & \varepsilon_{1,t-1}\varepsilon_{2,t-1} & \varepsilon_{1,t-1}\varepsilon_{3,t-1} & \varepsilon_{1,t-1}\varepsilon_{4,t-1} \\ \varepsilon_{2,t-1}\varepsilon_{1,t-1} & \varepsilon^2_{2,t-1} & \varepsilon_{2,t-1}\varepsilon_{3,t-1} & \varepsilon_{2,t-1}\varepsilon_{4,t-1} \\ \varepsilon_{3,t-1}\varepsilon_{1,t-1} & \varepsilon_{3,t-1}\varepsilon_{2,t-1} & \varepsilon^2_{3,t-1} & \varepsilon_{3,t-1}\varepsilon_{4,t-1} \\ \varepsilon_{4,t-1}\varepsilon_{1,t-1} & \varepsilon_{4,t-1}\varepsilon_{2,t-1} & \varepsilon_{4,t-1}\varepsilon_{3,t-1} & \varepsilon^2_{4,t-1} \end{bmatrix} \tag{3}$$

The BEKK specification overcomes many of the problems associated with the VECH model that was first proposed by Bollerslev et al (1988), such as having fewer parameters to estimate and guaranteeing the positive semi-definiteness of the time-varying covariance matrices. Kroner and Ng (1998) extended the BEKK model by adding $\boldsymbol{D}'\boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}'_{t-1}\boldsymbol{D}$ to capture asymmetries often exhibited by stock prices and other financial data, thus:

$$\boldsymbol{H}_t = \boldsymbol{C}'\boldsymbol{C} + \boldsymbol{A}'\boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}'_{t-1}\boldsymbol{A} + \boldsymbol{G}'\boldsymbol{H}_{t-1}\boldsymbol{G} + \boldsymbol{D}'\boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}'_{t-1}\boldsymbol{D} \tag{4}$$

where ϵ_t is defined as ε_t if ε_t is negative and zero otherwise; while:

$$\boldsymbol{D} = \begin{bmatrix} d_{11} & d_{12} & d_{13} & d_{14} \\ d_{21} & d_{22} & d_{23} & d_{24} \\ d_{31} & d_{32} & d_{33} & d_{34} \\ d_{41} & d_{42} & d_{43} & d_{44} \end{bmatrix} \tag{5}$$

$$\boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}'_{t-1} = \begin{bmatrix} \epsilon^2_{1,t-1} & \epsilon_{1,t-1}\epsilon_{2,t-1} & \epsilon_{1,t-1}\epsilon_{3,t-1} & \epsilon_{1,t-1}\epsilon_{4,t-1} \\ \epsilon_{2,t-1}\epsilon_{1,t-1} & \epsilon^2_{2,t-1} & \epsilon_{2,t-1}\epsilon_{3,t-1} & \epsilon_{2,t-1}\epsilon_{4,t-1} \\ \epsilon_{3,t-1}\epsilon_{1,t-1} & \epsilon_{3,t-1}\epsilon_{2,t-1} & \epsilon^2_{3,t-1} & \epsilon_{3,t-1}\epsilon_{4,t-1} \\ \epsilon_{4,t-1}\epsilon_{1,t-1} & \epsilon_{4,t-1}\epsilon_{2,t-1} & \epsilon_{4,t-1}\epsilon_{3,t-1} & \epsilon^2_{4,t-1} \end{bmatrix} \quad (6)$$

We estimate the full BEKK model, equation (4), with all four-variables treated as endogenous, and a triangular BEKK (TBEKK) model where the crude oil price is treated as exogenous. The TBEKK model was also used by Beirne et al (2010) to examine volatility spill-overs from mature stock markets to regional and local emerging country stock markets. The TBEKK model uses the same formula as the full BEKK model, except the $\boldsymbol{A}$s, $\boldsymbol{G}$s, and $\boldsymbol{D}$s are constrained to be lower triangular, thus:

(7)

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & 0 & 0 & 0 \\ a_{21} & a_{22} & 0 & 0 \\ a_{31} & a_{32} & a_{33} & 0 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix};\ \boldsymbol{G} = \begin{bmatrix} g_{11} & 0 & 0 & 0 \\ g_{21} & g_{22} & 0 & 0 \\ g_{31} & g_{32} & g_{33} & 0 \\ g_{41} & g_{42} & g_{43} & g_{44} \end{bmatrix};\ \boldsymbol{D} = \begin{bmatrix} d_{11} & 0 & 0 & 0 \\ d_{21} & d_{22} & 0 & 0 \\ d_{31} & d_{32} & d_{33} & 0 \\ d_{41} & d_{42} & d_{43} & d_{44} \end{bmatrix}.$$

In both four-variable BEKK and TBEKK systems above, the numbers 1, 2, 3, and 4 denote the growth rates of the Ghana stock market, the Ghana exchange rate, the US stock market, and world oil prices, respectively. For the TBEKK model these numberings/orderings are based on the relative degree of exogeneity of the variables. Assuming macroeconomic conditions in Ghana will unlikely influence crude oil prices, crude oil prices are allowed to affect the domestic variables (the Ghana exchange rate and the Ghana stock market) as well as the US stock market. However, the domestic variables are not allowed to affect the crude oil price. This makes crude oil prices exogenous. The ordering also allows the US stock market to affect the Ghana cedi exchange rate and the Ghana stock market, however neither domestic variable affects the US stock market because domestic variables will have little influence on the world stage.

We also estimate a two-variable BEKK model and a two-variable TBEKK model using only oil prices and the Ghana cedi exchange rate. This is a robustness check that determines whether the exclusion of stock markets affects the relationship of oil prices and exchange rates. The coefficient and variance-covariance shock matrices in the two-variable BEKK model are:

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix};\ \boldsymbol{G} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix}; \boldsymbol{D} = \begin{bmatrix} d_{11} & d_{12} \\ d_{21} & d_{22} \end{bmatrix}. \tag{8}$$

$$\boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}'_{t-1} = \begin{bmatrix} \varepsilon^2_{1,t-1} & \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon_{2,t-1}\varepsilon_{1,t-1} & \varepsilon^2_{2,t-1} \end{bmatrix}; \boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}'_{t-1} = \begin{bmatrix} \epsilon^2_{1,t-1} & \epsilon_{1,t-1}\epsilon_{2,t-1} \\ \epsilon_{2,t-1}\epsilon_{1,t-1} & \epsilon^2_{2,t-1} \end{bmatrix}. \tag{9}$$

Similarly, the coefficient and variance-covariance shock matrices in the two-variable TBEKK model are:

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & 0 \\ a_{21} & a_{22} \end{bmatrix};\ \boldsymbol{G} = \begin{bmatrix} g_{11} & 0 \\ g_{21} & g_{22} \end{bmatrix}; \boldsymbol{D} = \begin{bmatrix} d_{11} & 0 \\ d_{21} & d_{22} \end{bmatrix}. \tag{10}$$

$$\boldsymbol{\varepsilon}_{t-1}\boldsymbol{\varepsilon}'_{t-1} = \begin{bmatrix} \varepsilon^2_{1,t-1} & 0 \\ \varepsilon_{2,t-1}\varepsilon_{1,t-1} & \varepsilon^2_{2,t-1} \end{bmatrix}; \boldsymbol{\epsilon}_{t-1}\boldsymbol{\epsilon}'_{t-1} = \begin{bmatrix} \epsilon^2_{1,t-1} & 0 \\ \epsilon_{2,t-1}\epsilon_{1,t-1} & \epsilon^2_{2,t-1} \end{bmatrix}. \tag{11}$$

In both two-variable models, 1 denotes the Ghana exchange rate whilst 2 represents the world oil price, making the latter exogenous in the TBEKK specification.

From the systems above, we can analyse the variance or volatility across the variables. Matrix $\boldsymbol{A}$ measures past shock effects and matrix $\boldsymbol{G}$ measures past volatility effects.[2] The asymmetric responses to negative and positive shocks, or 'bad news'

[2] Shocks are the errors (the difference between actual and fitted values, $\boldsymbol{\varepsilon}_t$) and volatilities the (conditional) variances ($\boldsymbol{H}_t$). All GARCH models predict the covariance matrix given past shocks. In the GARCH model, the coefficients on the lagged shocks are the ARCH coefficients, whilst the coefficients on the lagged

and 'good news', are measured by $\boldsymbol{D}$. The diagonal elements of matrix $\boldsymbol{A}$ (a_{ii}) measure the effects of market i's shocks on its own volatility, whilst the off-diagonal elements of $\boldsymbol{A}$ (a_{ij}) capture the effects of market i's shocks on market j's volatility[3]. Similarly, the diagonal elements of matrix $\boldsymbol{G}$ (g_{ii}) measure the effects of the own past volatility of market i on its conditional variance, whilst the off-diagonal elements of matrix $\boldsymbol{G}$ (g_{ij}) capture the effects of past volatility of market i on market j's conditional variance, also known as volatility spill-over. The diagonal elements of matrix $\boldsymbol{D}\,(d_{ii})$ are the asymmetric response of market i to its own past shocks and measure the difference between positive shocks and negative shocks. The off-diagonal elements of matrix $\boldsymbol{D}(\boldsymbol{d_{ij}})$ are the asymmetric responses of market j to the past shocks of market i. They measure the difference between positive and negative shocks of market i on market j's volatility. To measure the volatility spill-over effect of negative shocks, we take the sum of the coefficients of a_{ij} and d_{ij} $(a_{ij} + d_{ij})$. Similarly, for negative shocks of own volatility, we take the sum of a_{ii} and d_{ii} $(a_{ii} + d_{ii})$. Positive shocks are measured by a_{ii} and a_{ij}. Note that all coefficients in the (T)BEKK specification are squared making negative coefficient signs irrelevant because they become positive once squared.

We use the standard GARCH(1,1) specification. Engle (1995, p.xii) noted that the GARCH(1,1) is a generally robust model whilst Bollerslev et al (1992) suggests that this model seems sufficient when modelling variance dynamics over very long sample periods. Further, increasing the lag order of the BEKK model may pose practical issues due to the large number of parameters. Our BEKK models are also deemed

variances/covariances are the GARCH coefficients. The ARCH and GARCH coefficients are used to describe shock spill-over and volatility spill-over respectively (e.g. see Li, 2007, Li and Giles, 2015, Musunuru, 2014, and Joshi, 2011).

[3] Because of the standard use of the transpose of $\boldsymbol{A}$ as the pre-multiplying matrix, the coefficients of the BEKK model have the opposite interpretation to usual: $\boldsymbol{A}$(i, j) is the effect of residual i on variable j, rather than j on i.

valid since they all pass the autocorrelation and ARCH diagnostic tests (discussed below).

Engle and Kroner (1995) and Kroner and Ng (1998) state that the BEKK model can be estimated consistently and efficiently using the full information maximum-likelihood method. Let L_t be the log likelihood function of observation t and n be the number of variables. L is the joint log likelihood function assuming the errors are normally distributed, given by:

$$L = \sum_{t=1}^{T} L_t(\theta) \tag{12}$$

$$L_t(\theta) = \frac{n}{2}\ln(2\pi) - \frac{1}{2}ln|H_t| - \frac{1}{2}\varepsilon_t' H_t^{-1}\varepsilon_t \tag{13}$$

where T is the number of observations and θ denotes the parameter vector to be estimated.

Computation has been done in the RATS 8.2 software package. As recommended by Engle and Kroner (1995), we performed several iterations with the simplex algorithm. We then employed the BFGS (Broyden, Fletcher, Goldfarb, and Shanno) algorithm to obtain the final estimates of the variance-covariance matrices and the corresponding standard errors. The next section discusses the empirical results.

6. Results

Before considering the results, we test whether the models are adequately specified. We apply the widely used Ljung-Box Q-statistic for unmodelled autocorrelation in the multivariate residuals and squared residuals (ARCH effects) as well as the multivariate ARCH test. We report the Q-statistics for lag orders 12 (MVLB-Q(12)), 24 (MVLB-Q(24)) and 36 (MVLB-Q(36)) based on previous literature (see Li, 2007, Joshi, 2011, and Li and Giles, 2015). Harvey (1981) suggests that the number of lags to be included in the test should equal the square root of the sample size (approximately 300 in our applications). Thus, we also report Q-statistics for lag order 17 (MVLB-Q(17)). We also report a multivariate test for unmodelled ARCH effects of order 6 (MVARCH(6)). The statistics and their p-values (in parentheses) for both mean and variance models are reported in the bottom sections of the tables of results.

The models that treat world crude oil prices as endogenous are referred to as "endogenous crude oil price models" whilst those that treat world oil prices as exogenous are called "exogenous crude oil price models". We use a 5% level of significance for drawing inference in all models discussed below.

6.1 Endogenous crude oil price models

The four-variable BEKK model converges after 132 iterations and its results are presented in Table 4. The diagnostic tests suggest that the mean and variance models are adequately specified as there is no significant autocorrelation or unmodeled ARCH effects according to the test statistics (see the lower section of panel B in Table 4).

Table 4: Four-variable GARCH-BEKK model with endogenous oil prices

Panel A: Return, shock, and volatility spill-overs				
	Return (***R***): Mean Equation	***A***: ARCH effects	***G***: GARCH effects	***D***: Asymmetries
(1,1)	0.6827*** (0.0409)	0.9243*** (0.0808)	0.0367 (0.0954)	-0.0076 (0.2141)
(1,2)	-0.0194 (0.0641)	0.0016 (0.0130)	0.0085 (0.0141)	-0.0045 (0.0118)
(1,3)	0.1133* (0.0504)	0.0458 (0.0432)	-0,0316 (0.0465)	-0.2055*** (0.0501)
(1,4)	0.0301 (0.0230)	-0.0141 (0.1011)	0.0931 (0.1334)	0.2385 (0.1326)
(2,1)	0.0043 (0.0069)	0.1465 (0.1258)	0.1240 (0.1277)	-1.3953*** (0.3734)
(2,2)	0.6701*** (0.0418)	0.7799*** (0.0751)	0.7910*** (0.0361)	-0.0973 (0.1268)
(2,3)	-0.0387* (0.0151)	0.0494 (0.0933)	-0.0312 (0.0578)	0.0794 (0.1708)
(2,4)	0.0042 (0.0063)	0.4737* (0.2236)	-0.3764** (0.1570)	-1.5164*** (0.4130)
(3,1)	-0.0540* (0.0270)	-0.2128*** (0.0720)	0.0262 (0.0708)	-0.0562 (0.0961)
(3,2)	0.0899 (0.0594)	-0.0583*** (0.0160)	0.0033 (0.0116)	-0.0093 (0.0226)
(3,3)	-0.0726 (0.0556)	-0.2865*** (0.0769)	0.8406*** (0.0459)	0.4941*** (0.0977)
(3,4)	-0.0311 (0.0231)	0.5151*** (0.1483)	0.1243 (0.1518)	0.3315 (0.2232)
(4,1)	0.0275 (0.0699)	-0.0089 (0.0298)	-0.0385 (0.0599)	-0.0059 (0.0499)
(4,2)	0.1409 (0.1511)	0.0098** (0.0078)	-0.0250*** (0.0085)	0.0163** (0.0109)
(4,3)	0.1399 (0.1179)	-0.0804*** (0.0276)	0.0850** (0.0424)	-0.1324** (0.0531)
(4,4)	0.1858*** (0.0597)	-0.1570** (0.0801)	0.3894*** (0.1335)	0.4934*** (0.1239)
Panel B: Asymmetric Shocks				
(A+D): Negative ARCH shocks		A: Positive ARCH shocks		Series Key
$a_{13}^2 + d_{13}^2$	0.0443***	a_{13}^2	0.002	1. Ghana stock market
$a_{21}^2 + d_{21}^2$	3.3636***	a_{21}^2	0.0215	2. Exchange rate
$a_{24}^2 + d_{24}^2$	2.5239***	a_{24}^2	0.2243	3. US stock market
$a_{33}^2 + d_{33}^2$	0.3262***	a_{33}^2	0.0821	4. World oil prices
$a_{42}^2 + d_{42}^2$	0.0004**	a_{42}^2	0.0001	
$a_{43}^2 + d_{43}^2$	0.0240***	a_{43}^2	0.0065	
$a_{44}^2 + d_{44}^2$	0.0421***	a_{44}^2	0.0246	
Autocorrelation test for the mean equation				
MVLB-Q(12)	166.82 (0.905)			
MVLB-Q(17)	247.69 (0.852)			
MVLB-Q(24)	371.22 (0.671)			
MVLB-Q(36)	592.98 (0.3033)			
ARCH test for the variance equation				
MVARCH(6)	86.41 (0.832)			

Note: constants are omitted in the above table to save space. Standard errors (probability values) are in brackets in panel A (panel B). ***, **, and * denotes significance at the 1%, 5%, and 10% levels respectively. MVLB-Q(12), MVLB-Q(17), MVLB-Q(24) and MVLB-Q(36) stand for the multivariate Ljung-Box Q-statistic for the standardized residuals with 12, 17, 24 and 36 lags while MVARCH(6) denotes the multivariate ARCH test.

The diagonal parameters in matrix $\boldsymbol{A}$ measure the effects of own past shocks on their conditional variance (ARCH effects). All the estimated diagonal parameters of matrix $\boldsymbol{A}$ (a_{11}, a_{22}, a_{33} and a_{44}) are significant. The diagonal parameters in matrix $\boldsymbol{G}$ measure the effects of own past volatility on their conditional variance (GARCH effects). Except for g_{11}, all estimated parameters in the diagonal matrix $\boldsymbol{G}$ are significant. The significance of all the diagonal elements of matrices $\boldsymbol{A}$ and $\boldsymbol{G}$ (except g_{11}) indicates a strong GARCH(1,1) process driving the conditional variances of the four markets.

The diagonal elements of matrix $\boldsymbol{D}$ measure the asymmetric response (the difference in response to good news and bad news) of the markets to their own past shocks. The estimated diagonal coefficients in matrix $\boldsymbol{D}$ are not significant for d_{11} and d_{22} suggesting no significant asymmetries for the Ghana stock market and exchange rate. Meanwhile, the coefficients for d_{33} and d_{44} are significant indicating the presence of significant asymmetric effects for the US stock market and world oil prices. The results suggest that the own past negative effect of shocks for the US stock market ($a_{33}^2 + d_{33}^2 = 0.3262$) is larger in magnitude than its own past positive effect ($a_{33}^2 = 0.0821$). Similarly, the own past negative effect of oil price shocks ($a_{44}^2 + d_{44}^2 = 0.0421$) is larger in magnitude than its own past positive effect ($a_{44}^2 = 0.0246$). Thus, for both the US stock market and the world oil price, negative shocks have larger effects on their own conditional volatilities than positive shocks.

Next, we discuss the off-diagonal parameters of matrices $\boldsymbol{A}$, $\boldsymbol{G}$ and $\boldsymbol{D}$ which capture the transmissions across markets. Starting with matrix $\boldsymbol{A}$, which measures the overall shock spill-overs among the variables, the significant coefficients of a_{31} and a_{32} indicate that there are shock spill-overs from the US stock market to the Ghanaian stock market, and from the US stock market to the Ghana cedi exchange rate. However, the reverse off-diagonal parameters a_{13} and a_{23} are not significant. This implies shocks to the Ghana stock market and the Ghanaian currency exchange rates have no spill-over effects on the US stock market. In other words, news about shocks of the US stock exchange affects the volatility of the Ghana stock exchange and the Ghana cedi exchange rate though not *vice versa*.

Moreover, we find evidence of bidirectional shock spill-over between the US stock market and oil prices as the parameters a_{34} and a_{43} are both significant. News about the US stock market affects the volatility of oil prices and *vice versa*. There are also shock spill-overs from the oil price to the Ghanaian exchange rate since a_{42} is statistically significant. However, shocks to oil prices have no important spill-over effects on the Ghana stock market index since a_{41} is insignificant.

With regards to volatility spill-over (indicated by the off-diagonal elements of $\boldsymbol{G}$), there is bidirectional volatility spill-over between international oil prices and the Ghana cedi exchange rate because g_{42} and g_{24} are both significant. The evidence that past volatility of the Ghana cedi exchange rate significantly affects the conditional variance of oil prices is unexpected. There is also a unidirectional volatility spill-over from oil prices to the US stock market because g_{43} is significant while g_{34} is not significant.

The spill-over effects of asymmetric shocks are indicated by the off-diagonal parameters of matrix $\boldsymbol{D}$. There is evidence of asymmetric spill-overs between some of the variables. These include; asymmetric spill-overs from the Ghana exchange rate to the Ghana stock market; from oil prices to the US stock market; from the Ghana stock market to the US stock market; and from the Ghana cedi exchange rate to oil prices, since the parameters d_{21}, d_{43}, d_{13}, and d_{24} are significant. However, there are no significant asymmetric effects from oil prices to the Ghana cedi exchange rate and the Ghanaian stock market.

Finally, the relationship between the return variables in the mean equation is captured by the $\boldsymbol{R}$ matrix. The results reveal that the returns of the Ghana stock market, the Ghana cedi exchange rate, and oil prices depend on their own previous values since R_{11}, R_{22}, and R_{44} are significant. However, the coefficient of R_{33} is statistically insignificant, indicating that the returns of the US stock market does not depend on its first lag. Further, return spill-overs (in the mean equation) between the variables appear to be non-existent in this model since all the off-diagonal elements in matrix $\boldsymbol{R}$ are insignificant.

Overall, the results from this model suggest that crude oil prices have significant shock, volatility, and asymmetric spill-over effects on the Ghana exchange rate. However, crude oil prices do not have any effect on the Ghana stock market. An issue with this model is that some of the results that we found were rather surprising. For example, the results that the Ghana stock market has an asymmetric effect on the US stock market; and the Ghana currency has an asymmetric effect on the world oil price were not expected. Such unexpected results are prevented in the exogenous crude oil price models by construction.

The next model we estimate includes only oil prices and the exchange rate. We use 1 to denote the Ghana exchange rate and 2 to denote the crude oil price. The model converges after 34 iterations and the results are reported in Table 5. The diagnostic tests (reported at the bottom of the table) show that the model is free from both autocorrelation and ARCH effects.

Table 5: Two-variable GARCH-BEKK model with endogenous oil prices

Panel A: Return, shock, and volatility spill-overs				
	Return (***R***): Mean Equation	***A***: ARCH effects	***G***: GARCH effects	***D***: Asymmetries
(1,1)	0.6850*** (0.0443)	0.6885*** (0.0851)	0.8066*** (0.0468)	-0.0579 (0.1509)
(1,2)	-0.0030 (0.0074)	0.2633* (0.2435)	-0.4526 (0.2749)	0.4526 (0.4815)
(2,1)	0.0775 (0.1852)	0.0172*** (0.0095)	-0.0159 (0.0216)	0.0094 (0.0153)
(2,2)	0.1574*** (0.0569)	-0.2203*** (0.1093)	0.1222** (0.3392)	0.6165*** (0.1355)
Panel B: Asymmetric Shocks				
(A+D): Negative ARCH shocks		A: Positive ARCH shocks		Series Key
$a_{22}^2 + d_{22}^2$	0.4286	a_{22}^2	0.0485	1. Exchange rate
				2. World oil prices
Autocorrelation test in the mean equation				
MVLB-Q(12)	50.44 (0.3771)			
MVLB-Q(17)	84.75 (0.0825)			
MVLB-Q(24)	108.22 (0.1854)			
MVLB-Q(36)				
ARCH test in the variance equation				
MVARCH(6)	6.79 (0.6592)			

See notes to Table 4.

The results show that past shocks and past volatilities of the Ghana cedi exchange rate and the crude oil price have significant effects on their own conditional variances as the diagonal parameters a_{11}, a_{22}, g_{11} and g_{22} are significant. This result is consistent with the four-variable model. The diagonal element d_{22} is significant indicating the presence of asymmetric responses for oil prices. From panel B, the own past negative shock, $(a_{22}^2 + d_{22}^2)$ is higher (0.4286) than the positive shock, a_{22}^2 (0.0485). In the cross-market transmissions, the results differ from the four-variable model in terms of volatility spill-over. In the four-variable model oil price volatilities significantly affect the conditional variance of the Ghana cedi exchange rate. In the two-variable model however, g_{21} is not significant indicating that oil price volatility does not spill-over to the Ghana cedi exchange rate. Also, the significant volatility spill-over effect from the exchange rate to the crude oil price that was found in the four-variable model is not present in the two-variable model as g_{12} is not significant.

With regards to asymmetric responses, there are also significant differences between the two models. In the four-variable model, there was a bidirectional relationship between the Ghana cedi exchange rate and the crude oil price in terms of asymmetric effects. However, no such relationships exist in the two-variable model. Note here that the unexpected result that the Ghanaian currency has volatility and asymmetric spill-over effects on the world oil price disappear when stock markets are dropped from the model. In terms of returns linkages, the two models produce similar results. In both models, the returns of the two-variables depend on their own previous values however there are no significant cross-market return linkages. In general, some results are robust across the two models and this suggests that these inferences appear to be supported by the data. However, some results are not robust across the two specifications and this could be due to the exclusion of the stock markets. Hence, results that are not robust should be treated with caution.

6.2 Exogenous Crude Oil Price Models

We now consider specifications where crude oil prices are treated as exogenous using the TBEKK model. First, we consider the four-variable TBEKK model which includes the same variables as the four-variable full BEKK model (which are denoted with the same numbers). The model converges after 112 iterations and the results are reported in Table 6. The diagnostic tests reveal that the model passes the autocorrelation and ARCH misspecification tests (see the lower portion of panel B in Table 6).

Table 6: Four-variable GARCH-TBEKK model with exogenous oil prices

Panel A: Return, shock, and volatility spill-overs				
	Return ($\boldsymbol{R}$): Mean Equation	$\boldsymbol{A}$: ARCH effects	$\boldsymbol{G}$: GARCH effects	$\boldsymbol{D}$: Asymmetries
(1,1)	0.6196** (0.0481)	0.8104*** (0.0916)	0.0869 (0.1096)	-0.3730 (0.1720)
(2,1)	0.0038** (0.0080)	-0.0089 (0.0129)	-0.0269*** (0.0140)	0.0020 (0.0175)
(2,2)	0.6614*** (0.0525)	0.7092*** (0.0576)	0.8626*** (0.0173)	0.0734 (0.1417)
(3,1)	-0.0504** (0.0251)	-0.0503** (0.0410)	-0.0938*** (0.0565)	-0.2357*** (0.0542)
(3,2)	0.0444 (0.0634)	-0.0168*** (0.0964)	0.0142 (0.0411)	-0.1181** (0.0823)
(3,3)	-0.0634 (0.0567)	-0.1522 *** (0.1046)	0.8624*** (0.0365)	0.5500 *** (0.0951)
(4,1)	0.0457 (0.0624)	0.0404 (0.0893)	0.1127 (0.1328)	0.1863** (0.1954)
(4,2)	0.0497 (0.1670)	0.5379*** (0.0078)	-0.2908 ** (0.1979)	-0.8493*** (0.2730)
(4,3)	0.1004 (0.1003)	0.4236 *** (0.1788)	0.0598 (0.0424)	0.1728 (0.2485)
(4,4)	0.1638*** (0.0545)	-0.0819*** (0.0843)	0.1710*** (0.1726)	0.5812 *** (0.1199)

Panel B: Asymmetric Shocks				
(A+D): Negative ARCH shocks		A: Positive ARCH shocks		Series Key
$a_{31}^2 + d_{31}^2$	0.0001**	a_{31}^2	0.0053	1. Ghana stock market
$a_{32}^2 + d_{32}^2$	0.0142**	a_{32}^2	0.0003	2. Exchange rate
$a_{33}^2 + d_{33}^2$	0.3257**	a_{33}^2	0.0232	3. US stock market
$a_{42}^2 + d_{42}^2$	1.0106***	a_{42}^2	0.2893	4. World crude oil price
$a_{44}^2 + d_{44}^2$	0.3646***	a_{44}^2	0.0067	
Autocorrelation test in the mean equation				
MVLB-Q(12)	164.07 (0.9288)			
MVLB-Q(17)	236.41 (0.9417)			
MVLB-Q(24)	357.66 (0.8286)			
MVLB-Q(36)	588.13 (0.3540)			
ARCH test in the variance equation				
MVARCH(6)	95.64 (0.6048)			

See notes to Table 4.

The volatility of all the variables depend on their own past shocks as a_{11}, a_{22}, a_{33}, and a_{44} are all significant indicating a strong ARCH process. The off-diagonal elements of matrix $\boldsymbol{A}$ reveal that there are shock spill-overs from the US stock market to both the Ghana stock market and the Ghana cedi exchange rate since a_{31} and a_{32} are both significant. There are also shock spill-overs from the crude oil price to the Ghana cedi exchange rate. These results are consistent with the four-variable BEKK model results. With regards to the volatility spill-overs, the parameters in matrix $\boldsymbol{G}$ show that all the variables derive their own conditional variances from their own past volatility (except the Ghana stock market) as the diagonal elements g_{22}, g_{33}, and g_{44} are all significant indicating strong GARCH effects. From the off-diagonal elements of matrix $\boldsymbol{G}$, the Ghana cedi exchange rate and the US stock market both have significant volatility spill-over effects on the conditional variance of the Ghana stock market. The crude oil price also has significant volatility spill-over effects on the conditional variance of the Ghana cedi exchange rate. These results are similar to those from the four-variable BEKK model except that the volatilities of the Ghana cedi exchange rate and the US stock market have no effect on the Ghana stock market in the full BEKK model.

The significant diagonal parameters of matrix $\boldsymbol{D}$, d_{33} and d_{44}, indicate the presence of asymmetric responses of the US stock market and the crude oil price on their own past shocks. There are also significant cross-market asymmetric responses from the US stock market to the Ghana stock market and the Ghana cedi exchange rate. Asymmetric effects also spill-over from the crude oil price to the Ghana stock market and the Ghana exchange rate. For the asymmetries (see panel B), the effects of negative shocks are higher than positive shocks. These cross-market asymmetries were not found in the full BEKK model, and they represent differences in results from specifying crude oil prices as exogenous rather than endogenous.

In terms of return linkages in the mean equation, all variables depend on their previous values (except the US stock market) since R_{11}, R_{22}, and R_{44} are significant. These results are consistent with the four-variable BEKK model. R_{21} and R_{31} are also significant indicating the existence of return spill-overs from the exchange rate to the Ghana stock market, and from US stock market to the Ghana stock market. This contrasts with the four-variable BEKK model where no cross-market return linkages were found. Hence, the existence of cross-market return linkages in the TBEKK model represents a difference in treating crude oil prices as exogenous rather than endogenous. Some results are robust across the two models whilst others are not which could reflect differences in the specification of crude oil prices as either endogenous or exogenous. Further, the unexpected results obtained when all variables were treated as endogenous (for example, the volatility spill-over effects from the Ghana currency to the world oil price, and the asymmetric shock spill-over from the Ghana stock market to the US stock market) are not found in the TBEKK model where crude oil prices are treated as exogenous (by construction/restriction).

The final (two-variable TBEKK) model omits stock markets from the four-variable TBEKK specification. We use 1 to denote the exchange rate and 2 to denote the crude oil price. The model converges after 28 iterations, and there is no evident unmodeled autocorrelation or ARCH effects. The results are reported in Table 7 below.

Table 7: Two-variable GARCH-TBEKK Model for exogenous crude oil prices

Panel A: Return, shock, and volatility spill-overs				
	Return (***R***): Mean Equation	***A***: ARCH effects	***G***: GARCH effects	***D***: Asymmetries
(1,1)	0.6962*** (0.0492)	0.7334*** (0.0731)	0.7926*** (0.0364)	-0.0664 (0.1665)
(2,1)	0.0619 (0.1637)	0.2391 (0.2857)	-0.4336** (0.2434)	0.4721 (0.4968)
(2,2)	0.1526*** (0.1525)	-0.2287*** (0.1098)	0.1568** (0.3331)	0.6043*** (0.1274)
Panel B: Asymmetric Shocks				
(A+D): Negative ARCH shocks		A: Positive ARCH shocks		Series Key
$a_{22}^2 + d_{22}^2$	04175	a_{22}^2	0.0233	1. Exchange rate
				2. World oil prices
Autocorrelation test in the mean equation				
MVLB-Q(12)	49.27 (0.4221)			
MVLB-Q(17)	83.27 (0.1004)			
MVLB-Q(24)	107.54 (0.1977)			
MVLB-Q(36)	171.08 (0.0613)			
ARCH test in the variance equation				
MVARCH(6)	6.98 (0.6388)			

See notes to Table 4.

In the bivariate TBEKK model, shocks from crude oil prices do not affect the volatility of the exchange rate as a_{21} is not significant. However, oil price volatilities affect the conditional variance of the exchange rates because g_{21} is significant. The latter result is consistent with the four-variable TBEKK model, however, the former result is not. Another difference in results between the two models is that in the two-variable TBEKK model, crude oil prices have no asymmetric effects on the exchange rates, whereas this relationship is significant in the four-variable TBEKK model. Here, we can argue that the interactions of the stock markets in the model may play an important role in the asymmetric response between the crude oil prices and the Ghana cedi exchange rates.

The results from the models above show that world crude oil price movements have some influence on the Ghana stock market and Ghana exchange rate. In some cases, the results depend on the type of model, that is, whether the model is a two-variable or four-variable model; or whether restrictions are imposed on the model. One conclusion is that the crude oil price effect on the exchange rate is not qualitatively different in the endogenous and exogenous crude oil price models. In both models, the world crude oil price has shock and volatility spill-over effects on the Ghana exchange rate. However, the crude oil price effect on the stock market is different. In the exogenous crude oil price model, oil price shocks have asymmetric effects on the Ghana stock market. However, no such effects are found in the endogenous crude oil price model.

Our preferred models treat crude oil prices as exogenous on a priori grounds. This is based on our assumption that economic activities in Ghana cannot influence world oil prices because of the relatively small size of the Ghanaian economy. These models cannot provide implausible outcomes such as the Ghanaian currency exchange rate and the Ghana stock market affecting world crude oil prices, as found in the endogenous crude oil price model.

To explain our result that past shocks and volatility of world crude oil prices affect the volatility and conditional variance of the Ghana cedi exchange rate, we first note that Ghanaian importers of crude oil demand the US dollar. Since oil contracts in the world market are denominated in US dollars, oil importers in Ghana need to sell the Ghanaian cedi to obtain US dollars. Therefore, as oil prices increase, more US dollars are bought, which means selling more cedis. This increase in demand for the US dollar raises its exchange rate at the expense of the Ghana cedi. Hence, an increase in world oil prices will likely cause a depreciation of the Ghana cedi relative to the US dollar. Thus, world oil price shocks will likely affect the volatility of the Ghana cedi exchange rate.

Our results relating to the oil price-exchange rate relationship are consistent with Gosh (2011), Lizardo and Mollick (2011), Amano and Norden (2008), Chen and Chen (2007), Beckmann and Czudaj (2013), Turhan (2014), Aziz and Abu Bakar (2011) and Benassy-Quere et al (2007). These papers also found evidence suggesting that oil price shocks have a significant effect on the exchange rates of various countries. However, the findings of Sari et al (2010), Reboredo (2012), and Reboredo and Rivera-Castro (2013) are inconsistent with our results as they found a relatively weak relationship between oil prices and a range of currencies.

The evidence from the exogenous crude oil price model suggests that the impact of oil price movements on the stock market in Ghana is weak in terms of shock and volatility spill-overs. However, there are asymmetric shocks from oil prices to the Ghana stock market, with significant negative shocks and zero positive shocks. Lin et al (2014) found significant asymmetric effects from oil prices to the Ghana stock market which is consistent with our findings. However, in contrast to our results they found significant shock and volatility spill-over effects from crude oil prices to the Ghana stock market. This difference in results could be attributed to various factors such as the type of data and methodologies used. For example, Lin et al (2014) used weekly data from 2000 to 2010 whilst our paper used monthly data running from 1991 to 2015, which is a longer period. Also, whilst we employed four-variable BEKK models, Lin et al (2014) used bivariate VAR-GARCH, VAR-AGARCH, and DCC-GARCH specifications. However, unlike Lin et al (2014), our models additionally include exchange rates and treat crude oil prices as exogenous. Hence, our results are likely to be superior to those of Lin et al (2014) given our longer sample, inclusion of exchange rates and our more plausible treatment of crude oil prices as exogenous.

7. Conclusion

This paper explored the dynamic interactions between the world oil price, the Ghana cedi exchange rate, the Ghana stock exchange index and the US stock market index using a set of GARCH-BEKK models. The GARCH-BEKK models estimate shock spill-over, volatility spill-over, and asymmetric shocks to determine whether these markets have causal relationships between them. Because of the relative size of the Ghana stock market and the Ghanaian economy in general, the Ghana stock market and the Ghana exchange rate are not expected to influence international crude oil prices. Hence, we more plausibly treat crude oil price as exogenous in some models which represents a contribution of our paper. However, we also consider models where crude oil prices are treated as endogenous following the literature and to determine whether the treatment of crude oil prices affects the results.

Our findings suggest that the crude oil price effect on the Ghana cedi exchange rate is unchanged regardless of whether crude oil prices are treated as exogenous or endogenous. In both four-variable models, we found significant shock, volatility, and asymmetric spill-over effects from crude oil prices to the Ghana cedi exchange rate. However, the crude oil price has an asymmetric effect on the Ghana stock market in the exogenous crude oil price model, whilst in the endogenous crude oil price model, the crude oil price has no significant effect of any kind on the Ghana stock market. Hence, the model that treats the crude oil price as exogenous yields results that are more consistent with theory than the models that treat the crude oil price as endogenous. We also prefer the exogenous crude oil price model on a priori grounds since the model restricts the effects of the Ghana stock market and the Ghana exchange rate on the world oil price and US stock market to be zero, which is consistent with theoretical expectations. The endogenous crude oil price model implausibly indicates some significance of Ghana's economy on world and US markets. Hence, our conclusions are based on the four-variable TBEKK model that treats oil prices as exogenous.

Our results have some important implications for policy makers and investors. The significant shock spill-over effect from oil prices to the Ghana exchange rate implies that oil prices have a role in exchange rate movements in Ghana. Thus, the government must consider events in the world oil market when modelling the Ghana cedi movement. This result is also important for Ghanaian investors who hold diversified portfolios overseas. During turbulent times in the world oil market, internationally diversified portfolio investors in Ghana will need to evaluate their alternatives to protect their investments from exchange rate risk emanating from disturbances in the oil market. Investors can use hedging strategies such as currency forwards, futures, and options. They can also invest in hedged overseas assets such as hedged exchange-traded funds or avoid investing in overseas assets altogether.

This study has some limitations. First, we used monthly data instead of the preferred daily series. This is because daily price series for Ghana for all four-variables during our sample period was not available. Future research could re-examine this topic when daily price series for longer periods become available. Second, because governments in most developing countries such as Ghana usually provide subsidies and regulate the prices of petroleum products, the effects of domestic oil prices and world crude oil prices on economic activities could be different. Hence, future research could examine the volatility spill-over effects of domestic oil prices on the Ghanaian exchange rate and the Ghana stock market.

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Appendix

Spliced Ghana Stock Market Index, January 1991 to December 2014