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Article

Co-movement of stock exchange indices and exchange rates in Ghana: A wavelet coherence analysis

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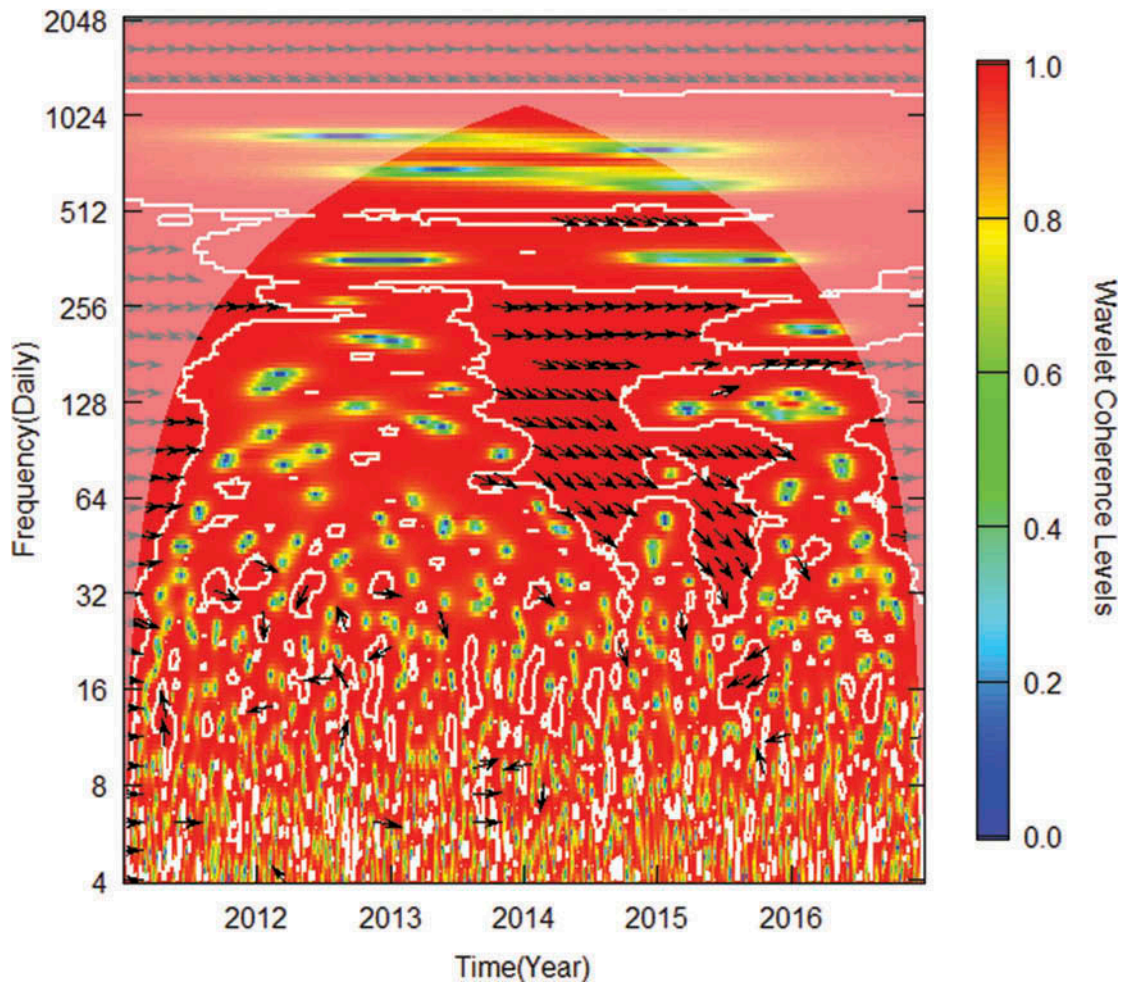
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USD/GHS and EUR/GHS prices



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BANKING & FINANCE | RESEARCH ARTICLE

Co-movement of stock exchange indices and exchange rates in Ghana: A wavelet coherence analysis

Peterson Owusu Junior^{1*}, Baidoo Kwaku Bofofo², Bright Kwesi Awuye³, Kwame Bonsu^{4,5} and Henry Obeng-Tawiah⁶

Abstract: By means of the Continuous Morlet Wavelet Transform fostering covariance/correlation, lead-lag causal relationship as well as coherency via the wavelets analysis, we explore the two indices on the Ghana Stock Exchange, the larger Ghana Stock Exchange Composite Index (GSE-CI) and the smaller Ghana Stock Exchange Financial Services Index (GSE-FSI) with the US dollar and Euro. Using daily data from January 2011 to December 2016 we confirm that there is mixed interplay of lead-lag relationships, mostly strong at lower frequencies, among the indices and the two most important exchange rates in Ghana. This paper serves as the first of its kind in the literature owing to its rich methodology and variables employed. Our study implies that investing selectively in either GSE-CI or GSE-FSI is very important and differences in co-movement of GSE-CI and GSE-FSI with the exchange rates. We reveal that there is narrowly identifiable lead-lag relationship between GSE-CI and USD/GHS and GSE-FSI and USD/GHS. Investors as revenue maximisation agents should consider the time and frequency spaces of the GSE-CI and GSE-FSI in their investment decisions involving diversification with the USD and EUR both in the short- and medium-terms (up to four years). Further, any policy meant to influence



Peterson Owusu Junior

ABOUT THE AUTHOR

Our main areas of research coalesce into financial econometrics. Coming from similar backgrounds of finance and financial engineering we delight in research encompassing these related fields. Some of our previous topics are in financial distributions, volatility models, interest convergence, long memory of interest rates, integration of African stock markets, generalised lambda distributions, etc. This study is in line with the broad studies on co-movement of across different asset classes.

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PUBLIC INTEREST STATEMENT

This research is important for the governments, traders and policymakers in Ghana and other emerging economies alike. There is the need to understand the interaction of stock markets with the various exchange rates for diverse reasons.

By the wavelets methodology we are able to show at what time of the year the dollar exchange or euro rates across the indices differed, in which months, in what direction, which rate caused the change, etc. using daily exchange rate Dollar, Euro, Ghana Stock GSE-CI and GSE-FSI data.

This will help policymakers to make informed decisions in working towards a more structured and liquid stock market. That the indices, on the one hand, move in different directions with each other and on the other hand with the exchange rates indicate to investors to take opposite positions in these assets so that they can reap the benefits of diversification as a risk management tool.

performance on the Ghana Stock Exchange should consider the time and frequency domains of the equities traded on the exchange.

Subjects: Macroeconomics; Econometrics; Finance

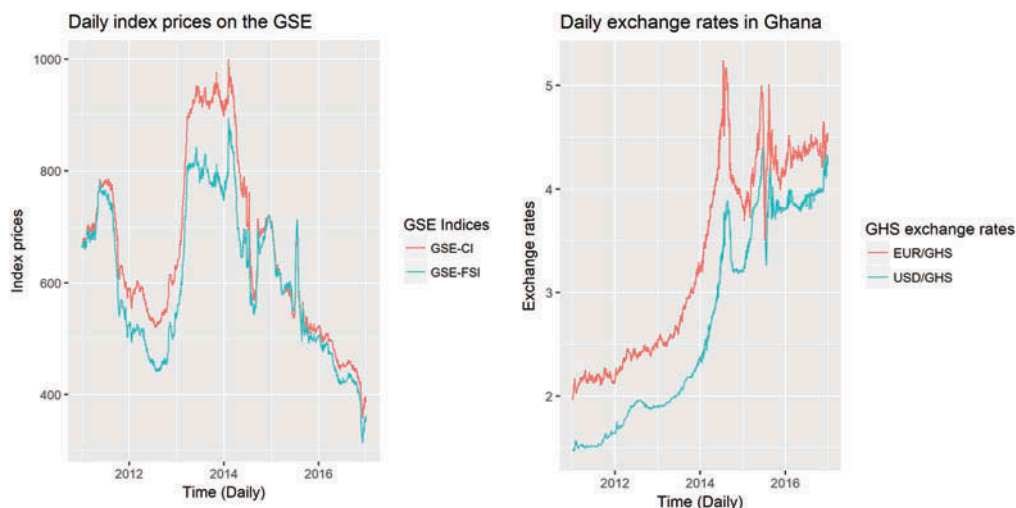
Keywords: wavelets; morlet wavelet transform; wavelet power spectrum; coherence; correlation

1. Introduction

Evidence from recent financial crisis indicates that financial markets are more dependent on each other than ever before. Price movements in one market can spread easily and instantly to another market. It is important to consider markets or prices jointly to better understand the dynamic structure underlying them. Knowing how markets are interrelated is of great importance in finance and thus for an investor or a financial institution holding multiple assets market dynamics play an important role in decision-making. There are inherent relationships among macroeconomic variables as well; the knowledge of them find use in government and private investment decision making as well. A plethora of literature has studied these relationships (see Adam & Tweneboah, 2008a; Anas, Billio, Ferrara, & LoDuca, 2007; Barakat, Elgazzar, & Hanafy, 2015; Billio, Anas, Ferrara, Duca, & others, 2007; Issahaku, Ustarz, & Domanban, 2013).

For two macro-financial time series such as the Ghana Stock Exchange Composite Index (GSE-CI) and the Ghana Stock Exchange Financial Services Index (GSE-FSI), an almost obvious economic relationship to consider is co-integration given that the latter is essentially a subset of the former. Yet another set of macro-economic variables are exchange rates; a similar relationship for the former pair can be ascribed to these, however, one is not a subset of the other. Qualitatively, one can perceive these relationships as depicted in Figure 1 for which the bigger series (in terms of magnitude) for most of the time seem to lie atop the smaller series. We use the US dollar and Euro against the Ghana cedi; respectively, USD/GHS, and EUR/GHS for this study vis-à-vis the two main indices on the GSE. The US dollar and Euro are by far the dominant international trade currencies though the use of USD on the Ghanaian market is more dominant than the Euro. Again, the United States has a well-developed financial market which contributes to the international demand for its currency (Tavlas, 1998), and Europe is Ghana's major trading block in the world, hence the choice of use of US dollar and Euro for the study. A co-integrating relationship may be seen as a long-term or equilibrium phenomenon, since it is possible that co-integrating variables may deviate from their relationship in the short run, but their association would return in the long run. The reverse implies that series could wander apart without bound in the long run. Many time series are

Figure 1. Daily indices prices on the GSE and exchange rates in Ghana.



non-stationary but “move together” over time—that is, there exist some influences on the series (e.g., market forces), which imply that the two series are bound by some relationship in the long run. Paired examples include consumption and income, different maturity interest rates, spot and futures prices for a given commodity or asset, ratio of relative prices and an exchange rate, equity prices and dividends, etc. (Brooks, 2008; Gujarati, 2011).

Macroeconomic variables are largely non-stationary and thus are modelled by vector autoregression models (VAR). If individual variables in VAR are non-stationary, but are co-integrated, we can estimate VAR by taking into account the error correction term, which is obtained from the co-integrating regression. This model is known as a vector error-correction model (VECM) which is shown to be a restricted form of the vector autoregression models (VAR) (Brooks, 2008; Gujarati, 2011). Closely related to co-integration is co-movement for which VECM has been a popular technique in analysing in multivariate framework.

The literature on co-movement of variables on a single stock exchange may not be as extant as macroeconomic variables in one economy or across economies. Since the GSE-FSI is a subset of GSE-CI it is obvious their co-movement is quite pronounced. In the light of this, our study concentrates on co-movement of these individual indices with the USD/GHS on the one hand and EUR/GHS on the other hand, and finally the co-movement between USD/GHS and EUR/GHS. In 1990 Stoll and Whaley used a multiple regression framework to examine the intra-day co-movement of the prices of index futures and stocks with the effect of infrequent trading corrected and incorporated into their analysis. Using data from Standard & Poor (S&P) 500 and Major Market Index (MMI) futures, they observed that returns lead stock index returns by about 5 min on average, but occasionally as long as 10 min or more, even after stock index returns have been adjusted for infrequent trading effects albeit the effect was not completely unidirectional, with lagged stock index returns having a weak positive predictive impact on current futures returns (Stoll & Whaley, 1990; Yong, 2006). Later, Chan (1992) validated that the MMI futures lead the underlying index despite the constituent stocks being traded more actively than the futures contract. Further evidence of futures market leadership is documented by Chatrath, Christie-David, Dhanda, and Koch (2002) in bullish market conditions using intra-day data for the futures and cash index for S&P 500 over the 1993–1996 sample period. The extent of the lead was, however, less pronounced under bearish market conditions.

For trading strategy, Brooks, Rew, and Ritson (2001) examined the lead-lag relationship between the FTSE 100 index and index futures price employing a number of time series models with 10-min intra-day observations from June 1996 to 1997. Again the spot prices were lagging their future counterparts; that lagged changes in the futures price can help to predict changes in the spot price; the best forecasting model being the error correction type, allowing for the theoretical difference between spot and futures prices according to the cost of carry relationship. For other spot-futures lead-lag relationship studies across Europe and Asia see Abhyankar (1995), Fung, Li, & Cheng (2001), Grünbichler, Longstaff, & Schwartz (1994), Iihara, Kato, & Tokunaga (1996), Lim (1992), Niemeyer (2012) and Yong (2006).

On the Ghana Stock Exchange studies of co-movement have centred on the GSE-CI and other macroeconomic variables (e.g., Adam & Tweneboah, 2008a, 2008b; Addo & Sunzuoye, 2013; Boako, Omane-Adjepong, & Frimpong, 2015; Issahaku et al., 2013). All of these studies together with those on other exchanges have used varied methodology except the wavelets analysis. Co-movement studies employing wavelets methodology in the African context have been limited, to say the least. Boako and Alagidede (2017a) and Boako and Alagidede (2016a) examine regional and global co-movement of Africa’s stock markets whereas Junior, Adam, and Tweneboah (2017) examine the co-movement of exchange rates of four countries in the West African Monetary Zone (WAMZ). Besides stock markets, the interdependence of currency markets has also been a matter of consideration.

According to Nikkinen, Sahlström, and Vähämaa (2006) the interdependence of currencies suggests that movements in exchange rates are affected not only by country-specific economic fundamentals and monetary policy, but also by other external (uncertain) drivers. In the words of Bekiros and Marcellino (2013) if currencies are linked then movements in one currency may influence other currencies beyond the impact of macroeconomic fundamentals. The trouble accompanying attempts to predict movements in exchange rates have stimulated relentless inquiries into its behaviour. Different strands have emerged from those investigations into the interdependence of exchange rate volatilities and potential contagion effects. Some earlier studies employed methodologies such as the generalised autoregressive conditional heteroskedasticity (GARCH), vector autoregressive models and Granger causality tests. In 1988, Engle, Ito and Lin based on GARCH model examined the yen/dollar pair in order to ascertain whether news in the New York market could forecast volatility in the Tokyo market many hour thence (Engle, Ito, & Lin, 1988). Following this, many papers have explored the interdependence of exchange rates based on the popular GARCH model and other variations (see Pérez-Rodríguez, 2006; Tamakoshi & Hamori, 2014). Other studies have also investigated the cause-effect relations amongst different currencies via Markov switching, VAR models and Granger causality tests (e.g., Antonakakis, 2012; Beirne & Gieck, 2014; Nikkinen et al., 2006).

Further researchers did also look at non-linear dependence based on the copula functions (see e.g., Dias & Embrechts, 2010; Patton, 2006). Patton (2006) employs a time-varying copula model and provides evidence that the dependence between the German mark and Japanese yen exchange rates is asymmetric. Also, the author reported that, the degree of dependence in times of depreciation is higher than in times of appreciation. Another study by Dias and Embrechts (2010) model the dependence of the euro and the yen returns based on the copula-GARCH model. They argued that a time-varying copula with the proposed interdependence specification gives better results than alternative dynamic benchmark models. Orlov (2009) examines the co-movements of exchange rates before and during the financial crisis (1996–1998) for nine exchange rate series from Asian countries. Using the cross-spectral methodology, he reports that the Asian crisis manifested itself in greater co-movements, particularly along the high-frequency components. Wang and Xie (2013) also used cross-correlation techniques and identified substantial cross-correlations between the Chinese yuan and the US dollar, euro, yen and the South Korean won.

In this paper, we not only study co-movement of exchange rates or stock market indices in Ghana, but we investigate the co-movement of the “cross” pairs of exchange rates and stock market indices. To the best of our knowledge, our paper seems to be the first of its kind to investigate the lead-lag relationship for two stock indices on the Ghana Stock Exchange with exchange rates via the wavelets methodology. This paper contributes to the literature by exploring the fine relationships between the GSE-CI (CI), GSE-FSI (FSI), USD/GHS (Dollar), and EUR/GHS (Euro) in pair-wise ordering for the period 4 January 2011 to 30 December 2016. By this study we are able to answer questions regarding the time and scale dynamics of these indices and exchange rates. The wavelet analysis can assess simultaneously how variables are related at different frequencies and how the relationship has evolved over time, and captures non-stationary features. This is a distinct and noteworthy aspect of wavelets as both time and frequency varying behaviour cannot be captured using previous approaches (Rua, 2010). By failing to capture time and frequency domain at the same time different techniques have yielded conflicting findings while studying co-movement between similar variables (Aloui & Hkiri, 2014a). Relatively new and adopted from physics, as compared to other major econometric methodologies, the extent of work is on the rise for the past decade mainly for advanced stock markets due to its admirable features. The wavelet multi-scale decomposition is a valuable means of exploring the complex dynamics of financial time series (Bekiros & Marcellino, 2013). The decomposition captures both time series and domain simultaneously, thus enabling higher and lower frequencies to be distinguished. Since the markets comprise of stakeholders who operate on different time horizons, and hence behave dissimilarly depending on their different time preferences (daily, weekly and monthly), the “wavelet” decomposition into sub-time series and their

localisation of the interdependence between time series becomes the most suitable econometric technique to examine the phenomenon of co-movement (Aloui & Hkiri, 2014a). Wavelet analysis takes into account both time and frequency domains of which the Vector Error Correction Model (VECM) being a widely used technique to assess co-movement is unable to accommodate simultaneously (Masih & Majid, 2013). The advantage of the wavelets technique over the VECM is the inability of the latter to accommodate frequency and time-scale domain of time series (Masih & Majid, 2013). Thus, it is possible to capture the time and frequency varying features of co-movement within a unified framework which constitutes an improvement upon previous approaches (Boako and Alagidede, 2016a; Rua, 2010).

Subsequently, latest attempts to determine the interconnectedness of currencies have used the wavelet methodology garnered by Grossmann and Morlet (1984). Examples include Yang, Cai, Zhang, and Hamori (2016) and Kumar, Pathak, Tiwari, and Yoon (2017). Yang et al. (2016) apply wavelet methodology to examine the co-movement among foreign exchange rate markets (pound, euro and yen) during the global financial crisis and the European debt crisis. They provide evidence of strong interdependence between the currencies at all frequencies especially for the euro and the pound. Kumar et al. (2017) studied the co-movement in returns of dollar, euro, pound, and yen currency pair futures contracts traded on the Indian stock exchange using the wavelet cohesion approach. The results suggest that the currency futures markets are nearly perfectly integrated in the long run, with small discrepancies that fade away within 3–6 months. On the basis of multiple-wavelet correlation and cross-correlation analysis, the pound was found to act as a potential dominating currency across scales.

Moreover, we are interested in knowing “the forest as well as the trees” with wavelets to capture useful insight on the structure and behaviour of these stock indices prices, returns and volatility (Vorlowa, 2003). What is more? We can decompose the series into frequency and time domain to reveal dynamic patterns of significant periodicities, co-movements, as well as lead-lag associations at specific moments in over the sample period courtesy wavelets. It is acknowledged that the emerging strand of the literature on the co-movement of exchange rates and stock market indices is scanty and has focused on developed economies. The paucity of the extant literature on exchange rates and their interconnectedness with stock market indices coupled with the limited knowledge has motivated a study of this nature. The results of this paper can be used by stock traders and portfolio managers on the Ghana Stock Exchange to assess the impact of the two main trading currencies in the Ghanaian economy and the efficiency in information available in the stock market. The GSE is one of the fastest growing in emerging markets which has seen keen interest from both local and international investors. Given that the GSE indices are denominated in Ghana cedi (which is very volatile against the USD and Euro) this paper can assist these investors to adopt best hedging strategies against both foreign exchange and currency risks, on the one hand, while watching the stock market (Hashim & Masih, 2015). For policy-maker and/or regulars this study helps to assess the impact of the USD dollar and Euro on the performance of the GSE-CI/ GSE-FSI. For instance, Adjasi, Harvey, and Agyapong (2008) in their study on exchange rate volatility on the GSE concluded that depreciation in the local currency leads to increase (decrease) in stock market prices in the long run (short run). This guides central bank in developing policies to protect the local currency and encourage investor confidence in the market. It also signals portfolio managers on the best investment positions to take depending on the performance of the local currency at any given time. With specific regards to the methodology, Do, Brooks, Trepongkaruna, and Wu (2016) note that the explicit understanding of linkages between stock and currency markets through wavelet coherence analysis can aid managers, investors and policy makers in forecasting reactions in the market and in minimising potential risks if adverse shocks are anticipated.

The remainder of the paper is organised as follows: Section 2 describes the methodological framework; Section 3 presents the data and statistical properties; Section 4 provides the empirical results; and Section 5 concludes the study.

2. Method

The properties of Continuous Morlet Wavelet Transform (CMWT) proposed by Morlet, Arens, Fargeau, and Glard (1982) make it a more suitable option for this study of Co-movement of the two indices on the Ghana Stock Exchange. Grinsted, Moore, and Jevrejeva (2004) identified the ability of CMWT to allow for a better isolation and identification of periodic signals through the balance between localisation of time and frequency; also best detect oscillations and peaks. The estimators of wavelet variance, wavelet correlation and wavelet cross-correlation, and wavelet coherence, which allows correlation analysis in the state-space, are key to this paper.

Using generalised Fourier integral Gabor (1946) express simultaneous time and frequency data in a signal (Heil & Walnut, 1989) and In and Kim (2013) define the continuous wavelet transform (CWT) as the product of integral over all time of the signal and scale, shifted versions of the wavelet function Ψ (scale (c), position (p), time (t)):

$$K(\text{scale, position}) = \int_{-\infty}^{\infty} x_t(c, p, t) dt \quad (1)$$

The CWT results in many wavelet coefficients K ; a function of p and s that can assume values compatible with the region of the t series x_t . If the signal is a function of a continuous variable (CV) and a transform that is a function of two CVs is needed, the CWT can be defined by Burrus, Gopinath, and Guo (1998) as:

$$F(m, n) = \int x_t \Psi\left(\frac{t-m}{n}\right) dt \quad (2)$$

Inversely

$$x_t = \iint F(m, n) \Psi\left(\frac{t-m}{n}\right) dm dn \quad (3)$$

Again Gabor (1946) uses a Gaussian window to define a windowed Fourier operator referred to as the wavelet transforms. Grossman and Morlet (1984) defined an affine coherent state integral operator. The Morlet wavelet, a plane wave modulated by Gaussian in the simplest form is as:

$$\Theta(\omega) = \pi^{-1/4} e^{i\omega\Psi} e^{-\frac{\omega^2}{2}} \quad (4)$$

where, ω is a non-dimensional “t” parameter. The “angular frequency” (or rotation rate in radians per unit time) is set to 6 to generate the permissibility of the Morlet function. The period or inverse frequency in t units is set to $2\pi/2$, since one revolution is equivalent to 2π (radians). $\Theta(\omega)$ is complex, non-orthogonal, and normalised to possess unit energy.

With the cross-wavelet power acting as correlation, we use the cross-wavelet coherence concept that offers a better examination of the time-varying relationship for bi-variate time series. Boako and Alagidede (2016a) best define wavelet coherence by investigating the cross-wavelet transform and wavelet power spectrum and phase difference.

Torrence and Compo (1998) define the bi-variate cross-wavelet transform (XWT) of x_t and y_t as:

$$W^{xy} = W^x W^{y*} \quad (5)$$

where W^x and W^y are the respective wavelet transforms which decompose the Fourier co- and quadrature-spectra in the frequency-time domain (Roesch & Schmidbauer, 2014). Concurring with Veleda, Montagne, and Araujo (2012), the WaveletComp implements the corrected version of (5) as:

$$W^{xy}(s, \tau) = \frac{1}{\tau} \cdot W^x(s, \tau) \cdot W^{y*}(s, \tau) \quad (6)$$

where s and τ are frequency and time, correspondingly. The modulus of (6) may be construed as cross-wavelet power (7); lending itself, albeit certain limitations, to an assessment of the similarity of the two series' wavelet power via:

$$P^{xy}(s, \tau) = |W^{xy}(s, \tau)| \quad (7)$$

The cross-wavelet transform (6) is the equivalence of the covariance and as with the latter (7) and is appealing geometrically since by depending on the unit of measurement of the series that may not be ready for interpretation for which wavelet coherency can remedy (Roesch & Schmidbauer, 2014).

Fourier coherency measures the cross-correlation between two time series as a function of frequency; a similar phenomenon in wavelet theory is the concept of wavelet coherency, which, requires smoothing of both the cross-wavelet spectrum and the normalising individual wavelet power spectra (without smoothing, its absolute value would be identical (Roesch & Schmidbauer, 2014). In tune with Torrence and Webster (1999), the bi-variate wavelet coherence of x and y can be given as:

$$R_t^2 = \frac{|S(W_t^{xy}(s))|^2}{S(s^{-1}|W_t^x(s)|^2) \cdot S(s^{-1}|W_t^y(s)|^2)} \quad (8)$$

where S is a smoothing operator. Mimicking the traditional correlation coefficient, it is useful to think of the wavelet coherence as a localised correlation coefficient in the frequency-time space (Ftiti, Tiwari, Belanès, & Guesmi, 2015; Madaleno & Pinho, 2010a, 2010b; Uddin, Tiwari, Arouri, & Teulon, 2013). Wavelet coherence close to one shows a higher similarity between the time series, whilst coherence near zero depict no relationship (Boako and Alagidede, 2016b).

As per Madaleno and Pinho (2012) and Torrence and Compo (1998), the phase for wavelet shows any lead-lag connections between two time series, and can be given as:

$$\theta_{xy} = \tan^{-1} \frac{I\{W_t^{xy}\}}{\Re\{W_t^{xy}\}}, \quad \theta_{xy} \in [-\pi, \pi] \quad (9)$$

An absolute value of θ_{xy} less (larger) than $\pi/2$ indicates that the two series move in phase (anti-phase, respectively) referring to the instantaneous time as time origin and at the frequency, whereas the sign of the phase shows which series is the leading one in the pair. In plots, the phase vectors are denoted by arrows (Boako and Alagidede, 2016b; Boako & Alagidede, 2017b; Ranta, 2010; Roesch & Schmidbauer, 2014).

Conraria and Soares (2011) argue wavelet analysis has the ability to extract all information about structural switched in the data through a phase difference technique. Correlation analysis, on the other hand, are unable to provide this. Differenced series showing similar periodicities do not automatically imply lead-lag relations (Pinho & Madaleno, 2011).

3. Data and descriptive analysis

3.1. Description of data

The GSE-CI is composed of all the 37 listed equity shares and the GSE-FSI constituting 13 of the listed shares with market capitalisation of USD 11,702.67 million and USD 2,601.49 million respectively. The data used are obtained from the Bloomberg Financial Database. The nominal exchange rates are the prices of a unit each of the two currencies in GHS terms, thus USD/GHS and EUR/GHS. Using the GHS as the numeraire for the two exchange rates is justifiable (Pukthuanthong & Roll, 2009); in alleviating exchange rate noise and to match the denomination of currency in the GSE. The Bank of Ghana's "Notice to Banks, Forex Bureaux and the General Public", Notice No. Bg/Gov/Sec/2014/04 indicate that exchange rates are the average interbank foreign exchange rate prevailing on the day of conversion (Bank of Ghana, 2014).

The analysis is based on 1487 daily data of GSE-CI, GSE-FSI (denominated in US dollars), USD/GHS, and EUR/GHS from 4 January 2011 to 30 December 2016; excluding weekends and holidays. The beginning of the sample period is chosen because the GSE switched from All Share Index to Composite Index by rebasing the former. Our analysis starts from thence to 30 December 2016 for which data was readily available. The exchange rates time series have been collected from the Bloomberg Financial Database as well. The USD/GHS and EUR/GHS merit use since they are fundamental currencies in many transactions around the world and more importantly in Ghana.

In our analysis we use the log returns and absolute log returns. The log return series was calculated as:

$$r_t = \ln(1 + R_t) = \ln(P_t) - \ln(P_{t-1}) \tag{10}$$

where r_t is the continuously compounded return (natural logarithm of the simple gross return of an asset).

3.2. Graphical representation

In Figures 1–3 we present the price, log-return, and absolute log-return series of the GSE-CI, GSE-FSI, USD/GHS, and EUR/GHS respectively. In Figure 1 the GSE-CI leads the GSE-FSI in magnitude for most part of the sample period except late 2014 and mid-2015. The GSE-CI return recorded negative returns during this period due to poor performance; however, the GSE-FSI outperformed the former as the prices of some financial stocks appreciated steadily during the period. These

Figure 2. Daily indices log-returns on the GSE and exchange rates log-returns in Ghana.

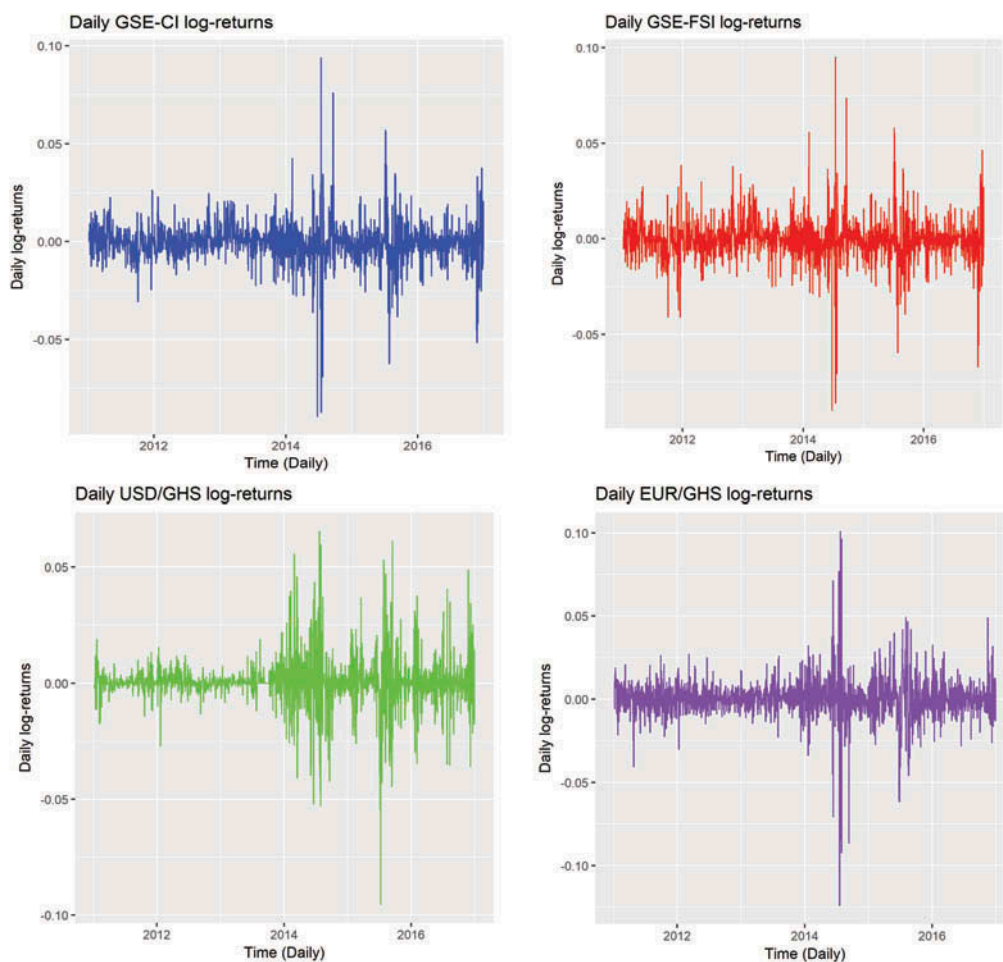
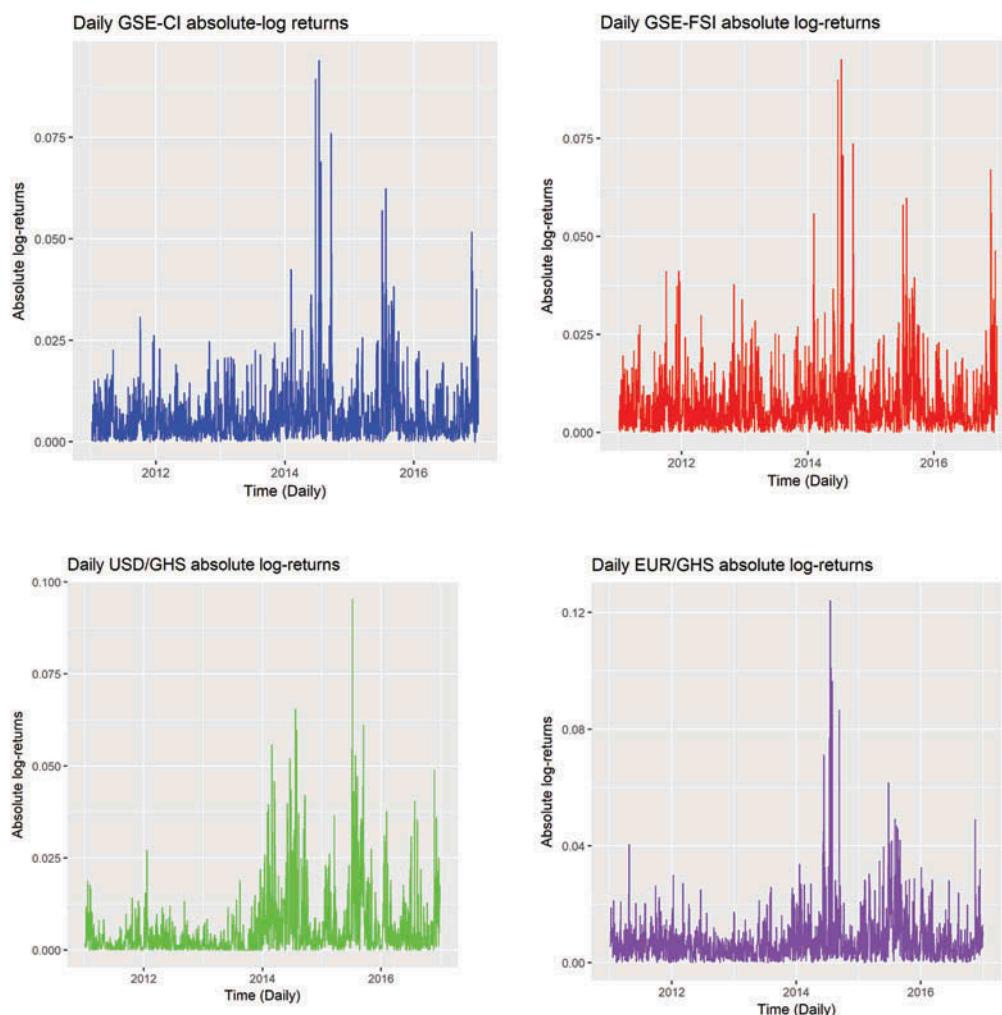


Figure 3. Absolute daily indices log-returns on the GSE and exchange rates log-returns in Ghana.



stocks, which are heavily weighted, culminated in the positive return for the GSE-FSI. On the right of Figure 1 EUR/GHS is comfortably higher than USD/GHS across the board save late 2015.

In Figure 2 the stationary (log-returns) plots of our time series are displayed. Stationarity confirmation is provided in Subsection 3.5. Figure 3 on the other hand plots the stationary series in absolute terms. Given the desirable and tractable statistical properties of returns over and against prices as the summary of investment prospects for the average investors (Campbell, Lo, & MacKinlay, 1997; Tsay, 2005), our analyses take a very intriguing turn. To be able to make co-movement analysis in absolute terms we elected to use the absolute log-returns in the wavelets methodology.

3.3. Descriptive/summary statistics

From Table 1 log-returns and absolute log-returns series are leptokurtic and heavy-tailed, and log-returns are left-skewed. It is of no surprise that the Jarque-Bera test rejects the null hypothesis of normality in all series at all conventional levels of statistical significance. The sizes of means and variances for the log-returns and absolute log-returns well differ in ordering.

3.4. Correlation analysis

Since the bi-variate wavelets analysis is in many respects correlation measured at higher powers of mathematical and statistical prowess, a simple Pearson product-moment correlation serves a good purpose for preliminary analysis. In Table 2 we find a very strong positive highly significant

Table 1. Summary statistics of indices on the GSE and exchange rates

Item Pair/ Measure	GSE-CI	GSE-FSI	USD/GHS	EUR/GHS
<i>Log-returns of indices & exchange rates</i>				
Mean	-0.0004	-0.0004	0.0007	0.0005
Variance	0.0001	0.0001	0.0001	0.0002
Skewness	-0.243	-0.0995	-0.139	-0.472
Kurtosis	15.418	11.167	12.008	348.296
Jarque-Bera	14,743 (0.000)	7729.3 (0.000)	8939 (0.000)	21,492 (0.000)
Observations	1487	1487	1487	1487
<i>Absolute log-returns of indices & exchange rates</i>				
Mean	0.0067	0.0075	0.0058	0.0079
Variance	0.0000	0.0000	0.0000	0.000
Skewness	4.156	3.523	3.308	4.723
Kurtosis	28.567	20.728	15.756	34.692
Jarque-Bera	54,841 (0.000)	29,696 (0.000)	18,094 (0.000)	80,098 (0.000)
Observations	1487	1487	1487	1487

Table 2. Correlation of indices on the GSE and exchange rates

Item/Measure	GSE-CI	GSE-FSI	USD/GHS	EUR/GHS
<i>Indices prices & exchange rates</i>				
GSE-CI	1.000			
GSE-FSI	0.962 (0.000)	1.000		
USD/GHS	-0.519 (0.000)	-0.439 (0.000)	1.000	
EUR/GHS	-0.381 (0.000)	-0.310 (0.000)	0.967 (0.000)	1.000
<i>Log-returns of indices & exchange rates</i>				
GSE-CI	1.000			
GSE-FSI	0.950 (0.000)	1.00		
USD/GHS	-0.375 (0.000)	-0.353 (0.000)	1.000	
EUR/GHS	0.0019 (0.940)	0.0053 (0.839)	-0.0348 (0.180)	1.000
<i>Absolute log-returns of indices & exchange rates</i>				
GSE-CI	1.0000000			
GSE-FSI	0.940 (0.000)	1.00		
USD/GHS	0.3748 (0.000)	0.3245 (0.866)	1.000	
EUR/GHS	0.2022 (0.504)	0.165 (0.330)	0.1863 (0.000)	1.000

correlation between the two indices and exchange rates; the highest coming from the exchange rate price pair (0.967), followed closely by the indices price pair (0.962). The rest are moderately and weakly albeit inversely correlated; GSE-CI-EUR/GHS (-0.519), GSE-FSI-USD/GHS (-0.439), GSE-CI-EUR/GHS (-0.381), and last by GSE-FSI-EUR/GHS (-0.310). All these correlations are significant at all conventional levels of confidence.

Further, log-returns except for GSE-CI-EUR/GHS, GSE-FSI-EUR/GHS, and USD/GHS-EUR/GHS which are insignificant at all conventional levels of confidence, the significant correlations are similar to those of the price series. Lastly, absolute log-returns apart from USD/GHS-GSE-FSI, GSE-CI-EUR/GHS and GSE-FSI-EUR/GHS which are insignificant at all conventional levels of confidence, the remaining pairs share resemblance with the log-returns. This does not pose a problem for the wavelets methodology which allows us to examine the relationship between the “trees” instead of the “forest” provided by the Pearson product-moment correlation. The simplest explanation for differences in the correlation between the pairs (for prices, log-returns and absolute log-returns) is the data generating process (DGP) via the log-return and absolute log-return transformations. It is, thus, not surprising that, on the one hand, the price and absolute log-return correlations differ only in magnitude but not direction; on the other hand the log-return correlation contrasts both in magnitudes and direction.

3.5. Stationarity test

To ascertain the stationarity status of the series we employ the Augmented-Dickey Fuller (ADF) test by Dickey and Fuller (1981) for level, log-returns and absolute log-returns series. The ADF rests on the null hypothesis that the series is non-stationary (or has a unit root). The results of the test are displayed in Table 3.

From Table 3 at the 5% significance level all the indices and exchange rates are non-stationary at level. The opposite is the case for both log-returns and absolute log-returns for all the series. Thus, all the variables are integrated of order one (i.e. I(1)).

3.6. Co-integration test

Following Table 3 that all the variables are I(1) we can further tests for co-integration between the pairs GSE-CI-GSE-FSI and USD/GHS-EUR/GHS based on the same null hypothesis from the ADF test but this time of the regression of these pairs. However, critical values for this test are provided by Engle and Yoo (1987). If the residuals from the regressions are I(0) then the corresponding pair is co-integrated. This test, known as the Engle-Granger co-integration test’s results are shown in Table 4.

Table 3. Augmented Dickey–Fuller test of indices on the GSE and exchange rates

Item	DF-stat	Lag order	p-Value
<i>Indices prices & exchange rates</i>			
GSE-CI	-1.280	11	0.8831
GSE-FSI	-1.4439	11	0.8137
USD/GHS	-2.7299	11	0.2693
EUR/GHS	-2.6244	11	0.3140
<i>Log-returns of indices & exchange rates</i>			
GSE-CI	-9.578	11	0.01
GSE-FSI	-9.4645	11	0.01
USD/GHS	-11.354	11	0.01
EUR/GHS	-11.736	11	0.01
<i>Absolute log returns of indices & exchange rates</i>			
GSE-CI	-7.7124	11	0.01
GSE-FSI	-7.7813	11	0.01
USD/GHS	-5.8803	11	0.01
EUR/GHS	-8.1522	11	0.01

Table 4. Engle-Granger co-integration test of indices on the GSE and exchange rates

Item	DF-stat	Lag order	P-value
<i>Log-returns of indices & exchange rates</i>			
GSE-CI—GSE-FSI	-9.0854	11	0.01
USD/GHS—EUR/GHS	-11.18	11	0.01

Table 4 confirms that the log-returns series of these pairs are co-integrated at the 5% level of significance. However, we cannot look at co-integration in the absolute values since they are stationary. If that is the case does it presuppose that co-movements between the indices and the exchange rates are the same? Perhaps not! This question is duly answered in Section 4 of this paper.

4. Results and discussions

4.1. Univariate analysis of log-returns

Roesch and Schmidbauer (2014) regard wavelet power as relative to unit-variance white noise and thus can be compared to results of other time series. Hence, we employ the wavelet power spectrum (WPS) as a measure of local variance of the underlying series in the univariate case. The WPS is given in plots with contours in time (years) and frequency (daily) axes indicated on the horizontal and vertical axes, in that order. In line with Boako and Alagidede (2016a) and Yang et al. (2016) and for easy interpretation time is expressed in years and frequency in powers of two—ranging from 4 days (lower or bottom of plot) to 2048 days (upper or top of plot). Thick white contours indicate regions of energy denoting significance at the 5% (95% confidence) level. Following a white noise process, the WPS is estimated from Monte Carlo simulations. To the right of the WPS is a colour bar depicting the steep power gradient of the significant contours ranging from blue (lower power) to red (higher power) distributed according to the intervals in the frequency. The n-shaped cone indicates the region of influence affected by edge effects. By convention periods outside the cone do not represent statistical confidence and are not considered for analysis.

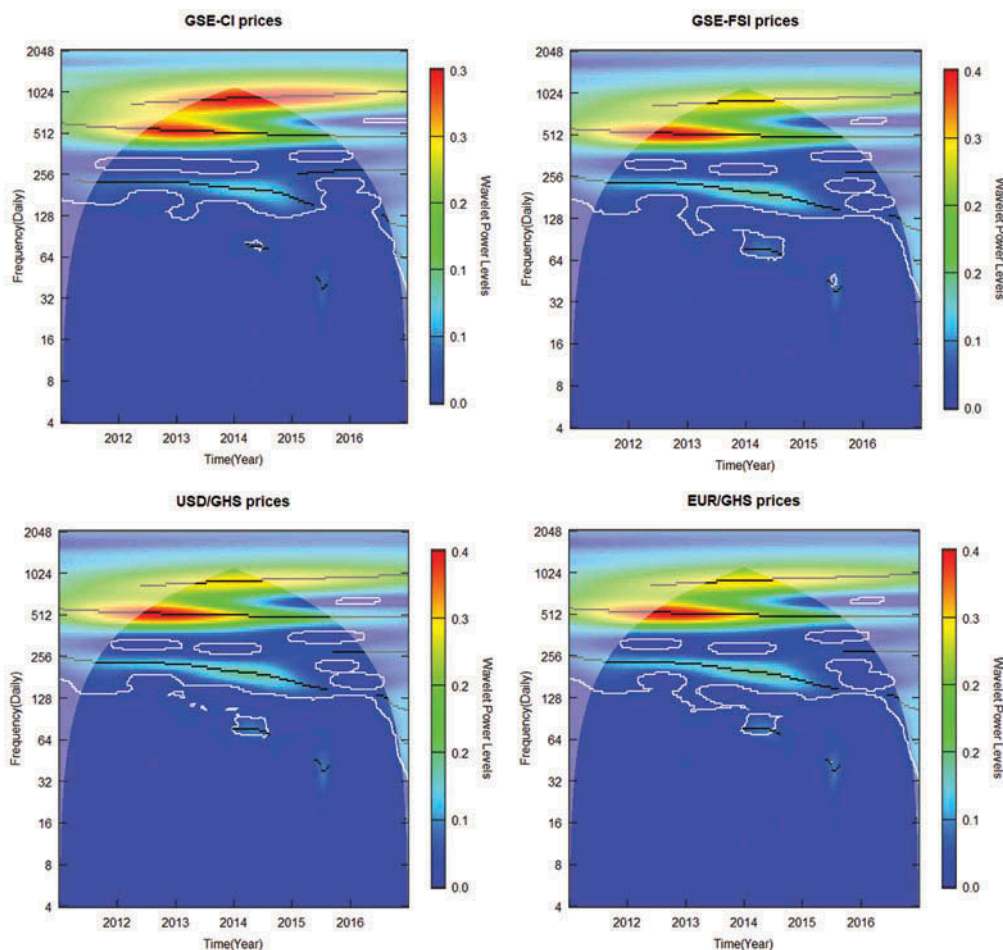
In Figure 4 is the exhibition of WPS of GSE-CI, GSE-FSI, USD/GHS and EUR/GHS in prices. That the cone of influence is unable to cover the entire daily frequency of eight-year scale (2048 days) is suggestive of the fact that long-term prediction of these indices is hardly adequate. In all cases most of the areas of high significance lie outside the cone of influence from 430 days, close to the two-year scale (512 days) on a 240-day trading per annum. There are no significant variances below the one-eighth-year scale (32 days), however, significant contours exist between the 32–340 bands across the sample horizon for all the series, albeit some of them subsumed in the insignificant regions outside the cone from mid-2015 to end of 2016.

In Figure 5; for absolute log-returns of the same series the accuracy of long-term prediction is questionable; the significant cone covers only up to the four-year scale (1024 days) but the significant contours densely populate cones, noting that the indices record high significant variances mid-2014 in the 4–16 day band but no contours prior and after mid-2015 in the 4–64 day band. In the 4–240 band there are virtually no contours for the exchange rates from 2011 to early 2014, however, moderately isolated significant variances exist for the US dollar early 2014–2016 in the 4–20 band and euro mid-2014 in the 4–8 band.

4.2. Co-movement of indices on the Ghana stock exchange

In this sub-section, we employ the wavelet coherency and phase difference to examine the co-movement of stock indices and exchange rates in Ghana. We show these plots to examine bivariate co-movements in the frequency-time domains with the wavelet coherency as a measure of local correlation among our variables; and phase differences to depict any lag or lead (causality) relationships between currency markets. In the wavelet coherence plot, we note that the area of

Figure 4. WPS of index on the GSE and exchange rates in Ghana.

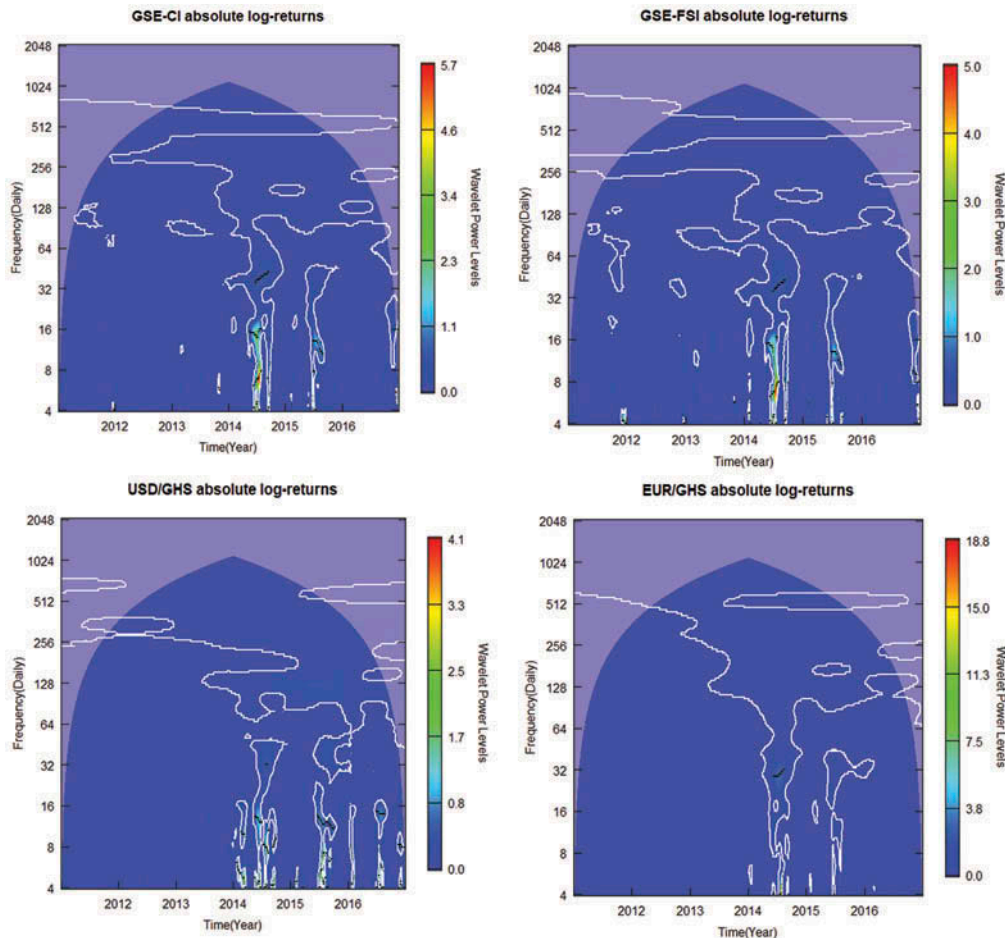


significance at 5% confidence is where the arrows are plotted only within white contour with Bartlett default smoothing window type.

Arrows to the right are suggestive of series are in-phase. To the right and up indicate the first series lags. Arrows to the right and down indicate first series is leads. Arrows to the left signal the two series are out-of-phase. To the left and up shows the first series is leading. When the move goes to the left and down, then the first series is said to be lagging (Roesch & Schmidbauer, 2014). A red colour inside the white contour at the bottom (top) of the plots represents strong co-movement at low (high) frequencies, whilst a red colour in the white contours at the left-hand (right-hand) side symbolises strong co-movement at the beginning (end) of the sample period. Arrows indicate the phase difference between two series. The order of the series corresponds with the plot headers. Further, phase-difference (for lead-lag relations) depicted by the direction of arrows differs across pairs of indices and exchange rates, frequencies and time period. Therefore, we can reject the null hypothesis that there is no (joint) periodicity in the pairs of series via *p*-values obtained from simulation (see Appendix A).

To start with we note that once again we could not rely on long-term forecasts of the indices and exchange rates since cone of influence is unable to cover the entire eight-year scale (2048 days) but only up to the four-year scale (1024 days) across the five price pairs of GSE-CI and USD/GHS, GSE-CI and EUR/GHS, GSE-FSI and USD/GHS, GSE-FSI and EUR/GHS, and USD/GHS and EUR/GHS in Figure 6 of wavelet coherencies. We also note that there are similarities between the

Figure 5. WPS of absolute daily log-returns of indices on the GSE and exchange rates in Ghana.

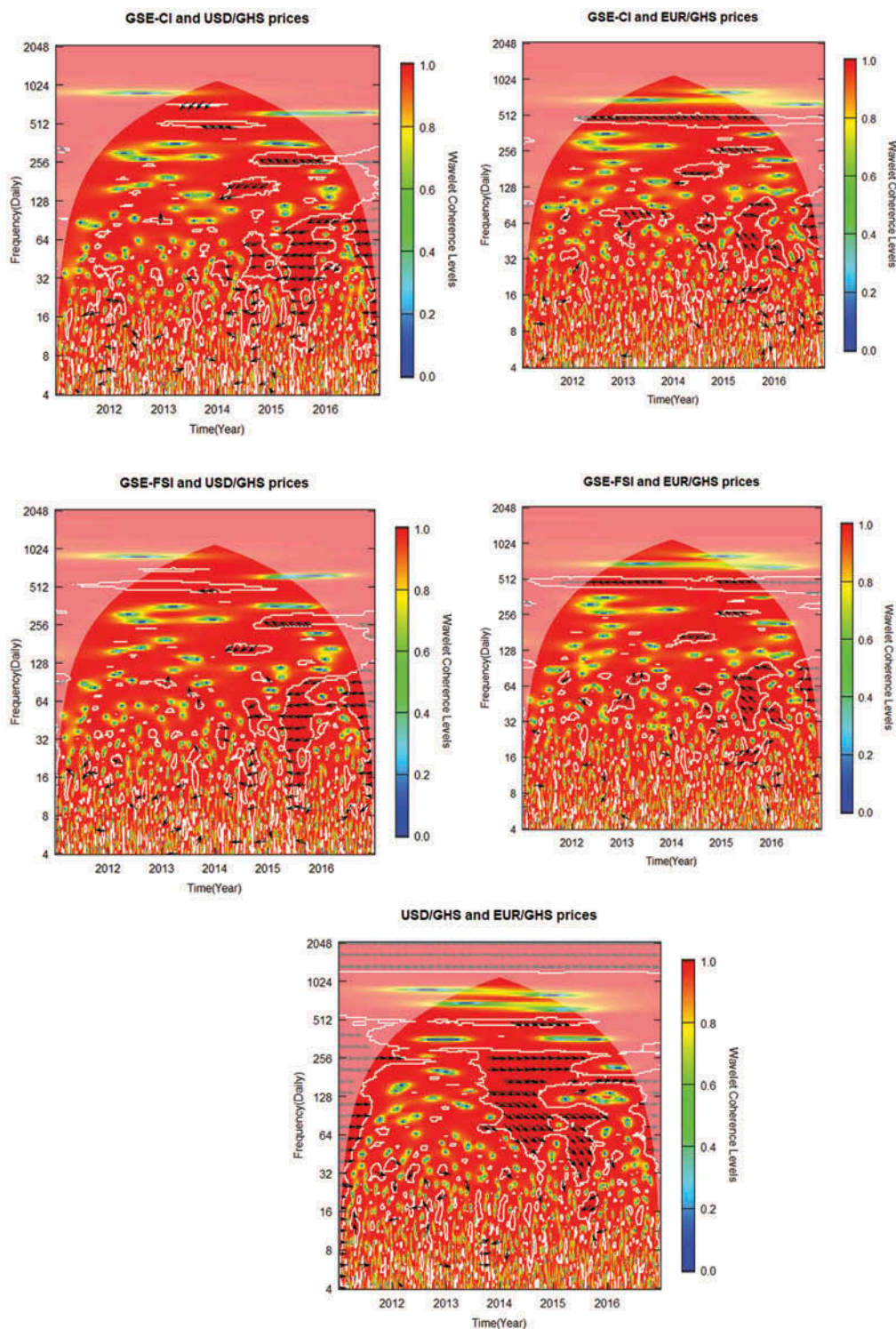


co-movement of GSE-CI and USD/GHS and GSE-CI and EUR/GHS in levels of significance, phase-difference, and no phase-difference co-movements in the two series across the sample horizon albeit contours below the two-year scale (512 days). For both pairs there are varied phase-differences sparsely populating the 4–64 daily band over the sample horizon.

Out-of-phase the CI leads on the 768 level for 2013, in the 120–192 band for 2014, for the most part of mid-2014 to late 2016 in the 12–96 band, however, it lags at the two high-frequency bands of around 400–500 and 200–300 from mid-2012 to late 2014 and mid-2014 to 2016, respectively. By size of contours USD/GHS leads the pair. For CI-Euro pair the Euro leads overwhelmingly out-of-phase over the sample horizon within the 32–512 band save it lags in 2014 inside the 128–256 band. With the FSI and Dollar duo the sparsity of co-movement is worth noting except in the 8–64 band mid-2015 where FSI leads mostly out-of-phase, also in 500–512 band for 2012–2015 and just above 128 days for 2014, but the Dollar leads around 240–280 band from mid-2014 to early 2016. The dynamics for the FSI-Euro tandem is very minimally different than the previous pair but for the 400–512 band Euro leads 2012–2016, at 200 days for 2015, in the 24–96 band 2015-mid-2016, but lags for most of 2014 a little over 128 days out-of-phase. Last in Figure 6 is the exchange rates pair (Dollar-Euro) which is densely populated only from mid-2013 to end of 2015 in the 28–270 band where the Euro leads convincingly in-phase and well as from mid-2013 to mid-2015 in the 400–512 band. The summary of the lead-lag in Figure 6 is provided in Table 5.

Figure 7 presents the wavelet coherencies of absolute log-returns pairs for the same pairs in prices. Like the price pairs we could not rely on long-term forecasts of the indices and

Figure 6. Cross-wavelet coherency of index prices on the GSE and exchange rates in Ghana.



exchange rates by the same token that the cone of influence is unable to cover the entire eight-year scale (2048 days) but only up to the four-year scale (1024 days) across the five pairs albeit very high co-movements exist beyond this excepting Dollar-Euro. Further the

Table 5. Summary of lead-lag relationship for Figure 6

Pair	Lead
GSE-CI and USD/GHS	GSE-CI
GSE-CI and EUR/GHS	EUR/GHS
GSE-FSI and USD/GHS	GSE-FSI
GSE-FSI and EUR/GHS	EUR/GHS
USD/GHS and EUR/GHS	EUR/GHS

sparsity of these pairs far outweighs those of their prices and that most paucity of co-movements are below 64 days.

It is clear the Dollar leads CI-Dollar pair summarily in-phase; at 512 days from 2012 to mid-2013, in the 190–320 from 2013 to early 2016, and 64–128 days from mid-2014 to mid-2015. On the other hand, the CI leads in-phase for 64–128 days from mid-2013 to mid-2014. In the CI-Euro pair CI leads narrowly in-phase judging by levels of frequency albeit paucity of density in significant contours and arrows from the one-quarter of a year scale (64 days) and below. The CI leads just below 1024 days for 2013–2014, by majority in the 240–512 band, and a bit in the 110–240 band from 2012 to early 2016, it lags, however, in-phase for 64–128 days mid-2015.

Further in the FSI-Dollar couple amidst no-phase difference at about 300 days for 2013 to mid-2016, Dollar lead at about 200 days in mid-2015 and in the 64–140 band from mid-2013 to late 2016 in-phase, the FSI thinly leads in-phase in composite elsewhere. Penultimately in the FSI-Euro we can confirm Euro lead in-phase in the neighbourhood of the two-year scale (512 days) from 2012 to mid-2013, in 2014 at 200 days, in 2016 at 190 days, in the 64–128 band in 2015, and late 2016 around 64 days. These subsume the leads of FSI in the cone of influence.

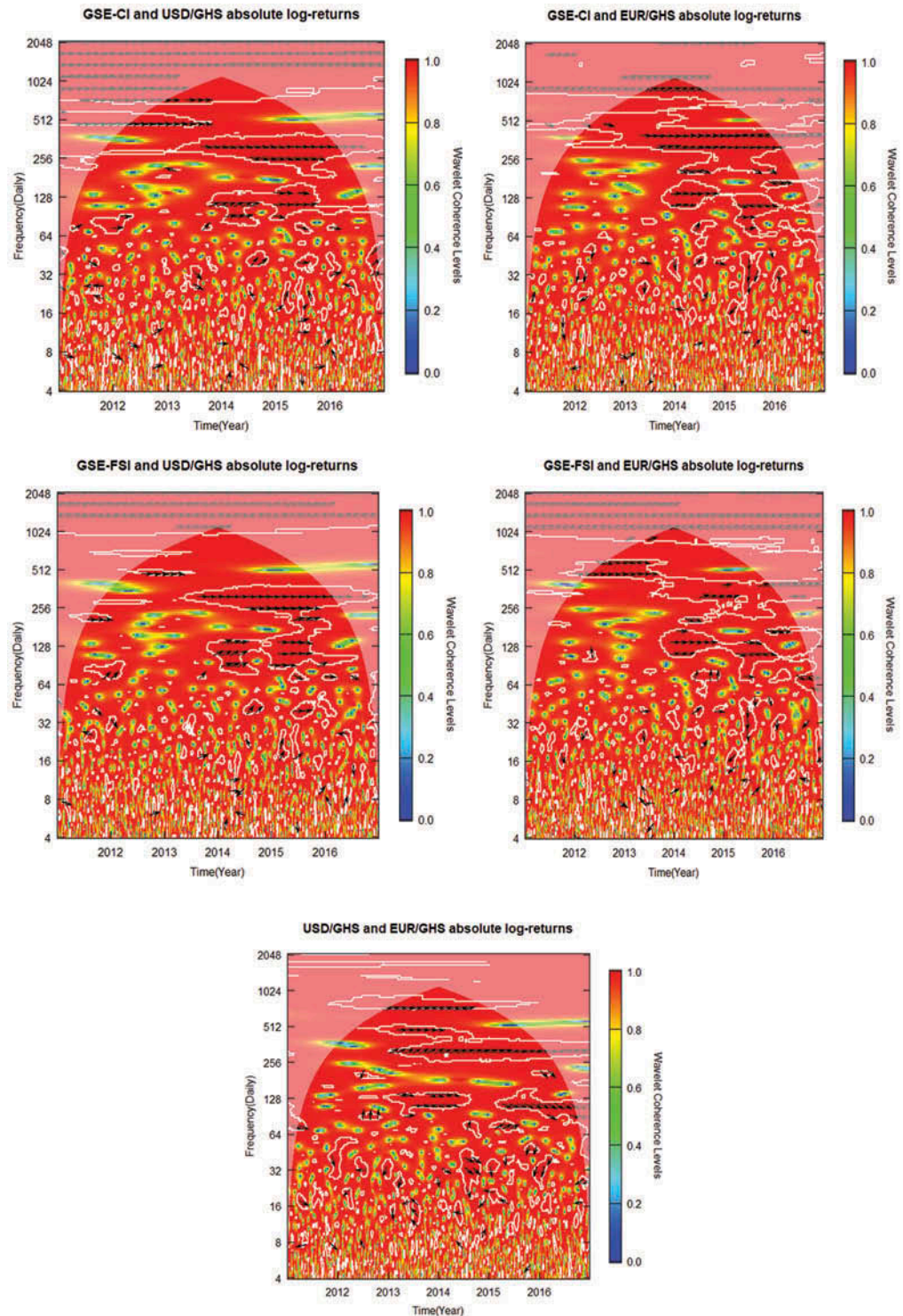
Lastly, we look at the exchange rates pair (Dollar and Euro) in Figure 7. The cumulative lead of the Dollar in-phase is rather fiercely contested at frequencies 128 days and below. But at the very high levels from 256 days the Dollar is far stronger from mid-2012 to 2016. The summary of the lead-lag in Figure 7 is provided in Table 6.

The results of this study has many similar findings in the literature. For example, the results of Aloui and Hkiri (2014b) can be compared to the results of this study in that the pattern of co-movements changes often between the countries in the Gulf Cooperation Council (GCC) at both higher and lower frequencies. Similarly, Rua and Nunes (2009) find co-movement in between Germany, Japan, United Kingdom and United States stock markets to be strong at lower frequencies suggesting that the benefits from international diversification may be relatively less important in the long-term than in the short-term which is also evident in this study (for diversification involving the USD, EUR, GSE-CI and GSE-FSI). Furthermore, that the co-movement between the indices GSE-CI and GSE-FSI vis-à-vis USD and EUR vary across time and frequency in this study is in consonance with the study by Loh (2013) which examined co-movement of Asia-Pacific with European and US stock market returns via wavelets. On emerging markets, Graham, Kiviaho, and Nikkinen (2012) investigated integration of 22 of these stock markets between the US by wavelet coherency and found high degree of co-movement at relatively lower frequencies. Also that the strength of co-movement differs by country is in line with our study that co-movements vary by index and/or currency. On the contrary, and rarely so, no lead-lag relationships between Chinese and USD markets were discovered despite their tight connectedness in the study by Kristoufek (2015) aimed at uncovering the drivers of Bitcoin price.

5. Conclusions and recommendations

The study of co-movement between finance and economic variables may find relevance for a very long time going forward. For co-movement in macroeconomic variables in Ghana, the study

Figure 7. Cross-wavelet coherency of absolute daily log-returns of indices on the GSE and exchange rates in Ghana.



through different econometric methodologies are not scarce in the literature but that cannot be said of the two main indices on the Ghana Stock Exchange and exchange rates, especially employing the superior method of wavelets. The novelty in this paper is mainly in the methodology and the variables used. That there is a long-term or co-integrating relationship between them may be

Table 6. Summary of lead-lag relationship for Figure 7

Pair	Lead
GSE-CI and USD/GHS	USD/GHS
GSE-CI and EUR/GHS	GSE-CI
GSE-FSI and USD/GHS	GSE-FSI
GSE-FSI and EUR/GHS	EUR/GHS
USD/GHS and EUR/GHS	USD/GHS

inconsequential but comparing the frequency contents and drawing conclusions about the two series' synchronicity at certain periods and across certain ranges of time is certainly not trivial.

We have, by the wavelet power spectrum (WPS), coherency and phase differences using the CMWT explored the frequency and time dynamics of the GSE-CI GSE-FSI, USD/GHS, and EUR/GHS. By the WPS we have been able isolate significant periods (frequency level) of the year (time) from their antithesis. Also by the wavelets coherency we were able to identify lead-lag associations between the series at specific times and frequencies over the sample horizon. The implications of these co-movements are duly argued by Antonakakis (2012) that the interdependence and volatility spillovers associated with currency rates, and their evolution over time are of great relevance for monetary authorities, international financial transactions, risk management and portfolio diversification.

The empirical outcomes of the study show that we could not rely on long-term forecasts of the indices and exchange rates beyond four years since significant co-movements populate only the four-year scale (1024 days) across the five pairs rather than the entire eight-year scale (2048 days). That there is narrowly identifiable lead-lag relationship between GSE-CI and USD/GHS and GSE-FSI and USD/GHS for absolute log-returns is indicative of near weak associations and hence investors stand to reap more benefits from investing in a pair of the Euro either with GSE-CI or the GSE-FSI having regard for the direction and duration for those positions. Further, it is instructive that the heterogeneity of co-movements in these assets in terms of time horizons and phase-differences should reflect in investors' decisions. In other words diversification is the key.

Thus, short-term investors could use the GSE-CI and GSE-FSI has a hedging instrument because of its weak association with either the Dollar, unlike medium- and long-term investors who may incur losses from strong coherence in middle- and low-frequency bands that defeat the benefits of diversification from others pairs of the respective assets; similarly to the conclusion in Dahir, Mahat, Razak, and Bany-Ariffin (2017). This study revealed hidden information about Ghana's equity market which hitherto were not known. Any policy meant to influence performance on the Ghana Stock Exchange should consider the time and frequency domains of the equities traded on the exchange. Further and as revealed in other studies similar to this, investors as revenue maximisation agents should consider the time and frequency spaces of the GSE-CI and GSE-FSI in their investment decisions involving diversification with the USD and EUR both in the short- and medium-terms (up to four years).

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Appendix A
p-Values from wavelets simulation

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	[12]	[13]	[14]	[15]	...		
[1,]	0.92	0.88	0.81	0.75	0.71	0.68	0.75	0.77	0.81	0.79	0.68	0.62	0.57	0.57	0.6		0.97	1.00
[2,]	0.92	0.88	0.81	0.77	0.71	0.64	0.74	0.83	0.9	0.88	0.74	0.63	0.64	0.64	0.65		0.91	0.99
[3,]	0.94	0.89	0.82	0.78	0.7	0.7	0.79	0.88	0.98	0.91	0.79	0.68	0.67	0.66	0.69		0.92	1.00
[4,]	0.94	0.86	0.83	0.8	0.73	0.71	0.8	0.88	0.93	0.87	0.8	0.71	0.67	0.64	0.69		0.95	0.99
[5,]	0.91	0.84	0.81	0.78	0.7	0.68	0.75	0.8	0.81	0.83	0.73	0.68	0.66	0.67	0.69		0.94	0.98
[6,]	0.9	0.85	0.79	0.71	0.62	0.64	0.65	0.7	0.7	0.68	0.67	0.65	0.65	0.68	0.72		0.87	1.00
...																...		
...																...		
...																...		
[176,]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
[177,]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
[178,]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
[179,]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
[180,]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
[181,]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0



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