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Comovement between commodity returns in Ghana: the role of exchange rates

Zynobia Barson[1*], Peterson Owusu Junior[1] and Anokye Mohammed Adam[1]

*Correspondence: barson.zynobia01@gmail.com

[1] Department of Finance, School of Business, University of Cape Coast, Cape Coast, Ghana

Abstract

This paper examines the relationship between commodity returns in Ghana and if any, the role of exchange rate on such relationship using wavelet analysis and monthly data from September, 2007 to March, 2021. We test for the robustness of the empirical findings using multiple wavelet analysis. We find that exchange rate plays an intrinsic role in the dynamic comovement of commodity returns with strong coherence at short and medium terms. The partial wavelet coherence analysis shows that exchange rate drives commodity interdependence. This study is of relevance to other developing export-dependent countries and the Ghanaian government in making strategic trade policies and to investors that are interested in these cross-sector commodities. Governments and investors that are privy to the intrinsic role of exchange rate on its dependent commodities can benefit from this study to diversify against exchange rate fluctuations and the implicit effect of inflation.

Keywords: Connectedness, Wavelet analysis, Export-dependent, Coherence, Ghana

1 Introduction

Commodity prices influence the economic growth and standard of living of developing or low-income countries (Addison et al. 2016) empirically identified as import-dependent with relatively low exports as compared to aggregate imports (Arezki et al. 2014). In such countries, commodity prices could affect the demand and supply of other currencies used for trading because implicitly, exchange rates determine trade levels (Cashin et al. 2004; Ahmad et al. 2014). Frankel and Rose (2010) asserted that commodity prices might potentially affect exchange rates and as stipulated by Arezki et al. (2014), there are long-term trade fluctuations in commodity prices that cause changes in exchange rate prices. There is also a plethora of studies contributing to the literature that exchange rates are influenced by commodity prices (Chen and Rogoff 2003; Arezki et al. 2014; Bashar and Kabir 2013; Chen et al. 2010; Zhang et al. 2016; Salisu et al. 2018; Liu et al. 2020). Literature has also proven that there is comovement between exchange rates and commodity prices where both variables interdependently lead and lag at various time horizons noting their bi-directional causality as well (Chen and Rogoff 2003; Chen et al. 2010; Salisu et al. 2018). As has been empirically proven, primary commodity prices predict exchange rate prices (Arezki et al. 2014; Zhang et al. 2016; Salisu et al. 2018; Liu

et al. 2020) and in most export-dependent and developed countries (Haider et al. 2021). There is also a surfeit of literature exploring the connectedness of commodity prices (Pindyck and Rotemberg 1990; Ai et al. 2006; Bouri et al. 2021; Cai et al. 2019; Frimpong et al. 2021).

Pindyck and Rotemberg (1990) have reported that there is comovement between commodities in different production sectors or unrelated commodities attributable to macroeconomic variables and the effects from the commodities' past and current prices. Looking at studies from Diebold et al. (2017), Balli et al. (2019), Zhang and Broadstock (2020), Luo and Ji (2018), Kang et al. (2019), Kumar et al. (2021), Maitra et al. (2021), Albulescu et al. (2020), Caporin et al. (2021), Kirikkaleli and Güngör (2021), Farid et al. (2022), Naeem et al. (2022a), Naeem et al. (2022b), Umar et al. (2022), Barson and Owusu Junior (2023), etc., there is enough evidence backing Pindyck and Rotemberg (1990)'s claim of cross-sector commodity connectedness. Comovement of commodity returns reflects time-varying lead–lag relationships at various phase differences (Ohashi and Okimoto 2016; Kang et al. 2019; Liu et al. 2020; Farid et al. 2022; Mastroeni et al. 2022; Naeem et al. 2022a, 2022b); with significant comovement in the short run as opposed to the long-run comovement (Sari et al. 2010; Chen et al. 2010; Zhang et al. 2016; Ohashi and Okimoto 2016) which, however, does not affect the bi-directional granger causality that exists between commodities (Bashar and Kabir 2013; Liu et al. 2020; Zhang et al. 2016).

With increasing cross-sector commodity connectedness which strengthens in the events of crises (Diebold and Yilmax 2015; Baruník et al. 2016; Balli et al. 2019; Xiao et al. 2020; Bagheri and Ebrahimi 2020; Zhang & Broadstock 2020; Balcilar et al. 2021; Bouri et al. 2021; Mensi et al. 2020; Ozili 2022), we use the theory of balance of payment to explain the link between exchange rates and commodity returns in Ghana. First, Malik and Umar (2019) were able to show that shocks in oil prices significantly caused simultaneous volatility in exchange rates after the global financial crisis (GFC). Their study was a confirmation of literature from Krugman (1983) and Bloomberg and Harris (1995) which theoretically showed that the domestic balance of payment accounts of countries that trade in oil is favourable based on the demand of the respective exchange rates of oil exporting countries. Implicitly in line with the balance of payment theory, an export-dependent country would have a favourable (unfavourable) balance of payment account when the commodity prices cause an appreciation (depreciation) in the currency based on the benefits of the law of demand and supply as reflected in the variations of the exchange rate. Studies like that of Buetzer et al. (2016), Ridler and Yandle (1972), Gilbert (1989), Lizardo and Mollick (2010), Plumb et al. (2013) and Archer et al. (2022) have confirmed that the increase (decrease) in commodity prices causes an appreciation (depreciation) of the export-dependent country' currency via exchange rates affirming the wealth effect mechanism (Golub 1983; Krugman 1983). Across global forex markets also, Wen and Wang (2020) averred that commodity export, forex regimes and macroeconomic policies (monetary) cause fluctuations in exchange rate markets (see Barunik et al. 2016; Tiwari and Albulescu 2016; Albulescu et al. 2019). Congruently, Cashin et al. (2004) found evidence for a long-run relationship between exchange rates and commodity prices emphasising its time-varying nature and deflating the purchasing power parity theory.

In Ghana, there is literature from Archer et al. (2022) who explored the asymmetric dependence between commodity prices (cocoa, crude oil and gold) and exchange and Boateng et al. (2022) who have also assessed the interconnectedness among the export-dependent commodities and external shocks considering the real sector of Ghana, respectively. Archer et al. (2022) showed that prices of crude oil (turbulent conditions) and cocoa (normal and extreme market conditions) cause appreciation in the Ghanaian Cedi. The findings from Boateng et al. (2022) also revealed that in the medium term, gold causes an increasing inflation rate but not cocoa and crude oil—from 2006 to 2011—but in 2019, commodities were the leading variables and had a negative relationship with inflation. Also, Damba et al. (2021) found that among gold, cocoa and crude oil, investors would be better off if they invested in cocoa than the other commodities due to improved premium prices. Another study by Boako et al. (2020) also showed that the oil prices in Ghana are more correlated with other stocks than gold and cocoa are to stock markets.

With these studies in Ghana exploring the link between commodity prices and exchange rate, determining which commodity is more profitable to investors, barely is there any literature that has explicitly assessed the cross-sector comovement of the commodities that Ghana is export-dependent on. Also, as a developing country, the Ghanaian government ought to know the impact of macroeconomic variables such as the exchange rate on its commodities so that it can serve as a reference for policy-making and investment decisions. Furthermore, the debate on the dominance of either commodity prices or exchange rates in predicting the other is still open (Sari et al. 2010; Owusu Junior et al. 2019). Hence, if commodities are strategically positioned, would their returns predict exchange rate or otherwise, and/or are they interrelated? Thus, this literature seeks to explore the comovement in the dominant commodities in Ghana (gold, cocoa and Brent crude oil). Secondly, we examine the role exchange rate may have on these commodity comovements by exploring its direct and controlled effect on the respective commodity returns. Lastly, if the export-dependent commodities comove as stipulated by Pindyck and Rotemberg (1990), there would be a need to analyse if exchange rate initiatives the comovement between commodities.

For this study, we use the nominal exchange rates based on the purchasing power parity (PPP) hypothesis of one price however, exchange rates have been more volatile than relative price levels (Stockman 1980). PPP is reportedly a model-based criterion of nominal exchange rates (Qayyum et al. 2004) and also defined by Dornbusch (1985a, b) as the "inflation theory of exchange rates". The PPP theory is most reflective in the long run where one can explore if changes in exchange rates produce changes in relative prices, and are not fully reflected in differential inflation (Qayyum et al. 2004). As a price-based theory of exchange rate determination, the PPP focuses on changes in price levels, as the overriding determinant of exchange rates (Dornbusch 1985a, b; Nakorji et al. 2021). Collins et al. (1980) assert that to have a reflective meaning to the relationship between exchange rates and commodity prices, one should use nominal exchange rates which capture inflation rates. The nominal exchange rates which are reflective of inflation have been empirically proven to comove with commodity prices (Nakorji et al. 2021). We also use the monthly returns of gold, cocoa and crude oil based on the 2021 State of Commodity Dependence Report—which states that these three commodities are the most

traded in Ghana. In the United Nations Conference on Trade and Development (UNCTAD) 2-year State of Commodity Dependence Report (2021), commodity dependence is exclusively a developing country phenomenon. The report states that Ghana is dependent on the export of minerals, ore, and metals. However, its three leading commodity exports are in the sectors of agriculture, fuels, and metal; cocoa, Brent crude oil and gold, respectively.

To contribute to the literature on the increasing commodity connectedness and the relationship between exchange rate and commodity prices, we explore the comovement of commodity returns in Ghana and the role of exchange rate on that comovement if any. First, we explore the comovement of export-dependent commodities in Ghana using the bivariate wavelet approach. We adopted the biwavelet technique to explore the level of comovement in a time–frequency domain keeping in mind that investors or traders are heterogeneous and adaptive in the markets (Müller et al. 1997; Lo 2004). Our second contribution is towards the debate of the dominancy in either exchange rate or commodity prices (returns) in predicting the other. The biwavelet approach provides outputs that help to determine which of the variables leads or lags at a particular point in time. Lastly, if there is any comovement in the cross-sector commodities, we contribute to the literature on the role of exchange rate in such comovement using the partial wavelet technique to explore the controlled effect of exchange rates on commodity returns comovement. The biwavelet and partial wavelet techniques were used due to their uniqueness in decomposing data into localised time and frequency, for analysing the control external effects and suitable for working with non-stationary data (Bakas and Triantafyllou 2018; Rouyer et al. 2008; Tweneboah et al. 2019; Owusu Junior et al. 2019). We also use the multiple wavelet coherence analysis to test the robustness of the findings (Oygur and Unal 2021).

The findings from the biwavelet analysis show a dominant transmission from exchange rate to gold and crude oil only. But the dominating characteristics of the exchange rate give it a contagion effect on crude oil and gold just as cocoa has on exchange rate. The biwavelet analysis also shows that the unrelated commodities comove depicting features of interdependence (Pindyck and Rotemberg 1990; Zhang and Broadstock 2020; Luo and Ji 2018; Maitra et al. 2021; Albulescu et al. 2020; Caporin et al. 2021; Farid et al. 2022; Barson and Owusu Junior 2023). Thus, we went on ahead to explore the contribution of exchange rate on such comovement. The results subsequently prove the significant effect of exchange rate on commodity comovement (Harri et al. 2009; Bodart et al. 2015; Zhang et al. 2016) because the strong coherence between the commodity prices no more exhibit comovements when exchange rate is controlled for. Still on the debate on the dominance of either exchange or commodity prices predicting the other, we report a contagion effect between both commodity returns and exchange rate where however, only cocoa dominates the contagion in exchange rate. The multiple wavelet analysis shows that our findings are robust because the returns of the commodity prices as explanatory factors barely show any coherence at the various frequencies.

The dynamic comovement between commodities at different localised time and frequency is influenced by the structure of the market and participants theorised to set prices of commodities according to different market situations across heterogeneous markets (Müller et al. 1997; Patil and Rastogi 2019; Barson et al. 2022). In a

heterogeneous market, the Adaptive Market Hypothesis (AMH) reports that the differences that exist in market participants adjust over time because market efficiency is dependent on market conditions (Lo 2004; Zhou and Lee 2013). The implications of this study would help government make effective policies that would put its exports in a strategic position in the global market. The interrelatedness of exchange rate and commodity returns could be capitalised on by individuals and firm producers who depend on imports for inputs, and investors who contribute to the balance of payment of the Ghanaian economy to diversify in the international markets. Also, to the government, when drawing up monetary (trade) policies and more importantly, as the government is taking measures to liberalise the structures of international trade through the African Continental Free Trade Area (ACFTA), the findings from this literature would be advantageous. The study also finds that the COVID-19 pandemic poses no threat to the comovement of commodity returns and exchange rate. Empirically, developing countries that are export-dependent on either gold, cocoa and or gold can also capitalise on these findings to make effective government decisions.

The rest of the paper is in Sect. 2 (Methodology); Sect. 3 (Data description); Sect. 4 (Results and discussion) and Sect. 5 (Conclusion of the study).

2 Methodology

The study investigates the time–frequency comovement between exchange rates and commodity returns. The wavelet analysis is suitable for the study because of the non-stationarity, non-linearity and asymmetry of the data series used. Wavelet overcomes the non-stationarity effect by decomposing the times series data into time and frequency (Rouyer et al. 2008). Also, the wavelet analysis allows the simultaneous analysis of comovement at the frequency level and localised time between the exchange rate and commodity returns (Owusu Junior et al. 2019). We used the biwavelet and vectorwavelet packages in the R programming software version 4.0.2.

2.1 Bivariate wavelet (biwavelet)

The biwavelet technique is employed to assess the time–frequency comovements of our variables. The biwavelet can also be used to infer interdependence (low frequency) and or contagion (high frequency) (Frimpong et al. 2021; Gallegati 2012).

2.1.1 Continuous wavelet transform (CWT)

We adopt the Continuous Wavelet Transform (CWT) for better extraction feature (isolation and identification) purposes, data compression, best detects peaks and oscillations and to map the changing properties of non-stationary signals (Yang et al. 2016; Owusu Junior et al. 2019; Asafo-Adjei et al. 2020). The fundamentals of wavelet analysis comprise two factors: time or location (Ø) and frequency (s), expressed below:

$$\Psi_{\phi,s}(t) = \sqrt{s}^{-1}\,\Psi(t-\phi)\left(s^{-1}\right), \Psi(\bullet) \in L^2(\mathrm{R}), \tag{1}$$

where $\sqrt{s}^{-1}$ is the standardisation factor, ensuring that the unit variance of the wavelet $\left\|\Psi_{\phi,s}(t)\right\|^2 = 1$; $\phi\|$ is the location factor, offering the exact place of the wavelet

coherence; $L^2(\mathrm{R})$ is a set of square-integrable functions on the real line; and s is the scale dilation factor, describing the overextended nature of the wavelet.

The Morlet wavelet can be expressed as below:

$$\varphi^M(t) = \frac{1}{\pi^{1/4}} e^{i\omega_o t} e^{-t^2/2}, \tag{2}$$

where the dominant frequency of the wavelet is ω_o. We set ω_o at 6 (Asafo-Adjei et al. 2020; Frimpong et al. 2021; Wu et al. 2020a, b) to generate the tolerability of the Morlet function (Owusu Junior et al. 2019).

The time series $x(t)$ can be decomposed, based on a selected mother wavelet as:

$$W_x(\phi, s) = \int_{-\infty}^{\infty} x(t) \sqrt{s}^{-1} \Psi^* \left(\frac{t - \phi}{s} \right) dt. \tag{3}$$

By protruding the specific waveletΨ (with * being the complex conjecture operator) onto the chosen time series, we undoubtedly attain $W_s(\phi, s)$. Compatibly, the crucial benefit of a CWT is its flair to decompose and reconstruct the function $x(t) \in L^2(\mathrm{R})$:

$$x(t) = \frac{1}{C_\varphi} \int_0^{\infty} \left[\int_0^{\infty} W_x(i, s) \Psi_{\phi,s}(t) d\phi \right] \frac{ds}{s^2}, s > 0. \tag{4}$$

The CWT is a pre-requisite for investigating coherency (lead–lag) and phase difference between two time series.

2.1.2 Wavelet transform coherence (WTC)

The squared absolute value of a wavelet cross-spectrum normalisation to a single spectrum of wavelet power is well known as the Wavelet Transform Coherence (WTC) (Torrence and Compo 1998). Accordingly, the squared wavelet coefficient is defined as:

$$R^2(x, y) = \frac{\left| \lambda \left(s^{-1} W_{xy}(\phi, s) \right) \right|^2}{\lambda \left(s^{-1} |W_x(\phi, s)|^2 \right) \lambda \left(s^{-1} \left| W_y(\phi, s) \right|^2 \right)}, \tag{5}$$

where λ is a smoothing factor, which balances resolution and significance, and $0 \le R^2_{xy}(\phi, s) \le 1$. A wavelet coherence near 0 specifies a weak or no relationship, whereas a figure near to 1 depicts a strong comovement between the variables (Yang et al. 2016; Owusu Junior et al. 2019; Asafo-Adjei et al. 2020; Mensi et al. 2020). The bias in the wavelet power spectrum and wavelet cross-spectrum is removed by the standardisation function (Frimpong et al. 2021; Wu et al. 2020a, b). For a precise significance level of the WTC, the Monte Carlo procedure would be used for simulation; the theoretical distribution of the WTC coefficient is unidentified (Torrence and Compo 1998).

2.1.3 WTC phase difference

The wavelet transforms coherence phase difference indicates the disruptions in the fluctuation of the observed time series. Following Bloomfield et al. (2004) and Torrence and Compo (1998) the phase difference between $x(t)$ and $y(t)$ is characterised as below:

$$\Omega_{xy}(\phi,s) = \tan^{-1}\left(\frac{\Im\{S(s^{-1}W_{xy}(\phi,s))\}}{\Re\{S(s^{-1}W_{xy}(\phi,s))\}}\right); \quad \Omega_{xy} \in [-\pi,\pi], \tag{6}$$

where $\Im$ and $\Re$ are the imaginary and real operators, respectively. In the wavelet coherence map, the directional arrows are used to differentiate diverse phase patterns of the wavelet coherence difference—$x(t)$ and $y(t)$ are in-phase (antiphase), the arrow points to the right (left); if the arrow points down (up), this implies that $y(t)$ (or $x(t)$) is leading (Asafo-Adjei et al. 2020; Frimpong et al. 2021; Wu et al. 2020a, b). Also, $|\Omega_{xy}| < \frac{\pi}{2}$ indicates that the two phase move in-phase and vice-versa, respectively (Owusu Junior et al. 2019).

2.2 Partial wavelet (PWc)

Partial wavelet coherence is a technique in wavelet analysis similar to the partial correlation which is considered effective for measuring the correlation between two time series ($x(t)$ and $y(t)$) after controlling for and removing the influence of time series $z(t)$. PWc helps in solving the problem of "untainted" correlation between two time series on wavelet coherence by eliminating the impact of the third effect (Frimpong et al. 2021; Mensi et al. 2020; Wu et al. 2020a, b). For this study, the partial wavelet coherence is used to eliminate the effect of exchange rate on commodity returns; cocoa, crude oil and gold. This would help find the real correlation and interconnectedness of these commodities if any.

The coherence among $x_{(t)}$ and $y_{(t)}$, $x_{(t)}$ and $z_{(t)}$ and $y_{(t)}$ and $z_{(t)}$ is transcribed as:

$$R(x,y) = \frac{\lambda[W(x,y)]}{\sqrt{\lambda[W(x)] \bullet \lambda[W(y)]}}, \tag{7i}$$

$$R^2(x,y) = R(x,y) \bullet R(x,y)^*, \tag{7ii}$$

$$R(x,z) = \frac{\lambda[W(x,z)]}{\sqrt{\lambda[W(x)] \bullet \lambda[W(z)]}}, \tag{7iii}$$

$$R(y,z) = \frac{\lambda[W(y,z)]}{\sqrt{\lambda[W(y)] \bullet \lambda[W(z)]}}, \tag{7iv}$$

$$R^2(y,z) = R(y,z) \bullet R(y,z)^*. \tag{7v}$$

Following Frimpong et al (2021), Mensi et al (2020), Wu et al (2020a, b), Wu and Wu, (2020), PWc can be designated using an equation analogous to the partial correlation squared, as

$$R_p^2(x,y,z) = \frac{\left|R(x,y) - R(x,z) \bullet R(x,y)^*\right|^2}{\left[1 - R(x,z)\right]^2\left[1 - R(y,z)\right]^2}, \tag{7vi}$$

where $R_p^2(x, y, z)$ ranges from 0 to 1. This section employs x and y to mean the commodity price returns while z denotes the exchange rate index. Monte Carlo methods are used to estimate the level of significance of the PWc. A low R^2p region observed where a high R^2 region indicates that time series y does not have a significant influence on x instead, the time series z dominates the variance of x. If there is no difference between R^2p and R^2, both y and z have a significant influence on x.

3 Data source and data description

From the UNCTAD (2021)'s State of Commodity Dependence report, dominantly, there are 5 countries (China, Germany, Japan, USA and Netherlands) contributing to 40% of global exports in 2008–2009 and, in 2018–2019, India (increased exports of 1.3%) replaced Netherlands (recorded a decrease in exports of 0.8%). The UNCTAD 2021 report groups the commodity dependent countries into geographical sectors where it reports that in the Africa geographical region, Southern African has the lowest level of commodity exports (with South Africa contributing the largest at 83%), Northern Africa follows closely (but in this region Algerian and Libya contribute 70% of exports), while Eastern Africa, Middle Africa and Western Africa contribute 78.9%, 94.7% and 94.8% to export-dependency all in 2018–19. Comparatively, Ghana as a sub-region in Western Africa, it contributes a relatively small percentage to the aggregate commodity dependency as compared to other sub-regions in Africa, Americas, Europa, Oceania and Asia though it is dependent on agricultural and mineral exports. Aside from this, Ghana has remained a commodity dependent country in both 2008–09 and 2018–19 as part of the larger group of developing countries (87 developing countries are commodity dependent). The UNCTAD (2021) report showed that Ghana is export-dependent on cocoa, Brent crude oil and gold. For countries that are export-dependent on cocoa (4 countries), gold (47 countries) and crude oil (44 countries), Ghana is ranked 3rd for its dependency on cocoa (16.6%), 9th for its dependency on gold (34.9%) and 26th for its dependency on crude oil (29.9%) as in the UNCTAD (2021) report; as per each country's merchandise and commodity export-dependence.

Sampling the commodity prices (cocoa, gold and crude oil) that Ghana is export-dependent on, the prices were gleaned from the Bank of Ghana Economic Indicators website (https://www.bog.gov.gh/economic-data/commodity-prices). The motivation to use these variables in our study is from the UNCTAD (2021) which records that these goods are strategically positioned in the Ghana trade sector. The data on exchange rate were extracted from YahooFinance (https://finance.yahoo.com/quote/GHS=X?p=X&.tsrc=fin-srch). The prices of the commodities are the international monthly average closing-selling-export prices of cocoa, Brent crude oil and gold in Ghana. The study uses monthly returns of the commodity prices covering the period of September 2007 to March 2021 after the data were cleaned for missing data (matched with trading dates of the commodity prices and exchange rates). The sampled data size is relatively large while complementing the method used with its span (Bakas et al. 2018; Chen et al. 2010; Owusu Junior et al. 2019) and nature (Pindyck 2004). The data set is quoted in the USD/GHS for exchange rate and the commodity prices as cocoa (USD/tonne), gold (USD/ounce) and Brent crude oil (USD/barrel).

The frequency of the data series is motivated by the monthly available data on commodity prices. The data on exchange rate are available from 2007 as such, we gleaned the data for the study from September 2007 to March 2021. As shown, the study was based on monthly returns of the commodities and the exchange rates ($r_t = lnP_t - lnP_{t-1}$; where r_t is the continuously compounded return, P_t and P_{t-1} are current and previous price indexes correspondingly).

Figure 1 presents the graphical presentation of raw series and returns of exchange rates and commodity prices. In Panel A, the commodity prices are reflecting a rising trend and are rightly skewed. Though the magnitude of the trend is unpredictable, all commodity prices are rising indicating comovement between the commodity prices. The fluctuations in the trends reflect the unsteadiness of the commodity prices making it a risky investment. In Panel B, the exchange rate trend series look quite stationary until the early part of 2019 and 2020. Also, the trends show time-varying volatility clustering, which is in line with the stylised facts of most financial assets (Peiro 1999; Karoglou 2010; Blau 2017).

Table 1 presents the descriptive statistics and the correlation matrix of the monthly price returns of the exchange rate and the commodity prices. The average returns for all the variables are positive but for crude oil implicitly exhibiting the lowest average returns; exchange rate has the highest returns and for the commodity returns, cocoa has the highest mean returns. The average returns also reflect the skewness of the data series in the same manner, aside crude oil and gold which are negatively skewed. The kurtosis measures also reflect that while exchange rate and crude oil are leptokurtic, cocoa

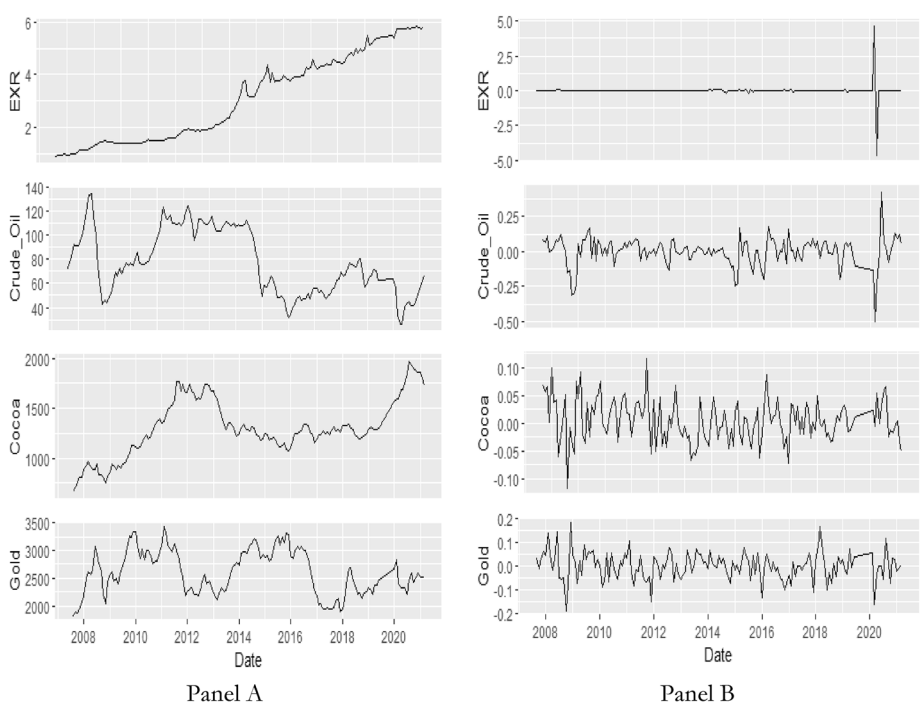

Fig. 1 Plots of commodity prices (Panel **A**) and returns (Panel **B**). The trend of the prices of crude oil and cocoa depict a similar movement. Though the trend of gold prices is fluctuating, it depicts an opposite trend when compared to the prices of crude oil and cocoa as and when they are rising and dropping

Table 1 Descriptive statistics and the correlation matrix of commodity returns and exchange rate

	EXR	Brent crude oil	Cocoa	Gold
Descriptive summary				
Mean	0.0117	−0.0006	0.0049	0.0016
Std. Dev	0.5279	0.1030	0.0376	0.0582
Skewness	0.1312	−0.9192	0.1292	−0.0559
Kurtosis	73.3183	4.8055	0.1762	1.0214
Normtest W	0.1469***	0.9003 ***	0.9948	0.9839*
ADF (1)	−8.2290***	−5.3930***	−4.7733***	−4.7928***
KPSS (1)	0.0190	0.0485	0.3525	0.1297
Correlation matrix				
EXR	1.0000			
Brent crude oil	−0.1460	1.0000		
Cocoa	−0.0863	0.0954	1.0000	
Gold	−0.1223	0.2752**	0.2179*	1.0000

(***), (**) and (*) represent significance at 1%, 5% and 10%, respectively. The H_0 for ADF test is unit root and KPSS is no unit root

and gold are platykurtic. The skewness and the kurtosis measures of the data reflect its non-stationarity property. We further use the Augmented Dickey Fuller (ADF) at first difference (ADF (1)) and the KPSS at first difference (KPSS (1)) to test for stationarity. At a 1% significant level, we reject the null hypothesis (of non-stationarity) for ADF and fail to reject the null hypothesis of KPSS (of stationarity) and conclude that the data are stationary. Thus, the returns of the data sampled for the study are stationary.

The Pearson's unconditional correlations of the data series give an introductory acumen into the data set. The correlations between gold and crude oil and between cocoa show significance at 5% and 10%, respectively, with coefficients between 0.2 and 0.3. Though the positive degree of correlation is relatively low, the commodity returns reflect abilities to comove. The correlation between the returns for exchange rate and the commodity prices are averagely of the same magnitude but show a negative relationship. What role would the exchange rate play on commodity prices if there is a negative linear correlation? Does the positive correlation between the commodity returns indicate comovement?

4 Results and discussion

To analyse the comovement, magnitude of coherence, interdependence or dominancy in a particular time and frequency, one needs to understand how to read the plots presented in Figs. 2 and 4. The phase difference is reflective in the arrows' direction: arrows moving in the same direction (in-phase) and in opposite direction (anti-phase). The interdependence characteristics between variables show the ability of one variable to either lead or lag another variable at a defined frequency. When a variable consistently, leads another variable, the variable dominates over the other variables and hence has a contagion effect on the other. An arrow pointing up (down) and in the right (left) direction shows that the first variable leads and otherwise, the variable lags. The Monte Carlo simulation at 95% confidence bound—Cone of Influence (CoI)—shows the level of diversification and which variable leads or lags. The CoI

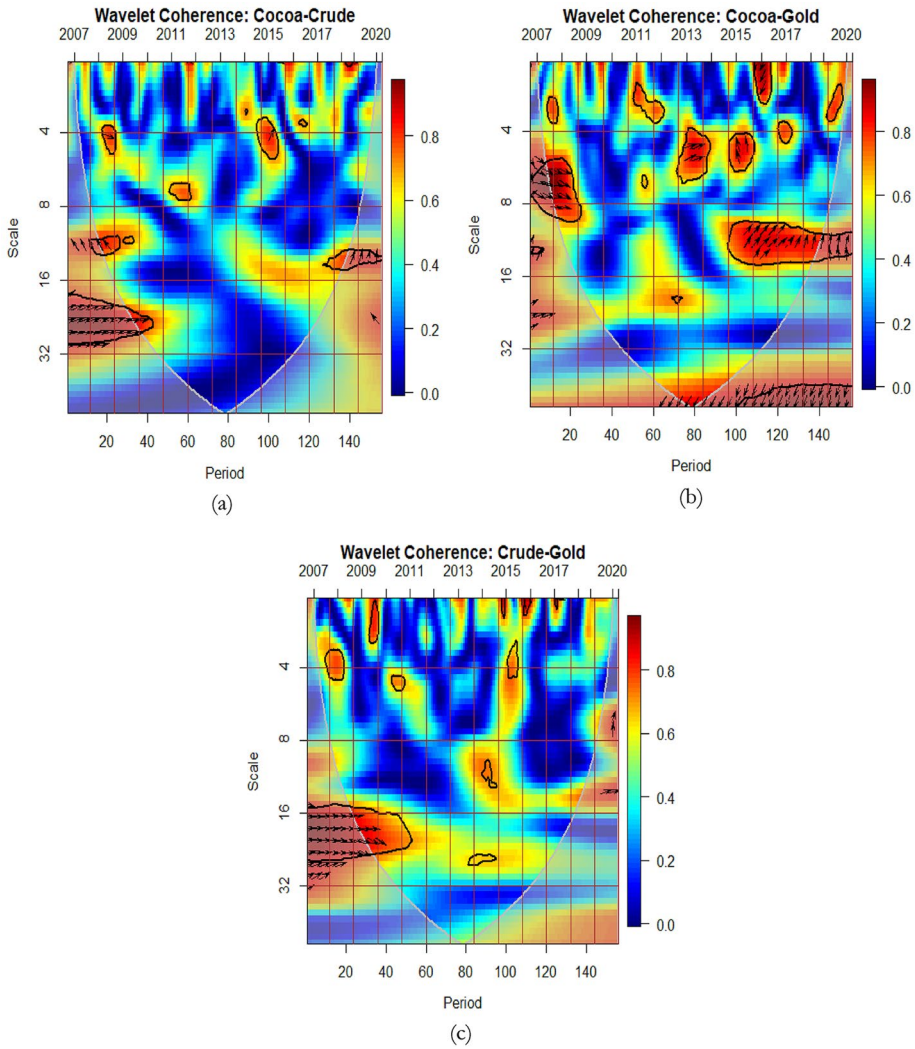

Fig. 2 Biwavelet coherence between respective commodity returns. **a** is the biwavelet coherence of Cocoa and Crude oil; **b** is biwavelet coherence of Cocoa and Gold; **c** biwavelet coherence of Crude oil and Gold. *Note* Left-arrows (positive-arrows) have negative (positive) correlations. An arrow pointing up (down) and in the right (left) direction shows that the first variable leads and otherwise, the variable lags. A variable is more sensitive to shocks when it leads in the market. A red (blue) pallet inside the Col indicate strong(low-)-comovement. Though mostly insignificant, the arrows of in band 16–32 of **a** and **c** are pointing upward to the right and pointing downward to the right, respectively

presents the significant results in colourful pallets and arrows (Owusu Junior et al. 2021). There is diversification when the pallets are blue and in the red pallets, the level of diversification reduces due to high levels of correlation. The right pointing arrows are risky but diversification is possible when the arrows are pointing towards the left. This is because investors can capitalise on due diligence as the impact of a variable may not cause aggravating losses in the other in the event there is market or economic downturn in that variable. Also, in the red pallets, the magnitude of the coherence (lead–lag relationship) is reflective in the top (high) and bottom (low)

frequencies and left (beginning) and right (end) scales (Mensi et al. 2020; Owusu Junior et al. 2019).

The wavelet factors are set at $lj, j = 1 \ldots 4$ associated with the 0–4 months (short term), 4–8 months (medium term), 8–16 months (medium term) and 16 months and above (long term) (Gallegati 2008; Hamrita and Tirifi 2011; Li et al. 2020).

4.1 Commodity comovement

From Fig. 2, we report that there is comovement in the dominant commodities in Ghana (Naeem et al. 2022b). The monthly returns of cocoa and crude oil show little comovement at the 95% confidence level however, there is strong comovement at the cycles of the various frequencies at which there is coherence. From the short-term through to the medium term, there is an interdependent relationship between cocoa and crude oil in diagram (a). For the latter part of 2008, in band 0–4 (short-term), there is a right arrow moving downwards and a right arrow moving upwards in 2015 (0–4; in the short-term) interpreting that the first variable is interdependent on the other.

Generally, at the 0–4–8-month cycle (particularly in 2008 and 2015), the arrow directions show interdependence relationship between cocoa–crude oil in the short-term and medium-term, respectively. At the coherence levels of measure, there is strong comovement between the variables. In Ghana, Archer et al. (2022) have shown that cocoa (normal and extreme) and crude oil (stressed) interchangeably cause appreciation in the market. This explains the interdependence of both commodities markets as shown in this study confirming the findings of Boateng et al. (2022). With increasing literature on commodity connectedness (e.g. Diebold et al. 2017; Frimpong et al. 2021; Mastroeni et al. 2022; Naeem et al. 2022a, b; etc.), Pindyck and Rotemberg 1990, Reboredo (2013), Wu et al. (2020a, b), Balcilar et al. (2021) and Damba et al. (2021) have proved that crude oil prices comove with other commodity markets. Natanelov et al. (2011) also proved that the prices of cocoa and crude oil behave and move in the market similarly.

In diagram (b), the phase difference shows frequencies that are in-phase and anti-phase while some arrows comove. In the years 2013 and 2015, the upward arrows move right and left, respectively, in the 4–8 band and were sharper than those recorded in 2008. Empirically, this shows interdependence as cocoa leads in 2013 (4–8 band) and lags in 2018 (while gold leads) in the medium term (8–16 band). But in 2016, the short-term cycle, the arrows move left ways and points downwards depicting strong comovement; cocoa is leading. In the cycle of 8–16, cocoa is leading in the years of 2015, 2016, 2017 and 2018 at the end of the cycle with strong coherence. There is also a strong comovement at the low frequency between the band of 16- to 32-month cycle of diagram (c). Irrespective of this comovement, there is no lead–lag relationship between the variables but the fact that the variables are in-phase mean that there could be risk transfer to the other because they move in the same direction. Empirically, Frimpong et al. (2021) show that there is an array of strong coherence in the comovement between agricultural commodities (particularly, oats, maize, soya bean and wheat) at different time-frequencies. Also, Ai et al (2006) stipulate that commodity prices comove and this is attributable to supply factors influencing their prices. Cai et al. (2019) also show a strong comovement between commodity sectors where there is interdependent relationship (lead–lag) in the sectors of agriculture-energy and agriculture-metals. These findings show the robustness

of the empirical assertion of Pindyck and Rotemberg (1990) that, "the prices of largely unrelated raw commodities have a persistent tendency to move together".

The findings from this paper confirm commodity comovement because, the time–frequency of diagrams (a), (b) and (c) in Fig. 2 show that there is comovement. With varying effects of interdependence and contagion between the price returns of gold, cocoa and crude oil which are, respectively, in the minerals sector, agricultural and oil sector, we find that there is comovement in cross-sector commodities. The ability of the commodities to have interdependency makes it possible for investors to diversify. The findings from this study are in line with literature from Mehmet et al. (2021) who assert that commodities such as crude oil have transmittable effects on other commodities. In diagram a, crude oil returns have a dominant leading effect on cocoa (agriculture-energy commodities; Cai et al. 2019) in the short run though averagely, there is interdependency, contradictory to Umar et al. (2021) who find that oil prices are granger caused by commodities such as wheat, cattle and grains. The findings in diagram (c) show no lead–lag relationship, however there is strong coherence between crude oil returns and gold returns. As in Bouri et al. (2021) who assert that there exists comovement between commodity prices with strong instability among energy-metals and a modest connectedness between agricultural commodities.

Empirically, our findings show that there is cross-commodity connectedness between gold, crude oil and cocoa. Just as stipulated by Pindyck and Rotemberg (1990), the cross-comovement of these commodities could be attributed to the joint effects of their respective lag constructs, present values and macroeconomic variables such as inflation, interest rates and exchange rates. For this assertion, we control and eliminate the effect of the nominal exchange rates used which is inclined to variations in inflation to see if indeed the comovement between commodities hold or if the assertion by Pindyck and Rotemberg (1990) is true.

Also, in the cone of influence bound, we observe weak comovement between the respective commodities; particularly in diagrams (a) and (c), throughout the sample period mainly in the short- and medium-term frequencies. This weak comovement shows that the COVID-19 pandemic which has resulted in financial crisis (Chen and Yeh 2021) did not influence the comovement between the returns of the dominant commodities in Ghana (though cocoa and gold recorded a strong correlated comovement during the medium term of 2019). This finding is contrary to the numerous literature that have reported that commodity comovement (connectedness) increased during crisis—GFC (Naeem et al. 2022a; Naeem et al. 2022b; Caporin et al. 2021; Reboredo and Ugolini 2016; Zhang 2017; Zhang and Broadstock 2020) and COVID-19 (Farid et al. 2022; Jareño et al. 2022; Umar et al. 2022). Implicitly however, the cross-sector commodity comovement may be deceptive due to the increased commodity financialisation and investor behaviour (Mastroeni et al. 2022). Because investors have dynamic responses to commodity markets (Barson et al. 2022), we have also showed that the comovement among commodities is time-varying (Caporin et al. 2021; Farid et al. 2022; Naeem et al. 2022a; Barson and Owusu Junior 2023).

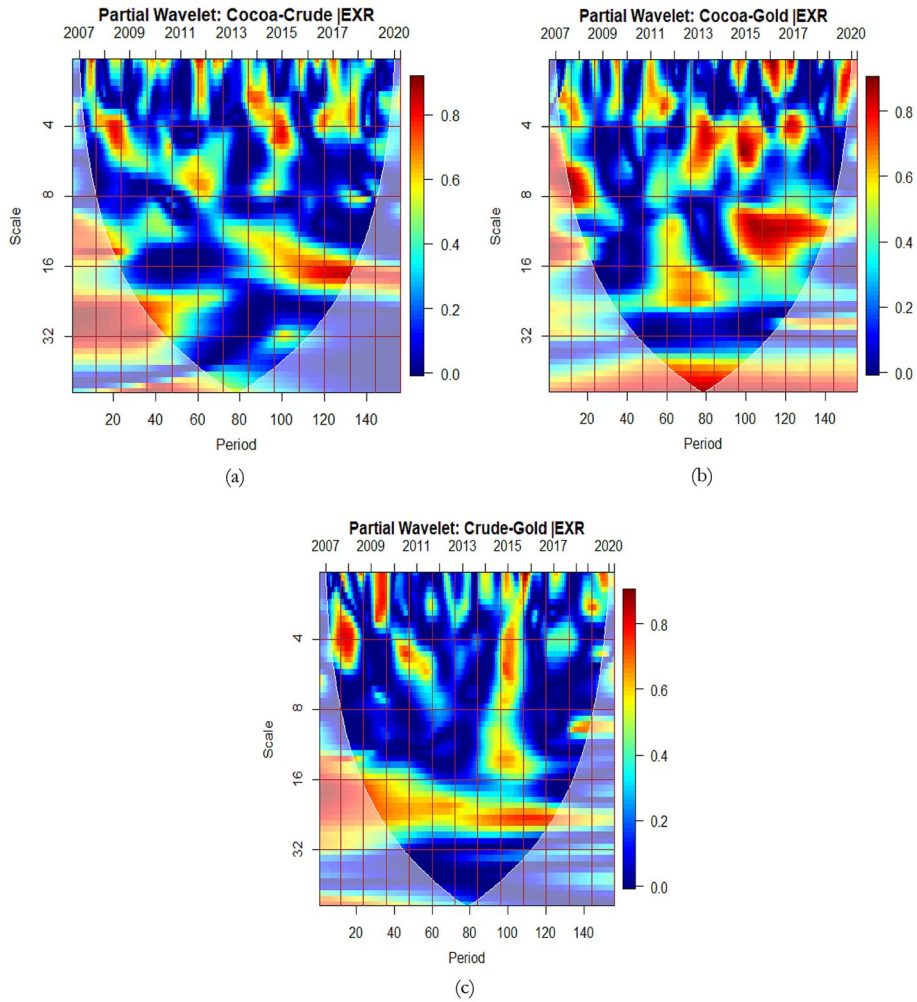

Fig. 3 Partial wavelet coherence; EXR controlled. **a** is the partial wavelet coherence of Cocoa and Crude oil when EXR is controlled; **b** is partial wavelet coherence of Cocoa and Gold when EXR is controlled; **c** partial wavelet coherence of Crude oil and Gold when EXR is controlled. *Note* A red (blue) pallet inside the CoI indicate strong(low-)-comovement

4.2 The role of exchange rate in commodity comovement

Figure 3 presents the partial wavelet coherence analysis after the effect of exchange rate has been controlled and eliminated from either combination of commodities: cocoa–crude, cocoa–gold and crude–gold. Empirically, the PWc analysis shows no phase difference (Hu and Si 2020). At the CoI, there is no comovement in either of the combinations as the diagrams (a), (b) and (c) show absent coherence between the various combinations of the variables which had depicted cross-comovement in Fig. 2. This implies that exchange rates are important drivers in the comovement of the returns of commodity prices making the findings in Fig. 3 robust (comovement between exchange rates and commodity returns) and as well, the robustness of Pindyck and Rotemberg (1990). Bodart et al. (2015) also showed a long-run relationship that contributes to the prediction of the comovement of commodity prices. Hence, we also contribute that in the short and medium term as well as in the long term, exchange rate is important in the comovement of commodities. This finding is contrary to that of Zhang et al. (2016) who

found that although there is a bi-directional causality between exchange rates and commodity prices in a developed setting, though the magnitude of causality from EXR to the returns of the commodity prices was less. This downplays its significant role in commodity prices comovement. Following the wealth maximisation effect and the balance of payment theories advanced earlier on, we also contribute to literature that, since EXR plays a significant role in the comovement of commodity returns, variations in commodity prices would either cause the appreciation or depreciation of a dominant trading currency (in this case, the Ghanaian Cedis) (Buetzer et al. 2016; Ridler and Yandle 1972; Gilbert 1989; Lizardo and Mollick 2010; Plumb et al. 2013; Archer et al. 2022).

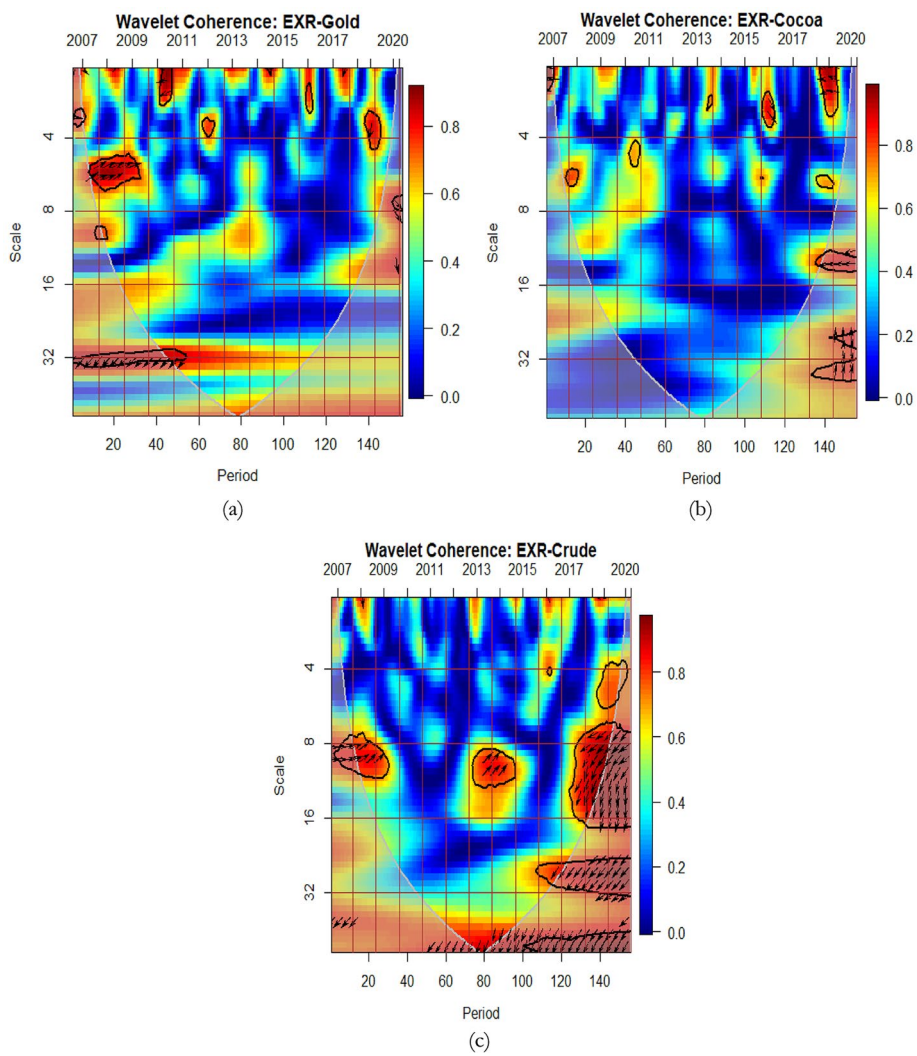

Fig. 4 Wavelet analysis of EXR and commodity returns. **a** is the biwavelet coherence of EXR and Gold; **b** is biwavelet coherence of EXR and Cocoa; **c** biwavelet coherence of EXR and Crude oil. *Note* Left-arrows (positive-arrows) have negative (positive) correlations. An arrow pointing up (down) and in the right (left) direction shows that the first variable leads and otherwise, the variable lags. A variable is more sensitive to shocks when it leads in the market. A red (blue) pallet inside the CoI indicate strong(low-)-comovement

4.3 Comovement between exchange rate and commodities

In diagram (a), Fig. 4, the variables are in-phase depicting cyclical effects and possibility of contangioness because the arrows ultimately depict that exchange rate is leading with very strong comovements at the 0- to 8-month cycle. At high frequencies of the heatmap, the short term and middle term—0–4, 4–8 and 8–16 cycles—respectively, you see strong comovement between the variables in 2008 to 2010. In the 4–8 cycle, there is an in-phase movement of arrows depicting the cyclical effects that exists between both variables. The rightwards moving arrows are pointing upwards indicating that EXR (Exchange rate) is leading in most part of the late 2007, through out to the middle terms of 2008 and 2009.

The same leading effects are recorded at the short-term bands of late 2010 and the very short time before the COVID-19 pandemic broke out in 2019 with left moving downward arrows. In this wavelet analysis, the cyclical effect reflects the contagion effect that exists in the ability of exchange rate to transfer risk to the commodity prices of cocoa making it risky and not viable for diversification purposes. The comovement between EXR and Cocoa in diagram (b) at the 5% significance level, show that only at the 0–4 months cycle do they show strong comovement. However, in 2016, EXR is lagging and at 2019, though the arrows are anti-phase, there is no lead–lag relationship but diversification is possible—where investors can protect themselves against unfavourable exchange rates that may cause losses if the invest in the dominant commodities.

The comovement between EXR and crude oil show no interdependence because ultimately, exchange rate is leading. Between the band of 8–16, years 2008 and early 2009, for most part of 2013 and 2014, the arrows are right and pointing upwards showing that Brent crude oil is lagging and has no effect on the returns of exchange rates. The arrows are moving leftwards and pointing downwards in the latter part of 2018 and most of 2019, however this does not read differently from the interpretation just given. Averagely, there is no interdependence between the variables but in the bands of 8–16 of years 2018 and 2019, diversification is possible. Because there is barely any interdependence, the level of correlation is low. Thus, investors that are interested in investing in the dominant commodities in Ghana can benefit from diversification by capitalising on the appreciation of the Ghanaian currency to invest in the commodities. At the low frequencies, in the years of 2013 and 2014, in the long run, there is a weak comovement between exchange rate and crude oil where again, exchange rate is leading.

At the 95% confidence bound of the COI, as has been empirically proven, the analyses of the heatmaps in Fig. 4 affirm literature that reports that the comovement between exchange rate and the returns of commodities is time-varying (Bashar and Kabir 2013; Ohashi and Okimoto 2016; Ma and Yang 2020; Yang et al. 2017) and dominantly, in the short and medium terms depicting a stronger correlation in the short term (Chen et al. 2014; Sari et al. 2010; Zhang et al. 2016). More so, at all significant levels of the comovement in this study, at the various localised frequencies, there is strong comovement. Averagely, the findings of the study show that indeed there is comovement between EXR and commodity returns (Chen and Rogoff 2003; Chen et al. 2010; Salisu et al. 2018; Yang et al. 2018; Archer et al. 2022). The comovement predominantly shows that there is strong coherence between the variables where mostly EXR has a contagion effect on gold and crude oil (Yang et al. 2017; Ma and Yang 2020).

Consequently, for the analysis of EXR and the commodities, in the high frequencies of the heatmap, the short term and middle term—0–4, 4–8 and 8–16 cycles—respectively, you see strong comovement between the variables; diagram (a) in 2008–2010; diagram (b) in 2015–2019; and diagram (c) in 2007–early 2009 and 2013–2015, 2017–2019. For the EXR-gold (diagram a), EXR leads in 2008–2010 in the 4–8 band; further leads in EXR-Cocoa in 2016 in the short-term (0–4 band) and dominantly in 2008–2009; 2013–2015 and 2017–2018 (8–16 band). This means that gold and crude oil are influenced by exchange rate movements while cocoa prices have the ability of influencing exchange rates (because EXR only leads the comovement in the short-term of 2016).

These findings are contradictory to literature that says that there is bi-directional causality (reflective when there is interdependence) between exchange rates and commodity prices (returns). Looking at Table 2, there is mostly a contagion effect from exchange rate to commodity price returns in Ghana. Schaling et al. (2014) report a bi-directional correlation and significant relationship between commodity prices and EXR. Bashar and Kabir (2013) also report a bi-directional causality between EXR and commodity prices however, in the very long run, EXR is determined by commodity prices. Zhang et al. (2016) also find that there is bi-causality comovement between exchange rates and commodity prices with effects of commodity prices on exchange rates been more dominant.

There is a magnitude of literature also supporting the argument that commodity prices predict EXR such as Haider et al. (2021) who stipulates that commodity prices better predict the prices of EXR in export-dependent countries; Liu et al. (2020) also reporting that in New Zealand, Canada, South Africa and Australia, commodity price returns can predict the returns of respective exchange rates; Chen et al. (2003) report that commodity prices of exports strongly affect the movement of floating real EXR for countries as Australia and New Zealand; and Scahling et al. (2014) also asserting that future and forward contracts of commodities may be important indicators of currency movements.

Contrary to the extent of literature asserting that exchange rates are predictable by commodity prices, the findings from this study prove otherwise for gold and crude oil but not cocoa. Also, EXR is the leading variable depicting contagion effects. Our findings are in line with Trezzi (2014) who reports that EXR lead commodity index prices

Table 2 Summary on wavelet coherence

Pair	Lead	Contagion/ interdependence
Biwavelet analysis between commodities		
Cocoa–crude oil	Crude oil	Interdependence
Cocoa–gold	Cocoa	Contagion
Crude–gold		Interdependence
Partial wavelet coherence analysis		
Cocoa–crude oil| EXR		
Cocoa–gold| EXR		
Crude oil–gold| EXR		
Biwavelet analysis between EXR and commodities		
EXR-gold	EXR	Contagion
EXR-cocoa	Cocoa	Contagion
EXR-crude oil	EXR	Contagion

in Australia; Kohlscheen et al. (2017), who condemn the ability of commodity prices to predict or lead the coherence on EXR and Chen et al. (2010) professing that EXR have the robust predictability effect on commodity prices.

The ability of EXR to dominantly lead in diagrams (a) and (c) reflect the risk there is to investors and producers of gold and crude, respectively. The EXR has the ability to transfer risk to gold and crude oil but not to cocoa which has a reverse action on EXR. However, in late 2010 for gold in the short and medium terms of most of 2018 and 2019 for crude oil, diversification is possible in order to reduce risk. Where diversification is possible, investors could diversify against inflation (Pindyck and Rotemberg 1990) which is reflective in the EXR that is generally leading the comovement between commodities.

4.4 Robustness test

Using the biwavelet (direct effect) and PWc (controlled effect) analyses, we find that the role of exchange rate is very intrinsic in the dynamic comovement of returns of the commodity prices. The direct effect of exchange rate is pretty dominant in determining commodity price returns and is evidently reflected when exchange rate is controlled for. As this is the first study of its kind in Ghana, we conduct a robustness test. We specify the use of the multiple wavelet analysis of Oygur and Unal (2021) which is an n-dimensional coherence analysis suitable for exploring the structure of the dynamic relationship between commodity price returns. Oygur and Unal (2021) define the blue and red shaded regions in the heatmap as low and high power coherence, respectively.

From Fig. 5, we find a low power coherence among the commodities to exchange rate at respective frequencies in diagrams (a), (b) and (c) due to the dominance of the blue pallets. The low power coherence shows that none of the combinations in commodities can manipulate changes in exchange rate (EXR). Also, diagram (d) shows deepening red shades in the heatmap at the 4- to 8-month cycle in years 2007–2011. However, dominantly, the blue pallets show that the commodities as explanatory variables do not capture the effect of EXR. We find that our results are robust. Specifically, we observe that the direct and controlled effect of exchange rate from Table 2 reflect the dominance of EXR in the connectedness of the commodities.

5 Conclusion

The paper uses wavelet coherence analysis to analyse the role of exchange rate on the dynamic comovement of dominant commodity returns in Ghana. The study contributes to literature by reporting findings that probably settles the debate on whether commodity prices (returns) are predicted by exchange rates or if exchange rates move commodity returns. The wavelet coherence analysis adopted in this study help analyse the comovement between commodity price returns at localised time-frequencies. We control for exchange rate effect and its direct effect on the strong coherence that empirically exists in the commodity returns. We use monthly data from Ghana; motivated by the report from UNCTAD (2021), identifying that Ghana is export-dependent on cocoa, Brent crude oil and gold.

Setting the frequencies at month cycles of 0–4 (short-term), 4–8 and 8–16 (medium terms) and at 16 and above for long term, we report strong coherence between the cross-comovement of commodity price returns, and between exchange rates and commodity

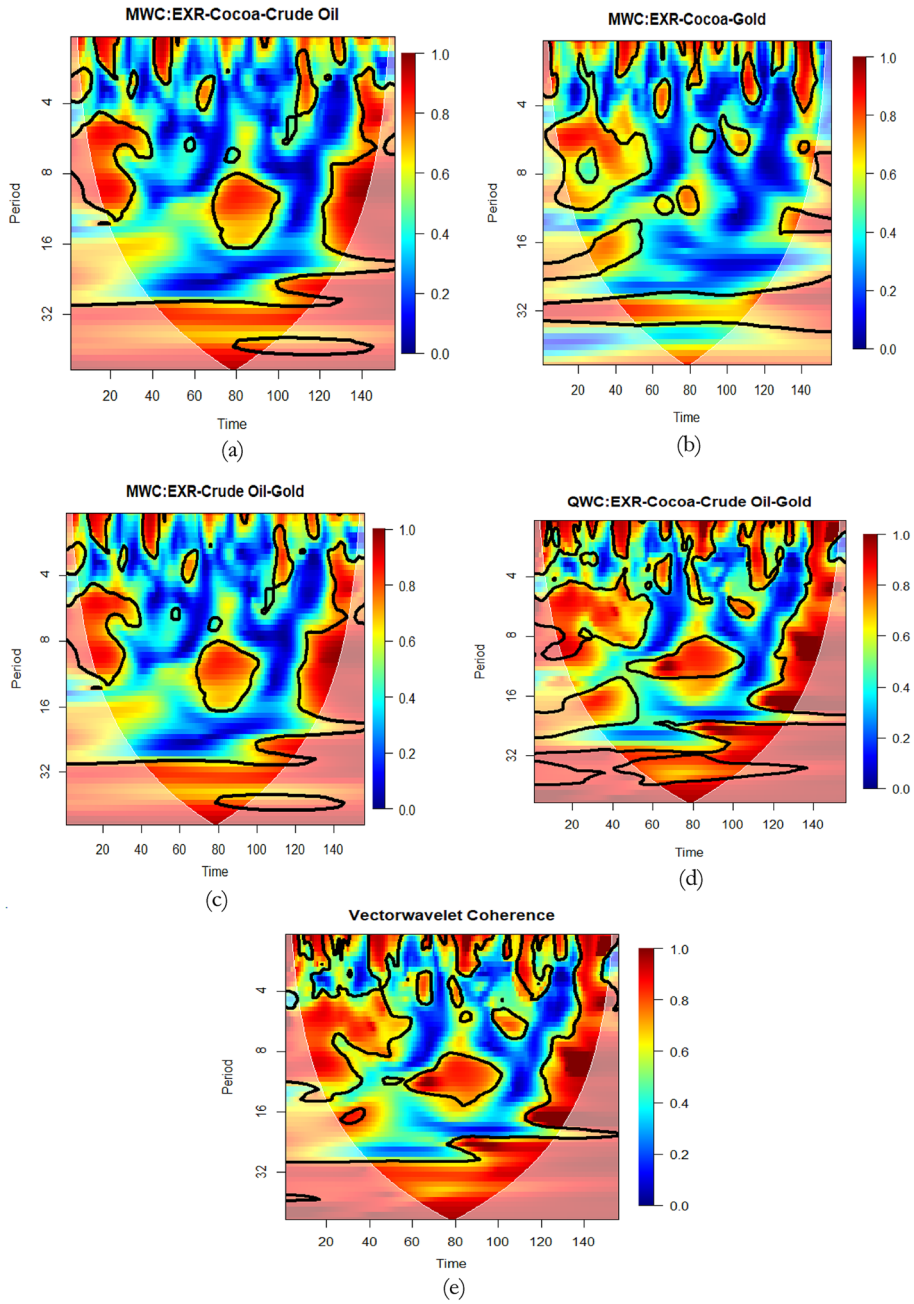

Fig. 5 Multiple vector wavelet analysis. **a** is a multiple wavelet coherence between EXR, Cocoa and Crude oil; **b** is a multiple wavelet coherence between EXR, Cocoa and Gold; **c** is a multiple wavelet coherence between EXR, Crude oil and Gold; **d** is a wavelet coherence between EXR, Cocoa, Crude oil and Gold; **e** is a vectorwavelet coherence analysis of EXR, Cocoa, Crude oil and Gold. *Note* A red (blue) pallet inside the CoI indicate strong(low-)-comovement

returns. The analysis shows that in the short-term, cocoa leads against exchange rate in 2016 though exchange rates lead against gold both in the short term and medium term for the years 2010 and 2008 to 2009, respectively, and also against crude oil in the medium band of 8–16 months. Dominantly, the comovement between exchange rates and commodity returns is recorded in the short to medium terms with strong coherence

and possess the ability to diversify. However, exchange rate comoves the price returns of gold and crude oil with contagion effects depicting its ability to transfer risk to these commodities. The same relationship is however been transmitted from cocoa to exchange rates.

The ability of exchange rate to dominate and lead commodity returns possess another concern of whether commodity returns comove due to the ability of exchange rate to pass contagion effects to their prices. We find that commodity returns comove as they interdepend on each other making it less risky to invest in those commodities. In Fig. 2, cocoa dominates in the medium terms for years 2008 and 2009 (4–8-month cycle) and 2015–2018 (8–16-month cycle) and in year 2016, dominates in the short term. Also, for the years 2008, 2009 and 2015, crude oil returns have in the short term and medium term, respectively, been leading the returns of cocoa. However, crude oil and gold interdepend on each other as there is a strong comovement in the long term. Also, we find that the COVID-19 pandemic does not influence the comovement between commodity returns in Ghana.

As the commodity returns are showing series of comovement, when the effect of exchange rate is controlled for, there is absence of coherence and comovement at either combination of the commodities. This means that commodity prices are driven by exchange rates which also show variations due to inflation. This shows robustness in the findings of the comovement between exchange rates and commodity returns. Empirically, as the exchange rates have been proven in this study to have contagion effects on commodity prices, it is just about right for commodity prices to be driven by exchange rate irrespective of their interdependence. The interdependence of the commodity returns however makes it suitable to hedge against inflation. Also, we show that exchange rates play an important role in the dynamic comovement of commodity returns which we empirically prove to be robust using the multiple wavelet analysis. Implicitly, we have also shown that variations in commodity price returns cause depreciation and appreciation in a country's currency for countries (traders) that depend on the exports of these commodities.

The implication of this study is very important to the Ghanaian government and any developing export-dependent economy in relation to how to make policies concerning exchange rate. Just as the economies are trying to deepen the economic integration between African countries through the African Continental Free Trade Area, member countries must make effective policies that seeks to strengthen their respective currencies and also equilibrise the Balance of Trade of respective countries. Countries that know the interdependence and the drivers of their currencies, would be able to make effective decisions that would promote economic growth and increase standard of living of its citizens. We recommend that for further studies, the excess comovement of commodities in Ghana can be explored using the Error Correction Method (ECM) approach following the seminar papers of Palaskas and Varangis (1991) and Deb et al. (1996).

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ZB (conceptualisation and method); POJ (review and method); AMA (review).

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Availability of data and materials
The data in relation to the findings of this study are available upon request.

Declarations

Competing interests

We declare that there are no competing interest.

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