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Global commodity and equity markets spillovers to Africa during the COVID-19 pandemic

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ABSTRACT

This paper examines the connectedness among 12 African equity markets and the global commodity, developed equity markets, paying particular attention to their evolution during the COVID-19 pandemic's peak period. We find that whilst African equity markets connect weakly to these markets, the levels of connectedness among these markets improved significantly during the pandemic. In addition, the energy market dominates the transmission of shocks in the system with commodity markets. Regarding the system with equity markets, the French and South African equity markets transmit the highest spillover in the full sample and during the pandemic's peak period, respectively.

1. Introduction

Although regional integration and other forms of bilateral and multilateral neighborhood agreements have increasingly enhanced global linkages across many countries, one of the conventional thinking is that African countries' financial markets are less integrated into the global financial markets. In recent times, however, this view is changing for at least two reasons. First, the arrival and the subsequent advancement of information and telecommunication technologies (ICT)—especially since the early 2000s—in the continent has increased the market efficiency of and reduced transaction costs of most African countries' stock markets. The subsequent advancement of ICT has also given precedence to enormous financial innovations such as allowing more flexible investment decisions through automated trading systems. Second, most African countries have also undertaken significant market reforms such as capital account liberalization which tend to increase international linkage and stock markets correlation (Valadkhani and Chancharat, 2008; Atenga and Mougoué, 2021).

Whilst the advancement in ICT coupled with the easing of financial restrictions across most African countries have enhanced their connectedness and interdependence to the global financial markets, most of these countries are marred by huge macroeconomic and

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political uncertainties that atrophy the risk appetite of investors. Such a high-risk environment offers higher returns on investments (Chen and Zhang, 1998; Goriaev, 2004; Atenga and Mougoué, 2021). In this case, understanding how international shocks are transmitted to African equity markets is important to better forecast the dynamic stock returns, identify the mechanisms to reduce financial risks, and determine the viability of the local financial market for international asset risk hedging and portfolio diversification. It is also important to account for intra-regional shocks transmission in such a framework since foreign shocks are transmitted into the local market directly from the crisis-originating countries and/or indirectly from neighboring countries that are exposed to the crisis-originating countries (Sugimoto et al., 2014). The focus of this paper is, therefore, on the connectedness and interdependence among African equity markets, the global commodity market, and the equity markets of developed and emerging economies, paying particular attention to how this relationship evolved during the COVID-19 period.

A growing body of literature examines the nexus between the financial markets of African countries and those of advanced and emerging economies. The two most important objectives pursued in this literature are determining the vulnerability of African countries' stock markets to external shocks as well as their international diversification benefits. Hence, this literature has particularly examined the co-movements, cross-market linkages, and bidirectional shocks and spillovers between African countries' stock markets and the stock markets of these advanced and emerging economies (e.g. Collins and Biekpe, 2003; Wang et al., 2003; Graham et al., 2013; Giovannetti and Velucchi, 2013; Sugimoto et al., 2014; El Ghini and Saidi, 2017; Ahmed and Huo, 2018; Atenga and Mougoué, 2021). However, the level of connectedness and interdependence between these African countries' stock markets and the global commodity markets or those of these advanced and emerging economies remain unexplored. This is surprising given the increased trading activity of commodities and co-movement with stocks, a phenomenon that is often referred to as "financialization of commodities" (Tang and Xiong, 2012; Creti et al., 2013; Urom et al., 2020).

Among others, equity investors are now increasingly interested in commodities as most of these commodities play a diversification, hedging, or safe-haven role to both conventional and modern financial assets, especially during crises (Ji et al., 2020; Shaikh, 2021; Adekoya and Oliyide, 2021). The culmination of these has led to these commodities serving as an alternative investment class and increased the level of connectedness between financial and commodity markets. Along this line, Creti et al. (2013) note that comparing the dynamic volatility of commodity and equity prices provides useful information about possible substitution strategies between commodity and other asset classes, as information about the evolution of each market can be inferred from the other.

Furthermore, to our knowledge, how the ongoing global pandemic drives the connectedness and interdependence between the African financial market and global financial and commodity markets remains unexplored. Indeed, the COVID-19 pandemic that started in December 2019, remains one of the greatest global natural shocks/disasters in the recent past. It started in China and by June 1st, 2021 all countries in the world except fourteen had recorded at least one case of the virus (World Health Organisation, 2021). The quick spread and continuous mutation of the COVID strand through the first, second, and third waves, triggered varying degrees of economic lockdown in almost all countries of the World. Most countries employed measures such as shutting down, land, air, and sea entry ports, restricting movements, banning public movements, reducing production and economic activities to just those providing essential services. The direct implication on the commodity markets is the collapse of the production chain and the ultimate reduction in production. Thus, the panic and uncertainties resulting from the spread and the government response of lockdowns, cum the need for extra cash for precautionary motives, led to panic sales that influenced the flow of the stock markets. Overall, it is clear that the shutdown of economic activities, directly and indirectly, affected the equity and commodity markets across the globe.

The current levels of global financial linkages offer reasons to believe that besides the direct effect of the pandemic on these markets, the COVID-19 pandemic may be driving the level of connectedness and interdependence among these markets. For instance, some prominent past studies such as Sands et al. (2016) present some theoretical and conceptual frameworks that demonstrate the consequences of infectious diseases outbreaks across the global economy. Among others, they show that pandemic disease outbreaks significantly influence investment decisions, risk-taking behavior, and economic activity. Empirical evidence on how COVID-19 affects the financial (e.g., Baker et al., 2020; Zhang et al., 2020; Harjoto et al., 2021; Bakry et al., 2021) and commodity (e.g. Shaikh, 2021; Umar et al., 2021; Borgards et al., 2021; Hung, 2021) markets have also been amassed. Studies have also examined how the pandemic drives the connectedness and return volatility between financial and commodity markets (e.g. Adekoya and Oliyide, 2021; Benlagha and El Omari, 2021; Lahiani et al., 2021; Maghyereh and Abdoh, 2021; Farid et al., 2021; Elgammal et al., 2021). While studies focusing on the above relationships are well established, only a few studies focus on how the pandemics drive the connectedness of international financial markets (Karamti and Belhassine, 2021; Belhassine and Karamti, 2021; Guo et al., 2021; Akhtaruzzaman et al., 2021; Liu et al., 2021a, 2021b; Wang et al., 2021). More importantly, the literature has ignored how the pandemic drives the connectedness of African countries' financial and commodity markets to the global financial market.

In this paper, we contribute to the above literature in four notable ways. First, we investigate the connectedness between 12 major African equity markets and the global commodity market. Specifically, we use the equity market composite indexes for the 12 most developed African equity markets while for the commodity market, we use the indexes of the five main commodity classes including Energy, Agriculture, Livestock, Industrial and Precious metals. Secondly, we consider the connectedness between the chosen African equity markets with the developed global equity markets. For developed equity markets, the study uses the composite equity indexes for France, Germany, The United Kingdom, the United States, and China. Thirdly, for both the connectedness with the global commodities and developed equity markets, we consider the impact of increased global economic uncertainty due to the COVID-19 pandemic. This enables us to shed light on the changes in the evolution of shock spillover during the peak of the global pandemic. Lastly, methodologically, this study is the first to adopt the newly introduced measure of spillover based on Dynamic Conditional Correlation–Generalized Autoregressive Conditional Heteroscedasticity (DCC-GARCH) of Gabauer (2020) in the analysis of market connectedness in the context of African equity markets with the global commodity and equity markets.

The rest of this paper is structured as follows: The next section discusses the related literature. Section 3 describes the research design by presenting the data sources, computation of variables, and estimation strategy. Section 4 presents the results, while we conclude in Section 5.

2. Related literature

The conventional view is that emerging markets offer great opportunities for diversification in the context of increased fluctuations in global markets. To determine the viability of this claim, a growing literature examining the co-movements and cross-market linkages between these markets and those of other regions have emerged. A strand of this literature to which our paper relates to focuses on African stock markets (e.g. Collins and Biekpe, 2003; Wang et al., 2003; Graham et al., 2013; Giovannetti and Velucchi, 2013; Sugimoto et al., 2014; Fowowe and Shuaibu, 2016; El Ghini and Saidi, 2017; Ahmed and Huo, 2018; Atenga and Mougoué, 2021). For instance, Wang et al. (2003) analyzed the interdependence among five African (South Africa, Egypt, Morocco, Nigeria, and Zimbabwe) and the USA stock markets. Their results showed that the interdependence between these African markets and the influence of the USA stock market was limited during 1996–2002, and this weakened further after the crisis. Giovannetti and Velucchi (2013) use the Multiplicative Error fully inter-dependent model (MEM) to investigate the nature of relationships among the financial markets of the USA, UK, and China and those of six African countries (Botswana, Kenya, Nigeria, South Africa, Egypt, and Tunisia). They found that South Africa and the USA shocks significantly affect African financial markets. Furthermore, while the USA, Kenya, and Tunisia are "net transmitters" of volatility spillovers, South Africa and China turn out to be net "receivers".

Sugimoto et al. (2014) examined the intra-regional return transmissions in seven African stock markets (Egypt, Mauritius, Morocco, Namibia, South Africa, Tunisia, and Zambia). They also examined spillovers from non-regional stock markets (of France, Germany, UK, China, Japan, and the US), and the commodity (gold and petroleum), and currency (Euro NEER and USD NEER) markets, and how this relationship evolved during the USA subprime and the European sovereign debt crises. Their results showed that African stock markets were mostly affected by spillovers from global markets and only modestly from commodity and currency markets. Conversely, regional spillovers within Africa are smaller than global ones, and hence, African markets were insulated from global crises. El Ghini and Saidi (2017) use the bivariate VAR-BEKK GARCH model to investigate the return and volatility linkages among the Moroccan stock market and that of the USA, France, Germany, and the UK before and during the financial crisis. Their results showed varying degrees of interdependence and spillover effects between the four considered major stock markets and the Moroccan emerging stock market before and after the global financial crisis.

Anyikwa and Le Roux (2020) use the ARDL and DCC-GARCH models to analyze the level of market integration and contagion among seven African stock markets (Egypt, Kenya, Mauritius, Morocco, Nigeria, South Africa, and Tunisia) and four advanced countries stock markets (France, Germany, UK, and the USA) during the periods of the global financial crisis and Eurozone sovereign debt crisis. They found limited evidence of integration between African and advanced countries' markets. However, the analysis of dynamic correlations shows that the conditional correlations are typically positive and higher during periods of crisis, indicating substantial evidence of contagion. Atenga and Mougoué (2021) examine the return and volatility spillovers from international financial markets (as captured by France, Germany, Japan, UK, USA, Brazil, China, Mexico, and Russia) to seven African stock markets (Egypt, Morocco, Tunisia, South Africa, Mauritius, Zambia, and Nigeria). Their results showed weak transmission of external shocks to African markets, although they show that high spillovers emerged during the 2008 global financial and the 2012 European debt crisis.

Although the above studies provide important insights about the nature of relationship understudy, they only examined how the financial crises such as the East Asian Crisis 1997, the Global Financial Crisis 2007–08, and the European debt crisis 2010–12. To date, whilst studies examining how COVID-19 drives the returns and volatility of African stock markets are relatively in abundance (e.g. Del Lo et al., 2021; Takyi and Bentum-Ennin, 2021; Omane-Adjepong and Alagidede, 2021), how COVID-19 shape the connectedness and interdependence of these markets to the global financial market remain unexplored. This is surprising as it is generally acknowledged that COVID-19 has amplified financial market risks, causing new challenges for financial risk managers (Belhassine and Karamti, 2021). Hence, our work differs from extant studies in that we distill the market integration among the African and global stock markets from the COVID-19 contagion effect. Along this line, the second literature our study relates to is a growing literature on how COVID-19 drives the connectedness of the international financial market (e.g. Adekoya and Oliyide, 2021; Bissoondoyal-Bheenick et al., 2021; Karamti and Belhassine, 2021; Belhassine and Karamti, 2021; Guo et al., 2021; Benlagha and El Omari, 2021; Akhtaruzzaman et al., 2021; Liu et al., 2021a, 2021b; Wang et al., 2021).

For instance, Adekoya and Oliyide (2021) examined the causal effect of COVID-19 on the connectedness among globally traded commodity and financial assets including oil, gold, stock, bitcoin, and dollar-euro exchange rate using the time-varying parameter vector autoregressions (TVP-VAR) model. Karamti and Belhassine (2021) used the Wavelet coherence method to analyze how the COVID-19 drives the connectedness of major financial markets including Japan, China, the USA, France, Germany, and the UK. Benlagha and El Omari (2021) examines the impact of the COVID-19 pandemic on the dynamic connectedness among gold, oil, and five leading stock markets (Japan, China, USA, Germany, and UK.) by applying a new DCC-GARCH connectedness approach. Belhassine and Karamti (2021) examine how the COVID-19 pandemic impacts the interconnectedness between the Chinese stock market and major financial and commodity markets as captured by gold, silver, Bitcoin, WTI, S&P 500, and Euro STOXX 50 stock indexes. Bissoondoyal-Bheenick et al. (2021) analyze the influence of COVID–19 stages and deaths on the return and volatility connectedness between the G20 countries using the Diebold and Yilmaz (2012) spillover method. As the above studies show, extant studies on how COVID-19 drives the connectedness of global financial and commodity markets has been limited to advanced economies. We, therefore, expand this literature by focusing on COVID-19 drives the connectedness among the African equity market and the global equity and commodity markets.

3. Data and empirical strategy

3.1. Data

To address our research objectives, we use daily stock price indexes for the period from January 19, 2011, to April 29, 2021. The starting date of our analysis is determined by data availability, especially for the selected African equity markets. To this end, we use the stock price indexes for 12 main equity markets across Africa including South Africa (sa), Botswana (bot), Egypt (egy), Kenya (ken), Morocco (mor), Nigeria (nig), Rwanda (rwa), Tanzania (tan), Tunisia (tun), Zambia (zam), Ghana (gha) and the Bourse Régionale des Valeurs Mobilières (brvm). The latter represents the regional stock exchange of the member states of the West African Economic and

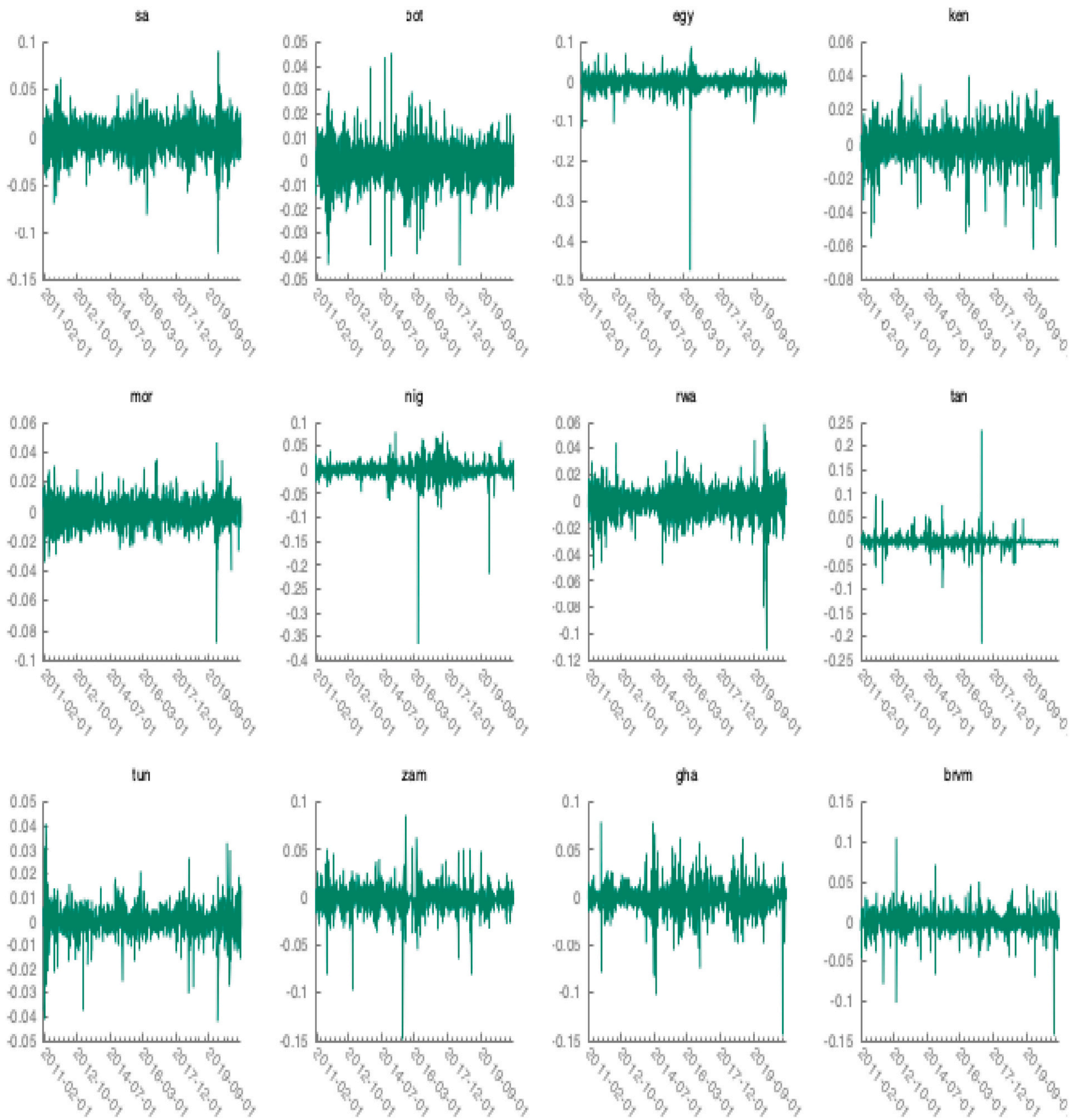


Fig. 1. Plots of market returns for selected African stock markets.
Note: South Africa (sa), Botswana (bot), Egypt (egy), Kenya (ken), Morocco (mor), Nigeria (nig), Rwanda (rwa), Tanzania (tan), Tunisia (tun), Zambia (zam), Ghana (gha), Bourse Régionale des Valeurs Mobilières (brvm),

Monetary Union (WAEMU), namely, Benin, Burkina Faso, Côte d'Ivoire, Guinea-Bissau, Mali, Niger, Senegal, and Togo. Following extant literature (e.g. Reboredo et al., 2017; Reboredo and Ugolini, 2020; Hammoudeh et al., 2020; Liu et al., 2021a, 2021b; Nguyen et al., 2021), we rely on the Bloomberg Commodity Index for the five main commodity classes such as Energy (ene), Agriculture (agr), Industrial metals (ind), Precious metals (pre) and Livestock (liv). Besides being widely used in the literature, our second motivation for using Bloomberg Commodity Index is because it is a very liquid and diversified index with a wide range of commodities (23 commodities from 6 different sectors). Lastly, we use the CAC 40, DAX 30, FTSE 100, S&P 500 (sp500), and the Shanghai Stock Exchange (sse) equity indexes to capture five globally developed equity markets corresponding to France, Germany, the United Kingdom, the United States, and China, respectively.

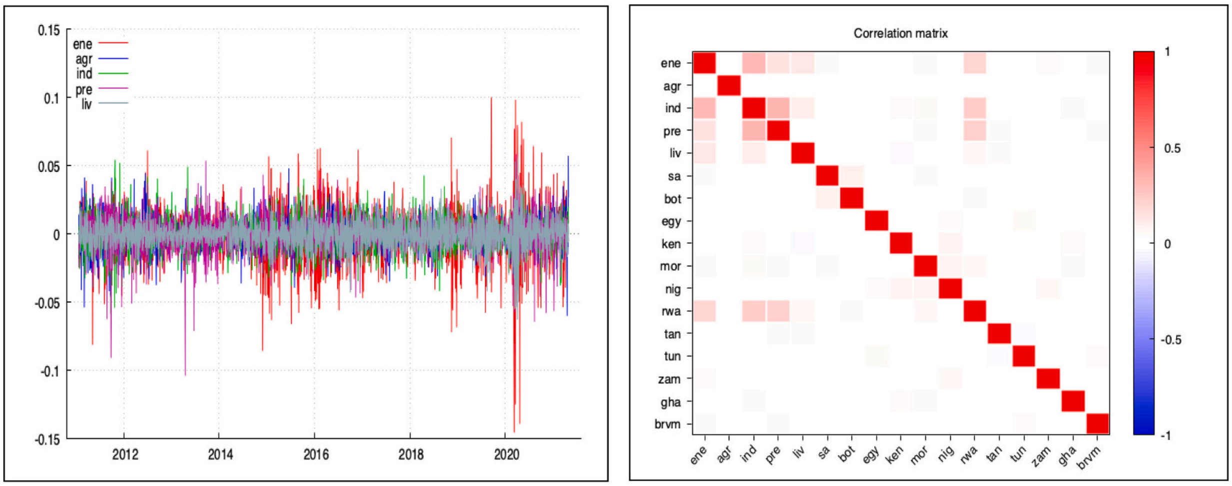
By considering these equity indexes, we can offer an in-depth analysis of the degree of equity market connectedness between African markets with those of developed nations as well as with main commodity markets both for the full sample and for a sub-sample that corresponds to the period of the COVID-19 pandemic. All daily series are converted to log returns by taking the log-difference of index values and are retrieved from Datastream International. The sub-sample for the COVID-19 period starts from January 1, 2020, to April 29, 2021. We present the evolution of stock market returns for the selected African markets in Fig. 1, while Table 1 contains the descriptive statistics for all the series. Besides, we show both the returns for commodities and their correlations with the selected African markets in Panels a - b of Fig. 2, respectively. Similarly, returns and correlations with African markets are displayed in Panels a - b of Fig. 3, respectively. In all cases, there are notable instances of an increase in return volatility around the period of the COVID-19 pandemic. This underscores our motivation to examine connectedness among these markets under this specific period to identify potential increase or decrease in shock transmission under the precarious situation in both global commodity and financial markets due to the pandemic.

Information from the descriptive statistics in Table 1 suggests that except for precious metals, all the chosen commodity indexes exhibit a negative mean return for the sample period and this is highest for energy commodities. In contrast, the mean return is positive for all the developed equity markets and is highest for S&P 500 while it is least for the FTSE 100. Regarding African equity markets, there are positive mean returns for South Africa, Kenya, Tanzania, and Tunisia but negative mean returns for the remaining markets. Further, returns are highest for the Tanzanian equity market. Besides, all return series appear to be negatively skewed with positive excess kurtosis, except the agriculture commodity index and the Tanzanian equity market which exhibit positive skewness. The standard deviation test suggests that the energy commodity market, followed by the Egyptian equity market are the most volatile markets with standard deviation values of 1.77% and 1.76%, respectively. In contrast, the Tunisian equity market is the least volatile with a value of about 0.55%. Lastly, evidence from the unconditional correlations using the two heat maps in Panel b of Figs. 2 and 3 suggests that the selected African equity markets exhibit a stronger correlation with the commodity market than with developed equity markets, especially in the case of Rwanda, Kenya, and Morocco.

Table 1
Descriptive statistics.

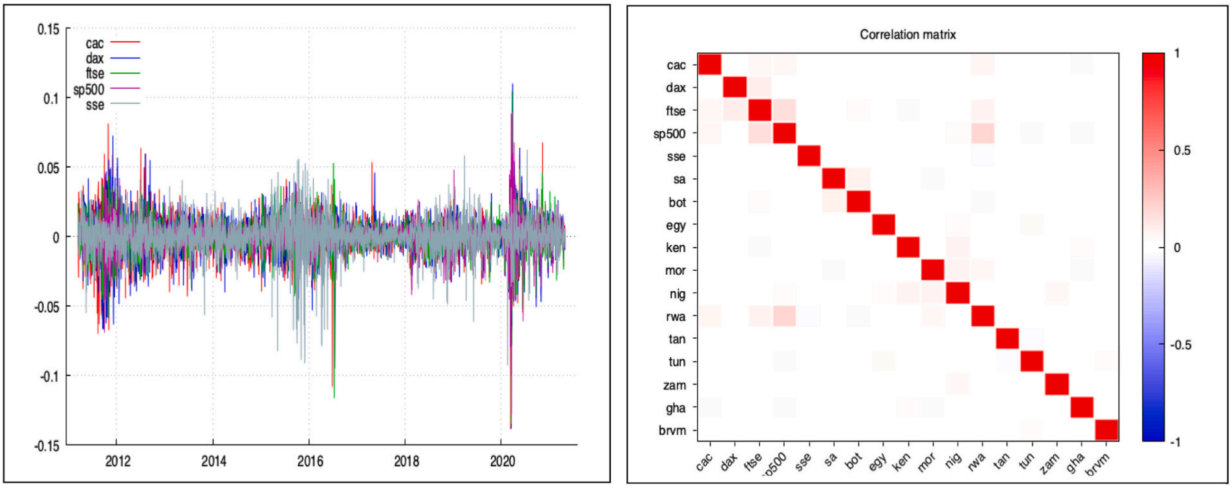
Variable	Mean	Med.	Min.	Max.	Std. Dev.	Skew.	Ex. Kurt.
ene	−0.0006	0.0003	−0.1454	0.1003	0.0177	−0.5255	6.6667
agr	−0.0002	−0.0003	−0.0599	0.0573	0.0103	0.0462	2.4508
ind	−0.0001	0.0002	−0.0583	0.0545	0.0113	−0.0650	1.5687
pre	0.0000	0.0002	−0.1038	0.0588	0.0120	−0.7884	6.5085
liv	−0.0002	−0.0001	−0.0627	0.0559	0.0106	−0.2497	2.7251
cac	0.0001	0.0006	−0.1385	0.0867	0.0141	−0.6478	8.2320
dax	0.0003	0.0006	−0.1380	0.1103	0.0142	−0.5493	8.0820
ftse	0.0000	0.0004	−0.1347	0.1046	0.0120	−0.9942	14.1200
sp500	0.0005	0.0007	−0.1277	0.0897	0.0110	−0.9253	17.7350
sse	0.0001	0.0005	−0.0925	0.0626	0.0139	−0.9346	6.3440
sa	0.0000	0.0003	−0.1219	0.0913	0.0161	−0.5865	4.7631
bot	−0.0002	0.0000	−0.0457	0.0454	0.0072	−0.3903	5.3357
egy	−0.0002	0.0006	−0.4745	0.0874	0.0176	−7.9620	205.0700
ken	0.0001	0.0003	−0.0616	0.0409	0.0092	−0.7323	5.5500
mor	−0.0001	0.0002	−0.0881	0.0465	0.0080	−0.9162	11.1210
nig	−0.0002	−0.0003	−0.3651	0.0799	0.0159	−5.5659	122.2500
rwa	−0.0002	0.0004	−0.1109	0.0588	0.0102	−0.8747	10.3700
tan	0.0003	0.0000	−0.2140	0.2341	0.0110	1.0436	145.6900
tun	0.0002	0.0001	−0.0419	0.0411	0.0055	−0.6878	11.1860
zam	−0.0005	−0.0004	−0.1482	0.0865	0.0118	−0.8711	17.3390
gha	−0.0002	0.0001	−0.1450	0.0795	0.0130	−0.7750	13.0170
brvm	−0.0002	−0.0003	−0.1424	0.1055	0.0111	−0.8043	20.2600

Note: South Africa (sa), Botswana (bot), Egypt (egy), Kenya (ken), Morocco (mor), Nigeria (nig), Rwanda (rwa), Tanzania (tan), Tunisia (tun), Zambia (zam), Ghana (gha), Bourse Régionale des Valeurs Mobilières (brvm), Energy (ene), Agriculture (agr), Industrial metals (ind), Precious metals (pre) and Livestock (liv). Lastly, we use the CAC 40, DAX 30, FTSE 100, S&P 500 (sp500) and the Shanghai Stock Exchange (sse) equity indexes to capture five globally developed equity markets corresponding to France, Germany, the United Kingdom, the United States and China, respectively.



(a) Returns for commodities (b) Correlation with African equity markets

Fig. 2. Plots of commodities returns and correlations with African equity markets.
Note. South Africa (sa), Botswana (bot), Egypt (egy), Kenya (ken), Morocco (mor), Nigeria (nig), Rwanda (rwa), Tanzania (tan), Tunisia (tun), Zambia (zam), Ghana (gha), Bourse Régionale des Valeurs Mobilières (brvm), Energy (ene), Agriculture (agr), Industrial metals (ind), Precious metals (pre) and Livestock (liv).



(a) Returns for developed equity Markets (b) Correlation with African equity markets

Fig. 3. Plots of commodities returns and correlations with African equity markets.
Note. South Africa (sa), Botswana (bot), Egypt (egy), Kenya (ken), Morocco (mor), Nigeria (nig), Rwanda (rwa), Tanzania (tan), Tunisia (tun), Zambia (zam), Ghana (gha), and Bourse Régionale des Valeurs Mobilières (brvm). Lastly, we use the CAC 40, DAX 30, FTSE 100, S&P 500 (sp500) and the Shanghai Stock Exchange (sse) equity indexes to capture five globally developed equity markets corresponding to France, Germany, the United Kingdom, the United States and China, respectively.

3.2. Empirical strategy

3.2.1. DCC-GARCH based connectedness approach

To address our research objectives, we adopt the newly introduced DCC-GARCH based volatility connectedness approach of Gabauer (2020). This approach offers an alternative to the VAR-based connectedness of Diebold and Yilmaz (2012); Diebold and Yılmaz (2014)) with some crucial advantages. For instance, it circumvents the empirical difficulties relating to arbitrary window size selection before retrieving dynamic connectedness measures. Also, in contrast to other techniques of estimating the conditional volatility transmission mechanisms using two models (e.g. Antonakakis, 2012; Beirne et al., 2013; Hoesli and Reka, 2013), this approach uses only one model.

The traditional DCC-GARCH model of Engle (2002) which estimates time-variation in conditional variance and covariance in a system of multiple time series may be written as follows:

$$x_t = \mu_t + \epsilon_t \ \epsilon_t \sim N(0, H_t) \tag{1}$$

$$c = H_t^{1/2}\epsilon_t \ u_t \sim N(0, H_t) \tag{2}$$

$$H_t = D_t R_t D_t \ ) \tag{3}$$

where μ_t and u_t are $m \times 1$ dimensional vectors representing the conditional mean and standardized error term, respectively. More so, R_t and $D_t = \ diag \ (h_{11t}^{1/2}, \ldots, h_{mmt}^{1/2}) \ m \times m$ dimensional matrices, demonstrating the dynamic conditional correlations and time-varying conditional variances. As noted in Bouri et al. (2021), the elements in D_t are estimated using the GARCH model of Bollerslev (1986) for each series. Also, following Hansen and Lunde (2005), one shock and one persistency parameter are given by:

$$h_{ii,t} = \Omega + \alpha\epsilon_{i,t-1}^2 + \beta h_{ii,t-1} \tag{4}$$

The second stage involves the computation of the dynamic conditional correlations as follows:

$$R_t = diag\left(q_{iit}^{-1/2}, \ldots, q_{mmt}^{-1/2}\right) Q_t diag\left(q_{iit}^{-1/2}, \ldots, q_{mmt}^{-1/2}\right) \tag{5}$$

$$Q_t = (1 - a - b)\widetilde{Q} + a u_{t-1} u_{t-1}^{'} + b Q_{t-1} \tag{6}$$

where Q and $\widetilde{Q}$represent $m \times m$ dimensional positive-definite matrices that denote the conditional and unconditional standardized residuals' variance-covariance matrices, respectively. Furthermore, $a(\alpha)$ and $a(\beta)$ are shock and persistency parameters that are non-negative and satisfy, $a + b < 1(\alpha + \beta \leq)$. Intuitively, as long as the condition: $a + b < 1$ is satisfied, Q_t and therefore, R_t will always be time-varying. Otherwise, as noted in Bollerslev (1986), the model reduces towards a CCC-GARCH model with R_t being constant over time.

Moreover, similar to the generalized impulse response function (GIRF), the volatility impulse response function (VIRF) captures the impact that a shock in variable $j's$ has on variable \$j\$'s conditional volatilities. This may be defined as follows:

$$\Psi_{j,t}^g(J) = VIRF\left(J, \delta_{j,t}, F_{t-1}\right) = E\left(H_{t+j} | \epsilon_{j,t} = \delta_{j,t}, F_{t-1}\right) - E(H_{t+1} | F_{t-1}) \tag{7}$$

Further, the DCC-GARCH model of Engle and Sheppard (2001) permits the forecasting of the conditional variance-covariance using the VIRF through three stages. First, the univariate $GARCH(1,1)$ is used to forecast the conditional volatilities ($D_{t+h}| F_t$) as follows:

$$E\left(h_{ii,t-1} | F_{t-1}\right) = \omega + \alpha\delta_{1,t}^2 + \beta h_{ii,t} \ h = 1 \tag{8}$$

$$E\left(h_{ii,t+h} | F_t\right) = \sum_{i=0}^{h-1} \omega(\alpha + \beta)^i + (\alpha + \beta)^{h-1} E\left(h_{ii,t+h-1} | F_t\right) \ h > 1 \tag{9}$$

The second stage consists of predicting $E(Q_{t+h}| F_t)$ according to,

$$E(Q_{t+t} | F_t) = (1 - a - b)\widetilde{Q} + a u_t u_t^{'} + b Q_t \ h = 1 \tag{10}$$

$$E(Q_{t+t} | F_t) = (1 - a - b)\widetilde{Q} + aE\left(u_{t+h-1} u_{t+h-1}^{'} | F_t\right) + bE(Q_{t+h-1} | F_t) \ h > 1 \tag{11}$$

where as in Engle and Sheppard (2001), $E(u_{t+h-1}u_{t+h-1}'| F_t) \approx E(Q_{t+h-1}| F_t)$ which permits the forecasting of the dynamic conditional correlations and lastly, the conditional variance-covariances as:

$$E(R_{t+h} | F_t) \approx diag\left(E\left(q_{iit+h}^{-1/2} | F_t\right), \ldots, E\left(q_{mmt+h}^{-1/2} | F_t\right)\right) E(Q_{t+h}) \times diag\left(E\left(q_{iit+h}^{-1/2} | F_t\right), \ldots, E\left(q_{mt+h}^{-1/2} | F_t\right)\right) \tag{12}$$

$$E(H_{t+h} | F_t) \approx E(D_{t+h} | F_t) E(R_{t+h} | F_t) E(D_{t+h} | F_t) \tag{13}$$

3.2.2. Dynamic connectedness measures

The dynamic connectedness measures of interest are computed in five steps. In the first step, the generalized forecast error variance decomposition (GFEVD) is estimated based on the VIRFs defined earlier. As noted in Gabauer (2020), the GFEVD may be interpreted as the variance share a variable explains on others. Besides, these variance shares may be normalized such that each row sums up to one, implying that all the variables jointly explain 100% of variable $i's$ forecast error variance. This may be computed as follows:

$$\widetilde{\Psi}_{ij,t}^g(J) = \frac{\sum_{t=1}^{J-1} \Psi_{i,j,t}^{2,g}}{\sum_{j=1}^{N} \sum_{t=1}^{J-1} \Psi_{i,j,t}^{2,g}} \tag{14}$$

where $\sum_{j=1}^{N} \widetilde{\Psi}_{ij,t}^N(J) = 1$ while $\sum_{i,j=1}^{N} \widetilde{\Psi}_{ij,t}^N(J) = m$. Intuitively, the numerator denotes the cumulative effect of the ith shock while the denominator captures the aggregate cumulative effect of all the shocks.

Table 2
Connectedness with commodities for the full sample.

	ene	agr	ind	pre	liv	sa	bot	egy	ken	mor	nig	rwa	tan	tun	zam	gha	brvm	From
ene	NA	0.06	4.97	1.64	0.45	0.05	0.02	0.01	0.02	0.03	0.18	3.90	0.05	0.00	0.05	0.05	0.05	11.53
agr	0.38	NA	0.12	0.06	0.17	0.21	0.02	0.09	0.03	0.04	0.35	0.06	0.37	0.01	0.05	0.09	0.03	2.07
ind	13.24	0.05	NA	7.65	0.69	0.11	0.01	0.06	0.04	0.06	0.04	3.15	0.11	0.01	0.03	0.23	0.01	25.48
pre	3.12	0.04	8.23	NA	0.08	0.12	0.01	0.04	0.01	0.04	0.04	2.48	0.12	0.00	0.08	0.21	0.02	14.63
liv	3.94	0.13	2.04	0.18	NA	0.10	0.02	0.05	0.07	0.03	0.15	1.44	0.15	0.01	0.05	0.13	0.04	8.54
sa	0.09	0.03	0.06	0.09	0.03	NA	0.13	0.06	0.01	0.02	0.17	0.02	0.04	0.00	0.06	0.06	0.01	0.88
bot	1.00	0.17	0.27	0.19	0.13	4.43	NA	0.21	0.11	0.17	0.63	0.47	0.73	0.04	0.23	0.77	0.10	9.64
egy	0.06	0.04	0.07	0.10	0.03	0.37	0.02	NA	0.04	0.02	0.11	0.08	0.02	0.02	0.05	0.07	0.02	1.12
ken	0.62	0.18	0.74	0.29	0.50	0.27	0.05	0.43	NA	0.09	1.76	0.19	0.22	0.03	0.15	0.58	0.10	6.20
mor	0.80	0.14	0.71	0.39	0.13	0.46	0.10	0.28	0.07	NA	0.50	0.79	0.24	0.03	0.07	0.42	0.08	5.21
nig	1.13	0.21	0.10	0.08	0.09	0.51	0.08	0.18	0.31	0.19	NA	0.07	0.17	0.01	0.37	0.14	0.09	3.72
rwa	17.73	0.06	7.59	6.65	0.76	0.11	0.05	0.10	0.03	0.16	0.18	NA	0.30	0.01	0.06	0.17	0.07	34.01
tan	0.38	0.40	0.23	1.15	0.26	0.18	0.12	0.10	0.06	0.07	0.30	0.69	NA	0.09	0.27	0.28	0.08	4.67
tun	1.42	0.33	1.54	0.43	0.34	1.18	0.24	1.03	0.37	0.50	0.49	0.38	2.41	NA	1.18	0.58	0.28	12.69
zam	0.81	0.09	0.18	0.30	0.17	0.55	0.04	0.12	0.07	0.05	0.65	0.11	0.22	0.03	NA	0.23	0.08	3.69
gha	0.49	0.07	0.38	0.20	0.19	0.24	0.06	0.08	0.15	0.07	0.12	0.15	0.10	0.01	0.05	NA	0.08	2.44
brvm	0.90	0.12	0.09	0.18	0.08	0.29	0.04	0.18	0.07	0.07	0.13	0.17	0.13	0.02	0.13	0.22	NA	2.83
To	46.12	2.14	27.31	19.59	4.08	9.18	0.99	3.01	1.46	1.61	5.78	14.14	5.37	0.31	2.87	4.24	1.16	
NDC	34.59	0.07	1.83	4.96	−4.46	8.30	−8.65	1.89	−4.74	−3.61	2.06	−19.87	0.70	−12.38	−0.82	1.80	−1.68	TCI = 8.79

Note: TCI and NDC denote the total connectedness index and Net directional connectedness under 10-ahead forecast horizon, respectively. South Africa (sa), Botswana (bot), Egypt (egy), Kenya (ken), Morocco (mor), Nigeria (nig), Rwanda (rwa), Tanzania (tan), Tunisia (tun), Zambia (zam), Ghana (gha), Bourse Régionale des Valeurs Mobilières (brvm), Energy (ene), Agriculture (agr), Industrial metals (ind), Precious metals (pre) and Livestock (liv).

In the second step, the total directional connectedness *TO* others represents how much of a shock in variable *i* is transmitted to all other variables *j*. This is written as follows:

$$C^{g}_{i\rightarrow j,t}(K) = \frac{\sum_{j=1,i\neq j}^{N}\widetilde{\Psi}^{g}_{ij,t}(K)}{\sum_{j=1}^{N}\widetilde{\Psi}^{g}_{ij,t}(K)} \tag{15}$$

Similarly, as the third step, the total directional connectedness *FROM* others represents how much variable *i* receives from shocks in all other variables *j*. This is defined as:

$$C^{g}_{i\leftarrow j,t}(K) = \frac{\sum_{j=1,i\neq j}^{N}\widetilde{\Psi}^{g}_{ij,t}(K)}{\sum_{j=1}^{N}\widetilde{\Psi}^{g}_{ij,t}(K)} \tag{16}$$

In the fourth step, the *net total directional connectedness* denotes the difference between the total directional connectedness *TO* others and the total directional connectedness FROM others, which may be explained in relation to the influence variable *i* has on the analyzed network. This may be written as:

$$C^{g}_{i,t} = C^{g}_{i\rightarrow j,t}(K) - C^{g}_{i\leftarrow j,t}(K) \tag{17}$$

where $C^{g}_{i,\,t} > 0(C^{g}_{i,\,t} < 0)$ implies that variable *i* is a net transmitter (receiver) of shocks since it is influencing all others more (less) than it is being influenced by then.

In the last step, the total connectedness index (TCI) may be denoted as the average amount of one variable's forecast error variance share explained by all other variables. Put differently, this expresses how much a shock in one variable influences all other variables on average. This may be written as:

$$C^{g}_{t}(K) = \frac{\sum_{j=1,i\neq j}^{m}\widetilde{\Psi}^{g}_{ij,t}(K)}{m} \tag{18}$$

4. Results and discussion

This section proceeds in two steps. First, we present and discuss the results of the connectedness of the selected 12 top African equity markets with the global commodity market. Second, we present and discuss the connectedness among African countries' equity markets and those of advanced equity markets. In line with our third objective, the results as presented in this section includes results from two samples including the full sample and a subsample that focuses on the COVID-19 peak period.

4.1. Connectedness with commodity markets

Table 2 presents the full sample results of spillover between the markets under consideration. The total spillover among markets is 8.79%, indicating a relatively low level of interconnectedness among the chosen African equity markets and the global commodity markets under consideration. Regarding the equity markets, we find that five out of the twelve African equity markets including South Africa, Nigeria, Tanzania, Ghana, and Egypt are net transmitters – i.e., outward return spillover ("TO") exceeds inward return spillovers ("FROM"). From an economic perspective, this suggests that these markets are less sensitive to changes in the system. Further, we find that among the equity markets, the highest spillover to the system comes from Rwanda, accounting for 14.4% of the system's forecast error variance. This is followed by South Africa (9.18%) and Nigeria (5.78%). Conversely, while the highest spillover receipt is attributed to Rwanda (34.01%), it is followed by the stock markets of Tunisia (12.69%) and Botswana (9.64%).

As per the commodity markets, except for the livestock market, they are all net transmitters. The energy market (46.12%) and the industrial metals (27.31%) market are the highest transmitters of spillover to the system, respectively. We also find that across each commodity market and countries' equity markets, the energy market transmits the highest shock to those markets, indicating the high reliance and vulnerability of African countries to that sector. This finding corroborates those of previous studies (e.g. Lin et al., 2014; Morema and Bonga-Bonga, 2020; Amendola et al., 2020). For instance, Morema and Bonga-Bonga (2020) focused on return and volatility spillovers between gold, oil, and the South African equity market. This study demonstrates that the South African equity market does not have much influence on the global commodity market, following a relatively low level of spillovers from South African equity markets to commodity markets, especially markets for energy and precious metals. Similar conclusions were presented by Lin et al. (2014) which focused on Ghana and Nigeria as well as Amendola et al. (2020) that focuses on six African commodity-exporting countries including Egypt, Nigeria, South Africa, Tunisia, Uganda, and Zambia.

On the other hand, Industry metals and livestock receive the highest spillover from the system. The highest part of spillover received by industry metals comes from energy (13.24%), precious metals (7.65%), and the Rwandan equity market (3.15%). For the livestock, the highest part of spillover receipt comes from the energy (3.94%), industrial metals (2.04%) and Rwanda (2.48%). Moreover, among the stock markets, the Rwanda equity market transmits the highest spillover across the commodity markets, except for agriculture where the Tunisian equity market tops the list and is followed by the Nigerian equity market. Focusing on the entire system, we find that in contrast to the equity markets, results for the commodity markets show a higher level of integration among each other in terms of the amount of spillover they receive and transmit to each other. This suggests that in contrast to the African equity markets that are less integrated, the commodity markets are more integrated. The weak connectedness among the equity markets of

Africa countries is not entirely surprising given the low level of integration among countries within this region that has been documented elsewhere in the literature (e.g., UNCTAD, 2019; Fowowe and Shuaibu, 2016; Fowowe, 2017; Amendola et al., 2020).

Next, we plot the connectedness relations among commodity and equity markets in Fig. 4. In the Figure, blue circles are used to denote markets that transmit more shocks than they receive from the system (i.e. positive net directional connectedness (NDC)), while red circles denote markets that receive more shock than they transmit to the system (i.e negative net directional connectedness (NDC)). Depending on whether a market is a net-transmitter or net-receiver of shock, the sizes of the circle rank the net directional connectedness with larger circles being markets with stronger net directional connectedness. That is, an arrow from C_i to C_j denotes that C_i contributes more to C_j than $C_i$receives from C_j. Red arrows and their sizes show the top 5 strongest net pairwise shock spillovers, while the grey arrows show the least net pairwise shock spillovers. Fig. 4 reemphasizes the obvious: the energy market, precious metals market, South Africa equity market, Egyptian equity market, Tanzanian equity market, industrial metal market, the agriculture market, and Ghanaian equity market are net-transmitters of shocks, with the energy market topping the list. Other markets in the system are net receivers of shocks with the Rwandan equity market topping the list.

With regards to the most significant spillovers received or contributed within the system, we observe that the energy market transmits significant shocks to the Rwandan equity market, and the livestock and industrial metals commodity markets, more than it receives from these markets or any other market in the system. The Rwandan equity market on the other hand receives significant shocks from the energy and precious metals commodity markets and transmits significant shocks to the livestock commodity market. Other markets in the system either receive significant shocks from one market or transmit significant shocks to other markets. The least shock spillover may be observed from the Agricultural commodity market to the Rwandan equity market. In summary, Fig. 4 supports our initial argument that across each commodity market and countries' equity markets, the Energy market transmits the highest shock to those markets. It also lends credence to our initial argument that the Rwandan equity market transmits significant shocks to the system, especially to the commodity markets.

Fig. 5 plots the evolution of the total connectedness of African equity and global commodity markets. Generally, the graph reveals that the total connectedness of the commodity markets has been time-varying. For instance, the graph shows that the total connectedness of commodity markets fail markedly by the end of the first quarter of 2016 when compared to its values in the previous periods. Whereas this fall persisted throughout the remaining periods in that year, the total connectedness of commodity markets started increasing again by the end of the first quarter of 2017. However, this rise was cut short by the end of 2019 which coincides with the first wave of the COVID-19 outbreak. Surprisingly, we observe a significant rise in the level of total connectedness among the commodity markets throughout the periods in 2020 which was the peak of the pandemic. The rise in connectedness between the periods of 2015–2016 could be explained by the oil price glut that occurred between 2014 and 2016. On the, other hand, the rise beginning towards the end of 2019 is tied largely to the COVID-19 outbreak. Particular, such rise in the level of connectedness among the commodity markets during this period may be explained by dynamics in the energy market in light of the pandemic that trickled down shocks to other commodity markets. It may also well be that this rise in connectedness is driven by global uncertainty associated

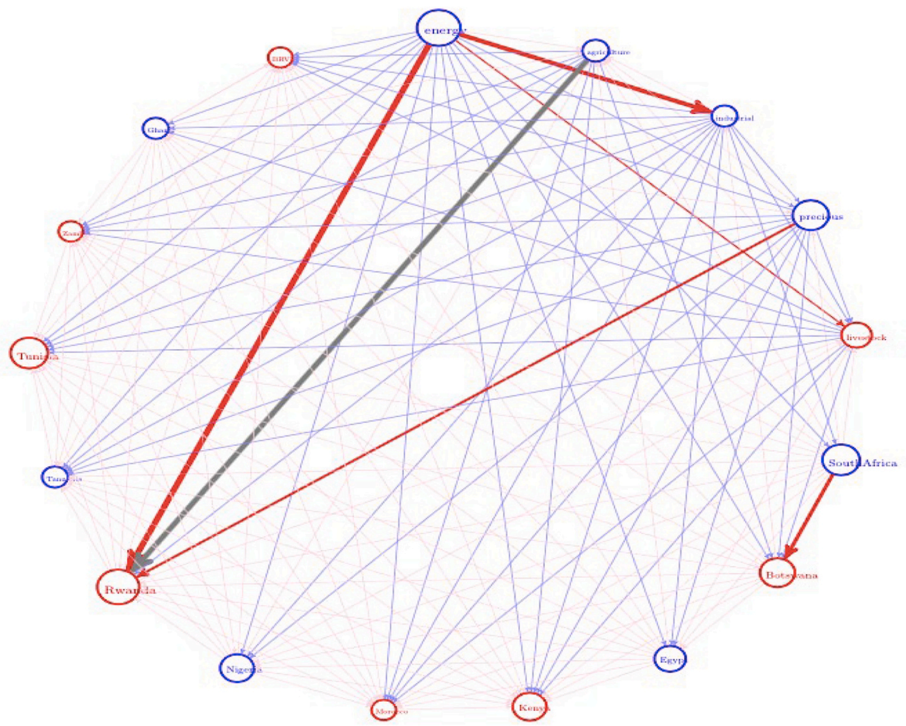


Fig. 4. Network graph with commodities markets for the full sample.

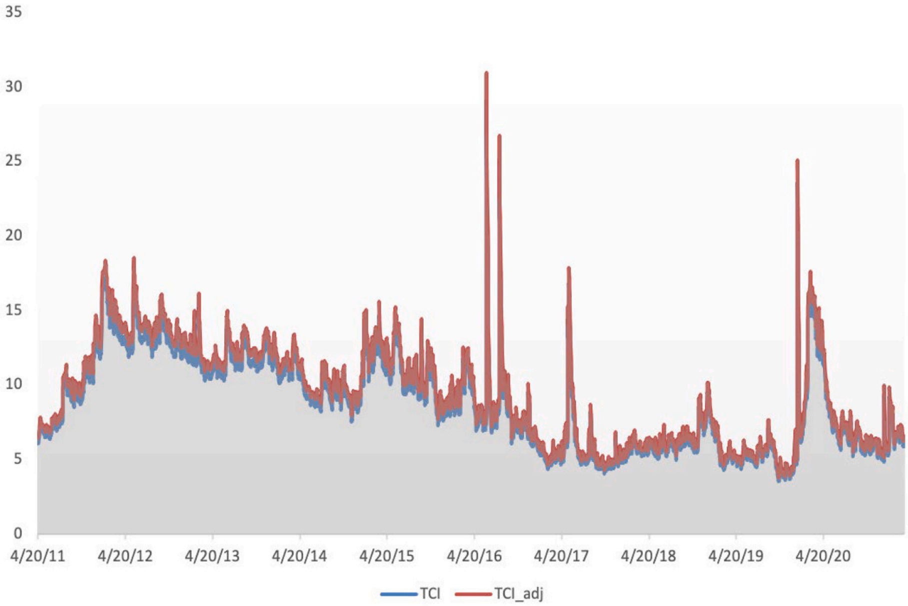


Fig. 5. Plots of total connectedness with commodities markets for the Full Sample.

with the pandemic that incentivizes investors to shift or substitute assets. Indeed, prior studies such as Adekoya and Oliyide (2021) provide compelling evidence suggesting that crises such as the recent COVID-19 increase the connectedness among commodity and financial markets. As the graph further shows, there has been a significant fall in total connectedness of the commodity markets by the end of 2020 and for the few periods in 2021 which our data covers. These periods are characterized as an era of new-normal with some stabilization in the oil market being attained.

To provide additional insights on the role of COVID-19 in driving the connectedness among the commodity markets, Table 3 reports the results for the spillover among the markets that are under study during the COVID-19 period. We find that the total connectedness among the markets during this period (37.39%) is significantly larger than the total connectedness we document for the full (8.79%). We also observe that for most of the commodity and equity market indexes, the level of spillovers they either transmit to or receive from the system has markedly increased. Regarding the commodity market, we find that they are all net-receivers except the energy and precious metal markets. This implies that they receive more shock than the transit to the system, a result that differs markedly from that of the full sample where they are all net transmitters except the livestock commodity market. Regarding the equity markets, we find that during the COVID-19 period, the equity markets of Kenya and the Bourse Régionale des Valeurs Mobilières alternate from being a net-receiver of shock as observed in the full sample to a net-transmitter of shock. Tanzanian and the Ghanaian equity market on the other hand alternate from being a net-transmitter observed in the full sample to a net receiver.

Fig. 6 plot the connectedness among commodity and the chosen African equity markets during the COVID-19 period. Description and characterization of the figure are discussed in Fig. 4. We observe that the energy market continued to significantly transmit shocks to other markets than any other market. Fig. 7 plots the evolution of the total connectedness among the markets during the COVID-19 peak period. The patterns observed in the graph confirm our initial argument about a much stronger connectedness among the commodity markets during the peak of the outbreak. Indeed, the figure shows that the level of connectedness among commodity markets during the pandemic is consistently higher than its previous values.

4.2. Connectedness with developed equity markets

Table 4 presents the full sample results for the level of integration among the equity markets of selected developed and African countries. The total connectedness among the markets under consideration is 17.92%, indicating a relatively low level of interconnectedness among the markets under consideration. As per the return spillovers, the developed equity markets receive more spillover from the system. This suggests that these developed equity markets may be exposed to many more risk sources that are unrelated to their internal markets. An exception to this is the French equity market that transmits more spillover to the system, making it a net transmitter. Particularly, the result shows that while the system only accounts for 15.63% of the error variance in the forecast of the French equity market, 30.73% of the forecasting error variance of the system comes from the French equity market. For the Chinese equity market, we find that the return spillovers to and from the system are almost identical. Regarding the African equity markets, six out of the twelve markets including South Africa, Egypt, Morocco, Nigeria, Zambia, and BRVM are net transmitters while the rest are net receivers.

Further, compared to the African equity markets in our sample, there is a high level of integration among the equity markets of developed countries as indicated by the number of spillovers each market transmits and receives from the other. The highest spillover

Table 3
Connectedness with commodities for the COVID-19 sample.

	ene	agr	ind	pre	liv	sa	bot	egy	ken	mor	nig	rwa	tan	tun	zam	gha	brvm	FROM
ene	NA	0.22	0.05	0.15	0.33	0.52	0.01	0.02	0.01	0.20	0.01	0.10	0.00	0.00	0.00	0.15	0.00	1.77
agr	37.74	NA	0.20	3.66	0.07	3.65	0.05	0.12	0.23	0.79	0.43	0.21	0.00	0.02	0.04	0.48	1.00	48.70
ind	37.57	0.99	NA	11.41	3.78	0.85	0.01	0.19	0.77	0.07	0.42	0.31	0.00	0.03	0.65	1.56	0.34	58.95
pre	1.92	0.08	0.06	NA	1.90	1.94	0.00	0.01	0.01	0.01	0.03	0.28	0.00	0.00	0.00	0.03	0.51	6.78
liv	39.06	0.11	0.27	13.18	NA	5.15	0.00	0.01	0.06	0.11	0.01	1.03	0.00	0.03	0.20	1.44	0.13	60.80
sa	0.05	0.07	0.01	0.81	0.23	NA	0.01	0.01	0.02	0.67	3.27	0.26	0.00	0.05	0.00	0.04	0.06	5.58
bot	49.64	0.93	0.07	0.62	0.06	7.15	NA	0.25	3.27	1.66	0.27	1.09	0.00	0.02	1.45	3.68	0.71	70.89
egy	4.20	0.10	0.06	0.65	0.05	0.42	0.01	NA	0.08	0.17	0.03	1.24	0.02	0.10	0.02	2.59	0.24	9.98
ken	2.66	0.05	0.04	0.27	0.23	1.32	0.04	0.02	NA	0.02	0.01	1.14	0.00	0.01	0.10	16.53	0.02	22.47
mor	25.24	2.06	0.02	0.31	0.57	17.12	0.01	0.23	0.19	NA	17.71	2.72	0.00	0.00	0.01	0.31	0.13	66.64
nig	0.59	0.06	0.02	0.21	0.01	21.46	0.00	0.00	0.01	3.01	NA	0.16	0.00	0.01	0.00	0.00	0.00	25.54
rwa	15.63	0.03	0.03	1.14	2.39	6.32	0.04	0.23	1.37	2.98	0.26	NA	0.00	0.07	0.00	5.45	0.14	36.08
tan	5.34	0.60	0.35	13.39	0.47	10.37	0.06	38.56	8.42	3.73	1.26	1.97	NA	0.41	0.73	2.64	0.33	88.61
tun	8.35	0.07	0.14	1.44	0.65	34.04	0.01	0.25	0.53	0.56	0.81	1.35	0.00	NA	0.01	4.27	1.04	53.53
zam	19.57	0.45	1.41	2.02	4.72	2.22	0.60	0.31	4.29	0.24	0.07	0.49	0.00	0.02	NA	0.84	0.13	37.38
gha	4.77	0.10	0.00	0.43	0.61	1.14	0.00	0.27	29.82	0.02	0.00	1.30	0.00	0.03	0.03	NA	0.04	38.57
brvm	0.38	0.17	0.01	2.25	0.02	0.35	0.00	0.02	0.01	0.02	0.00	0.09	0.00	0.01	0.00	0.05	NA	3.39
TO	252.72	6.09	2.75	51.96	16.09	114.02	0.87	40.48	49.08	14.24	24.59	13.73	0.03	0.81	3.28	40.07	4.82	635.65
NDC	250.96	−42.61	−56.20	45.18	−44.71	108.44	−70.02	30.50	26.61	−52.40	−0.95	−22.34	−88.58	−52.71	−34.10	1.50	1.43	TCI = 37.39

Note: TCI and NDC denote the total connectedness index and Net directional connectedness under 10-ahead forecast horizon, respectively. South Africa (sa), Botswana (bot), Egypt (egy), Kenya (ken), Morocco (mor), Nigeria (nig), Rwanda (rwa), Tanzania (tan), Tunisia (tun), Zambia (zam), Ghana (gha), Bourse Régionale des Valeurs Mobilières (brvm), Energy (ene), Agriculture (agr), Industrial metals (ind), Precious metals (pre) and Livestock (liv).

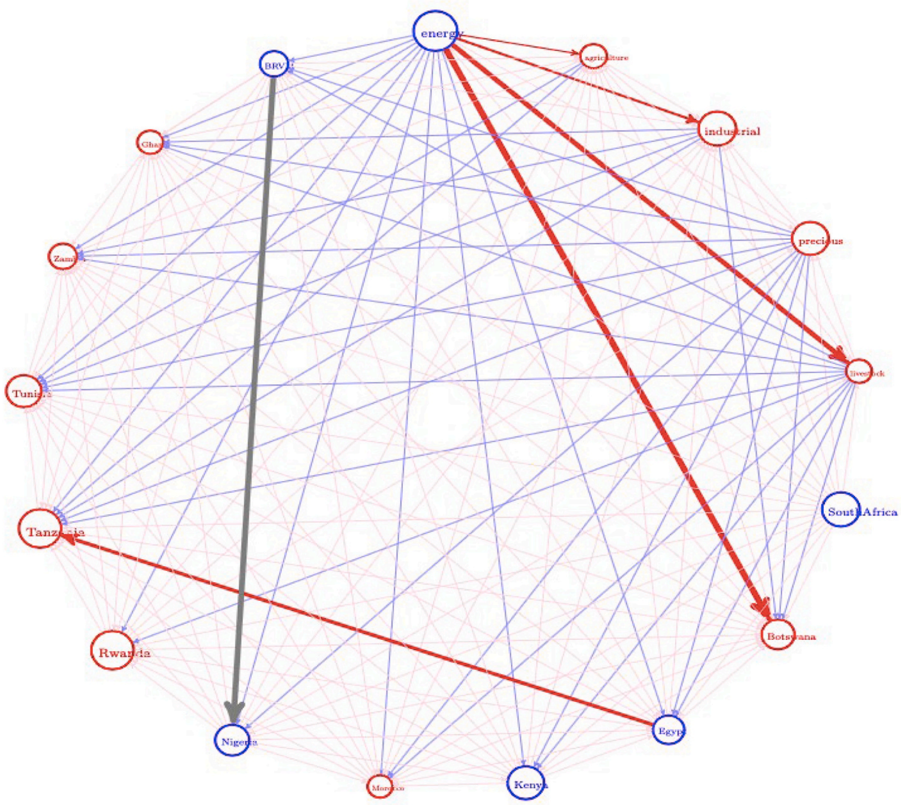


Fig. 6. Network graph with commodities for COVID-19 pandemic sample.

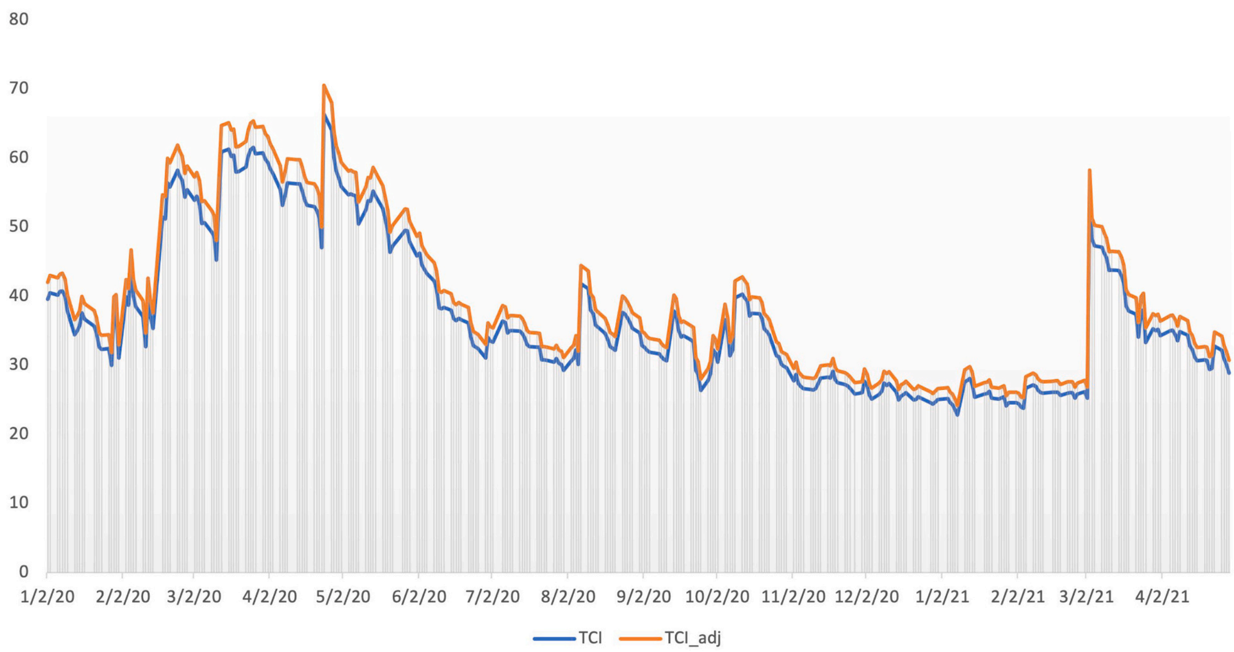


Fig. 7. Plots of total connectedness with commodities markets during the COVID-19 pandemic.

Table 4
Connectedness with developed equity market for the full sample.

	cac	dax	ftse	sp500	sse	sa	bot	egy	ken	mor	nig	rwa	tan	tun	zam	gha	brvm	From
cac	NA	1.05	1.62	0.84	1.44	1.09	1.05	0.53	0.94	0.98	0.86	1.21	0.73	0.70	0.64	1.10	0.85	15.63
dax	5.66	NA	5.59	3.03	0.67	1.60	0.91	0.92	0.89	0.76	0.90	1.65	0.93	0.78	1.10	1.20	0.75	27.35
ftse	6.44	2.14	NA	0.98	0.74	1.71	1.23	1.30	0.92	0.72	0.81	1.11	1.21	0.85	0.88	1.11	1.18	23.33
sp500	3.82	2.29	2.06	NA	1.00	0.68	1.03	1.31	0.56	1.07	1.09	6.74	0.69	0.91	0.84	1.20	0.71	25.99
sse	1.37	0.67	0.63	0.93	NA	0.97	0.80	0.79	1.17	0.93	1.18	1.36	0.83	0.76	0.83	1.20	0.93	15.34
sa	1.06	1.58	1.77	0.64	0.86	NA	2.71	0.99	0.85	0.91	0.91	0.53	0.74	1.45	1.16	0.72	0.74	17.62
bot	0.87	0.83	1.38	0.75	0.81	2.69	NA	0.74	0.82	0.88	0.91	0.94	0.97	1.08	0.97	1.17	0.94	16.77
egy	0.73	0.91	0.90	1.37	0.81	1.27	1.04	NA	1.16	0.76	0.62	0.64	0.61	1.05	1.07	0.57	0.93	14.44
ken	1.19	0.84	0.86	0.63	1.03	1.01	1.21	0.98	NA	0.98	1.20	1.17	0.81	0.71	0.99	0.96	0.79	15.35
mor	1.48	0.90	0.75	0.89	0.73	0.71	0.88	0.61	1.32	NA	1.83	1.38	0.67	1.23	1.12	0.92	0.72	16.15
nig	1.24	0.75	0.82	0.93	0.91	1.00	1.07	0.85	1.62	1.67	NA	1.28	1.50	0.90	1.17	1.11	0.79	17.62
rwa	2.22	1.71	1.40	3.30	1.52	0.70	1.39	0.72	0.89	1.03	1.17	NA	1.05	0.92	0.88	1.09	1.07	21.04
tan	0.88	0.94	0.96	0.81	0.99	0.61	1.13	0.55	1.16	0.81	0.82	1.10	NA	1.29	0.65	0.78	0.60	14.07
tun	0.69	0.82	0.77	0.76	0.74	1.00	1.07	1.07	0.66	1.09	0.89	0.84	1.55	NA	1.03	0.95	1.19	15.13
zam	0.92	1.02	0.97	0.76	1.06	1.18	1.43	1.02	0.84	1.15	1.24	0.83	0.61	1.09	NA	1.51	1.28	16.91
gha	1.28	1.01	0.76	1.41	1.18	0.71	1.39	0.60	1.00	0.88	1.09	0.79	0.92	0.88	0.97	NA	1.04	15.91
brvm	0.87	0.85	0.97	0.82	0.87	0.66	0.88	0.78	1.24	0.81	1.16	1.31	0.63	1.68	1.25	1.24	NA	16.03
To	30.73	18.31	22.22	18.86	15.35	17.59	19.21	13.79	16.04	15.45	16.70	22.87	14.45	16.25	15.57	16.81	14.50	
NDC	15.10	−9.04	−1.11	−7.13	0.01	−0.03	2.44	−0.66	0.68	−0.69	−0.93	1.83	0.38	1.13	−1.35	0.90	−1.53	TCI = 17.92

Note: TCI and NDC denote the total connectedness index and Net directional connectedness under 10-ahead forecast horizon, respectively. South Africa (sa), Botswana (bot), Egypt (egy), Kenya (ken), Morocco (mor), Nigeria (nig), Rwanda (rwa), Tanzania (tan), Tunisia (tun), Zambia (zam), Ghana (gha), and Bourse Régionale des Valeurs Mobilières (brvm). Lastly, we use the CAC 40, DAX 30, FTSE 100, S&P 500 (sp500) and the Shanghai Stock Exchange (sse) equity indexes to capture five globally developed equity markets corresponding to France, Germany, the United Kingdom, the United States and China, respectively.

receipt across these regional equity markets comes from the French equity market to the UK equity market (6.44%). This is followed by the spillover receipt by the German equity market from the French equity market (5.66%). It suffices to state that the highest spillover transmitted within the equity markets of these developed countries is from the French equity market, and followed by the UK equity market. Our findings of a weak connectedness among African equity markets relative to those of more advanced economies confirms those of previous studies (e.g., Fowowe, 2017; Ahmed and Huo, 2020). For instance, focusing on the two largest stock markets of the continent, Fowowe (2017) document a low level of return spillover between equity markets in Nigeria and South Africa. This implies that developed equity markets are more integrated than African equity markets. That is, unlike African equity markets, a developed equity market such as that of the USA is highly sensitive to changes in another developed equity market such as that of France. Other things remain equal, this suggests that whilst African equity markets may offer diversification benefits among themselves, that of developed equity markets may not offer such benefits.

Regarding the connectedness among the equity markets of the developed and African countries, the highest spillover transmitted from the equity market of developed countries to African countries is from the US (3.30%) and French (2.22%) to Rwanda. This is followed by the spillovers transmitted from the French equity market to the South African equity market (1.77%) and from the German equity market to the Rwandan equity market (1.71%). On the other side of the spectrum, the least transmitted spillovers from the developed countries to the equity market of developing countries are from the US equity market to the Kenyan equity market (0.63%). This is followed by spillovers from France to Tunisia (0.69%) and from either France to Egypt (0.73%) or China to Morocco (0.73%).

When we consider the spillover transmitted from African equity markets to those of advanced and emerging economies in our sample, the highest spillover transmitted from the equity markets in Africa to developed countries is from Rwanda to the US (6.74%) and Germany (1.65%), and from South Africa to the UK (1.71%) and Germany (1.60%). Conversely, the least transmitter of spillover to the developed countries from Africa is Egypt to France (0.53%). This is followed by Kenya to the US (0.56%) and South Africa to the US (0.68%). Overall, the results on the net pairwise return connectedness between developed equity markets and those of African equity markets are low, indicating that these markets are less integrated. Hence, compared to other developed equity markets, African equity markets offer better diversification benefits to developed equity markets. This corroborates the findings of Mensah and Alagidede (2017a, 2017b) which document that stock price movements in advanced equity markets do not possess significant spillover effects on Africa's emerging stock markets, suggesting that African markets are immune to risk spillover from advanced markets and could offer

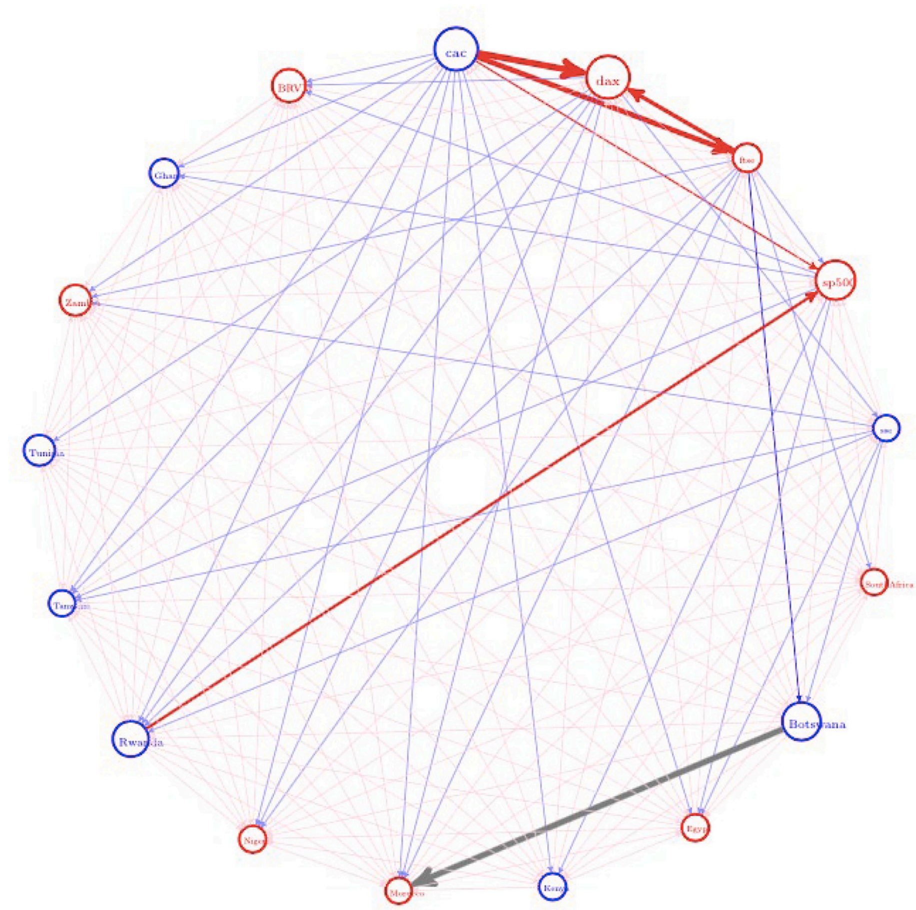


Fig. 8. Network graph with developed equity markets for full sample.

portfolio diversification gains.

Fig. 8 shows the network graph among the equity markets for the full sample. The description and characterization of the figure are as discussed in Fig. 4. The figure reveals that the equity markets of France, Botswana, Kenya, Rwanda, Tanzania, Tunisia, and Ghana are net transmitters of shock within the system with the equity market of France topping the list. Other equity markets in the system are net-receivers of shock with the equity market of Germany topping the list. Furthermore, the figure confirms our earlier conjecture that in contrast to the equity markets of most African countries in our sample, there is a high level of integration among developed countries' equity markets as indicated by their respective net pairwise-spillover. Indeed besides the Ghanaian equity market that transmits significant spillover to Zambia, we do not observe any other African country equity market transmitting spillover to another African market. The Figure also restates the obvious, the Rwandan equity market appears to be more integrated with the equity markets of developed countries compared to other African markets given the level of spillovers it receives and transmits to developed equity markets. Aside from spillovers within developed equity markets, as shown by the red arrows, positive net pairwise shock spillover runs from the Rwandan equity market to the United States.

Next, Fig. 9 plots the evolution of total connectedness among the equity markets of selected developed and African countries. While we observe a somewhat stable evolution of connectedness among these markets between 2012 and 2019, a major upward trend emerges by the end of the last quarter of 2019 but fails sharply towards the first quarter of 2021. The pattern observed in the figure is not markedly different from that of Fig. 4 and our initial argument in that section holds. Particularly, crises such as the COVID-19 raise fear and sentiments among investors and other economic agents, making them shift attention from the most adversely affected markets to another for safety (Adekoya and Oliyide, 2021).

Next, Table 5 reports the results for the subsample comprising the COVID-19 period. Consistent with the results presented in the previous section, the total connectedness among the equity market during the COVID-19 period is higher than that of the full sample. One of the plausible explanations for this may be due to investors' efforts to hedge against risks and diversify their portfolios by taking advantage of the temporal variation in the spread of the virus. Particularly, as the pandemic stroke major hubs at different times, Africa as a whole has remained less affected. Hence, making their equity market an investment destination to diversify from the most adversely affected equity markets. Fig. 10 shows the network graph with developed equity markets for the COVID sample. The description and characterization of the figure are as discussed in Fig. 4. Compared to the full sample results which show that much spillover transmitted by the developed equity markets was among themselves, we observe that the USA equity market (SP500) dominates the risk transmission, with Botswana, Rwanda and Morocco being the highest absorber of such transmitted risk. Following the USA equity market is the South Africa equity market that transmits significant risk to the Tunisian equity market.

Finally, Fig. 11 plots the evolving total connectedness among the equity markets for the COVID-19 period sample further corroborates this. Regarding the respective equity markets as shown in Table 5, we also observe that for the most part, the return spillover

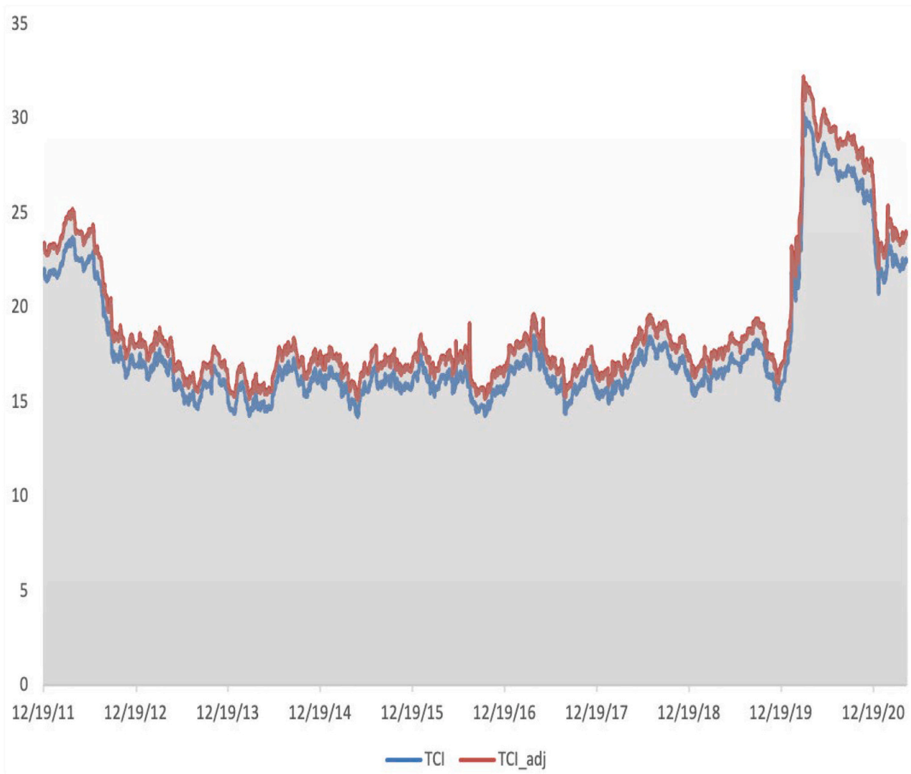


Fig. 9. Plots of total connectedness with developed equity markets for the full sample.

Table 5
Connectedness with develop equities for the COVID-19 sample.

	cac	dax	ftse	sp500	sse	sa	bot	egy	ken	mor	nig	rwa	tan	tun	zam	gha	brvm	FROM
cac	NA	0.45	2.62	3.36	0.08	0.42	0.03	0.04	0.04	0.67	0.00	2.01	0.00	0.06	0.04	0.30	0.11	10.24
dax	0.27	NA	0.38	3.55	0.18	0.15	0.00	0.01	0.14	0.62	0.00	0.19	0.00	0.01	0.01	0.38	0.01	5.91
ftse	2.84	0.62	NA	19.28	0.23	2.15	0.02	0.08	0.02	1.33	0.64	1.98	0.00	0.01	0.02	0.29	0.08	29.59
sp500	2.14	2.31	8.94	NA	0.02	3.42	0.04	0.04	0.66	0.15	0.00	2.81	0.00	0.08	0.05	0.12	0.06	20.84
sse	0.33	0.94	0.61	0.29	NA	0.13	0.00	0.14	0.05	0.01	0.00	0.03	0.00	0.00	0.05	4.37	0.03	6.98
sa	0.02	0.09	0.28	1.68	0.02	NA	0.01	0.00	0.03	0.66	4.15	0.25	0.00	0.05	0.00	0.05	0.05	7.35
bot	5.38	0.42	3.89	23.63	0.76	8.75	NA	0.31	3.27	1.78	0.42	1.23	0.00	0.04	2.14	4.61	1.07	57.70
egy	0.72	0.81	1.82	5.21	1.63	0.36	0.01	NA	0.07	0.15	0.03	0.84	0.01	0.10	0.02	2.47	0.24	14.49
ken	0.48	0.70	0.13	9.40	0.08	1.60	0.03	0.02	NA	0.01	0.01	0.75	0.00	0.01	0.10	15.41	0.02	28.74
mor	1.51	3.90	7.11	5.67	0.02	19.60	0.02	0.22	0.19	NA	20.46	3.38	0.00	0.00	0.01	0.25	0.15	62.49
nig	0.00	0.01	1.69	0.01	0.00	21.88	0.00	0.00	0.00	2.65	NA	0.14	0.00	0.01	0.00	0.00	0.00	26.40
rwa	8.90	0.91	8.90	22.48	0.05	4.91	0.03	0.16	0.94	2.36	0.18	NA	0.00	0.06	0.00	4.81	0.08	54.78
tan	2.79	9.08	10.53	5.02	1.54	5.52	0.15	10.50	4.31	4.02	1.15	1.45	NA	1.06	0.41	1.99	0.18	59.70
tun	5.93	1.03	1.41	15.91	0.43	23.35	0.01	0.23	0.46	0.52	0.79	1.04	0.02	NA	0.02	4.07	0.95	56.17
zam	4.57	1.50	1.70	8.10	8.68	2.18	0.73	0.28	3.86	0.22	0.09	0.71	0.00	0.02	NA	0.74	0.12	33.49
gha	0.07	0.18	0.17	0.82	0.79	1.28	0.00	0.27	29.75	0.02	0.00	1.63	0.00	0.03	0.03	NA	0.04	35.09
brvm	0.43	0.11	0.26	0.42	0.04	0.30	0.00	0.02	0.01	0.02	0.00	0.08	0.00	0.01	0.00	0.05	NA	1.75
TO	36.39	23.07	50.45	124.83	14.54	96.00	1.08	12.33	43.81	15.19	27.94	18.50	0.03	1.55	2.89	39.93	3.19	511.72
NDC	26.16	17.16	20.86	103.99	7.56	88.65	−56.62	−2.16	15.06	−47.30	1.53	−36.27	−59.67	−54.62	−30.60	4.84	1.44	TCI = 30.1

Note: TCI and NDC denote the total connectedness index and Net directional connectedness under 10-ahead forecast horizon, respectively. South Africa (sa), Botswana (bot), Egypt (egy), Kenya (ken), Morocco (mor), Nigeria (nig), Rwanda (rwa), Tanzania (tan), Tunisia (tun), Zambia (zam), Ghana (gha), and Bourse Régionale des Valeurs Mobilières (brvm). Lastly, we use the CAC 40, DAX 30, FTSE 100, S&P 500 (sp500) and the Shanghai Stock Exchange (sse) equity indexes to capture five globally developed equity markets corresponding to France, Germany, the United Kingdom, the United States and China, respectively.

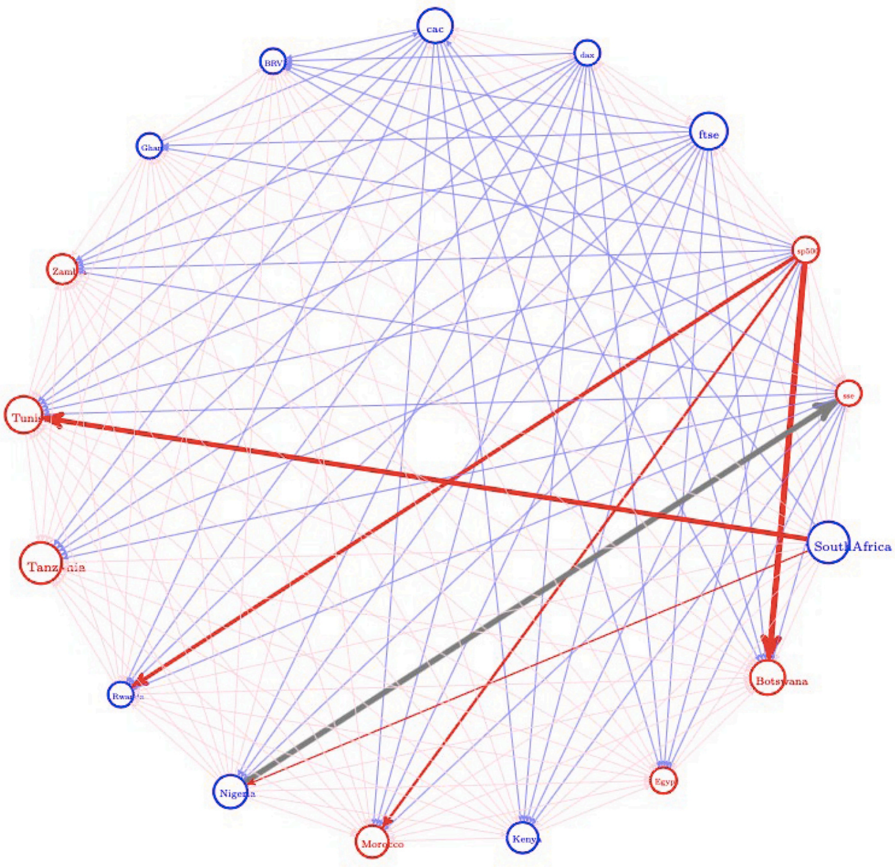


Fig. 10. Network graph with developed equity markets for COVID sample.

received from or transmitted to the system by these markets increased markedly during this COVID-19 period. These pieces of evidence reemphasized our initial argument that connectedness among equity markets is stronger during the peak period of the pandemic.

5. Conclusion

This paper uses the newly introduced DCC-GARCH based volatility connectedness approach of Gabauer (2020) to examine the connectedness and interdependence among African equity markets, the global commodity market, and the equity markets of developed and emerging economies, paying particular attention to how this relationship evolved during the COVID-19 period. Regarding the connectedness among commodity markets and major African global equity markets, we find that among the equity markets, the Rwandan stock market contributes the highest spillover to the system. It also receives the highest spillover from the system. For the commodity markets, the energy market transmits the highest spillover to the system, while the Agriculture market receives the highest spillover from the system. Across all markets in the system, however, the energy market transmits the highest amount of spillover to the system, accounting for 46.12% of the system's forecasting error variance. The amount of spillover it receives from the system is 11.53%, making it a net transmitter. This underscores the overreliance and susceptibility of Africa's commodity and equity market on the energy market. Moreover, except for agriculture and livestock commodity markets, we also find that two other commodity markets in our sample including industry and precious metals are net transmitters of spillovers to the system. Interestingly, the amount of spillover they transmit to the system is significantly higher than the amount of spillover the regional equity markets in our sample transmits to the system. Nonetheless, when we consider the level of integration among these markets either bilaterally using the pairwise directional connectedness or jointly using the total connectedness index, there is clear evidence of weak connectedness among the markets.

During the Covid-19 peak period, however, we observe a significant increase in the amount of connectedness among the markets. Particularly, unlike in the full sample which had a total connectedness index of 8.79%, the total connectedness among the market during the COVID-19 period is 37.39%. This rise in connectedness may be explained by dynamics in the energy market in light of the pandemic that trickled down shocks to other commodity markets. Indeed, we find that the energy market accounts for 252.72% of the forecasting error variance of the system within this period. Nonetheless, it suffices to state that this rise in connectedness is also driven by global uncertainty associated with the pandemic that incentivizes investors to shift or substitute assets. As our results suggest, all

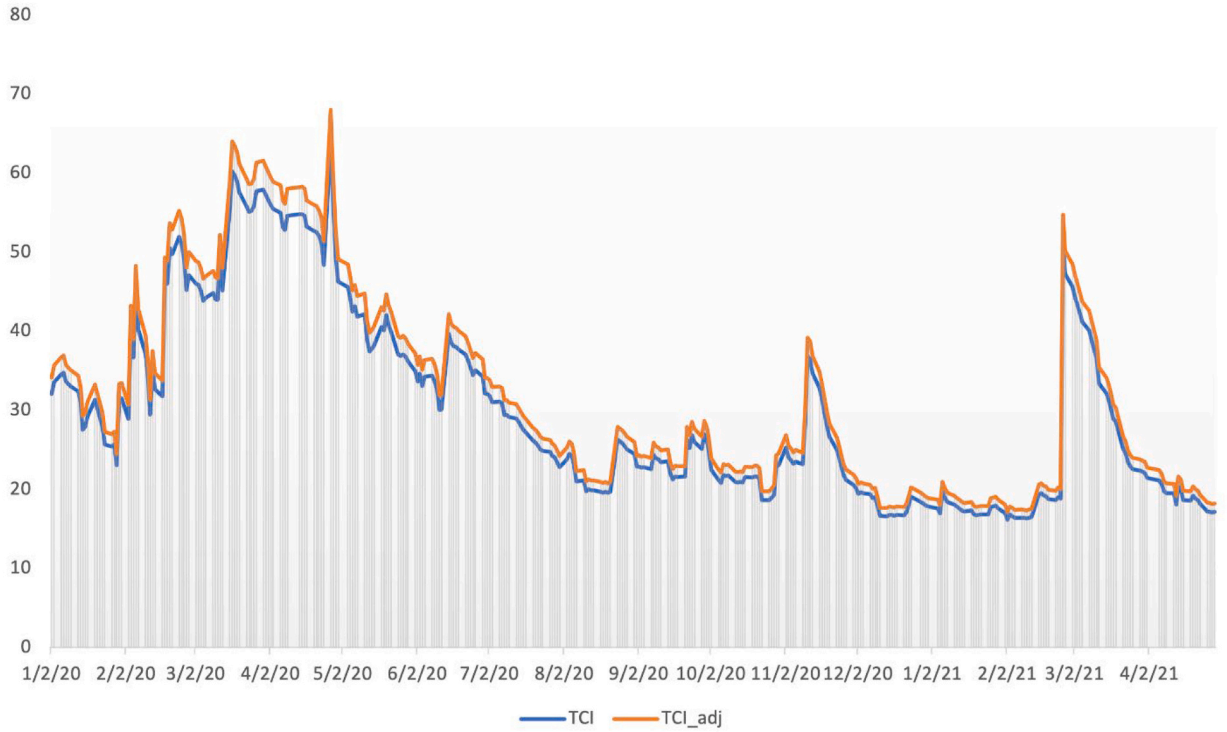


Fig. 11. Plots of total connectedness with developed equity markets for the COVID-19 period sample.

market in the system becomes net receivers of spillovers except for the energy and precious metals markets and the equity markets of South Africa, Egypt, Kenya, Ghana and Bourse Régionale des Valeurs Mobilières indicating that a potential shift in attention from one market to the others as they become adversely affected by the pandemic.

When we turn to the level of integration among the equity markets of developed and African countries, we find that equity markets of developed countries are more integrated than those of major African equity markets as revealed by their pairwise directional connectedness. The highest spillover receipt among the developed equity markets comes from France to the UK (6.44%). Regarding the pairwise net directional connectedness among the equity markets of the developed and African countries, the highest spillover transmitted from the equity market of developed countries to African countries is from the US to Rwanda, while the least transmitted spillover is from the US to Kenyan (0.63%). On the other hand, the highest spillover transmitted from the equity markets in Africa to developed countries is from Rwanda to the US (6.74%), while the least transmitter of spillover to the developed countries from Africa is Egypt to France (0.53%). When we examine the level of integration among the equity markets of developed and African countries during the COVID-19 peak period, we also find that a stronger connectedness among the markets than we do for the full sample.

Overall, our results indicate clear evidence of weak connectedness among African commodity and equity markets and the connectedness among global Africa equity market and global equity market. However, the current COVID-19 pandemic has significantly increased the level of connectedness among these markets. As noted earlier, one of the potential drivers of this is the global uncertainty associated with the pandemic that raised investments sentiments and a subsequent shift or substitute of assets across markets. Along this line, one of the implications of our findings for potential investors especially during a crises period is to incorporate close monitoring of markets into their investment strategies and adjust their investment portfolios accordingly to mitigate or circumvent losses. Policy-makers on the other hand need more concerted efforts in strengthening their commodity and equity markets to make them more resistant to external and internal shocks. There is also the need to diversify away from crude oil into more sustainable energy sources to make the region less vulnerable to sporadic oil market uncertainty.

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