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Article

African stock markets' connectedness: Quantile VAR approach

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Abstract: The present paper investigates African stock markets' linkages by considering stocks in the continent's largest economies, specifically Egypt, Kenya, Morocco, Nigeria, South Africa, and Tunisia. Using a dataset that spanned November 25, 2008, to September 18, 2023, the quantile connectedness approach of Chatziantoniou et al. (2021) is employed, and the results unfold these interesting dynamics of African market connectivity: (i) In the bearish market phase, South African stock dominated the entire network, transmitting shocks to the remaining stocks, while Moroccan and Kenyan stocks played similar role mildly. (ii) In the bullish market phase, Nigerian stock dominated the market as a major net transmitter of shock supported by South African and Kenyan stock markets. (iii), The Egyptian and Tunis stock markets are net shock receivers in both the bear and bull market phases. (iv), At the median quantile value, stocks become less riskier and the Kenyan stock market becomes the most vulnerable while Nigerian, Egyptian, and South African stock markets are influenced by other stock markets when markets are calm. (v), Though, African stocks are underperforming, interested portfolio managers will learn from the trading strategies to be adopted to maximize their returns. These findings will benefit portfolio managers, international stakeholders, and regulators.

Keywords: quantile dynamic connectedness; African stocks markets; market phases; vector autoregression; portfolio management; normal market condition; lower quantile of returns.

JEL Classification: C22

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1. Introduction

Stakeholders and regulators have recognized the importance of understanding the complex connections among financial institutions since the 2008/2009 global financial crisis (Tabak & Silva, 2018; Deev & Lyócsa, 2020). The 2020 COVID-19 pandemic, which has been regarded as the most devastating health crisis in history that crippled global financial markets, has further caused global and regional markets to be more integrated (Coskun et al., 2023; Yaya et al., 2021). Other important events that substantially influenced the global financial markets in one way or the other include the European debt crisis, the United Kingdom's vote to leave the European Union (Brexit), and the recent Russian-Ukraine. The transmission of shocks across financial markets and the resulting contagion effects from the highlighted crises are made possible by the increasing degree of globalization, which has been identified as a major factor influencing the linkage of the international markets, as reflected in the increase in interdependence, integration, and interconnectivity of the global economy (Acheampong et al., 2021; Hasan, 2019; Hassan, Xia, Huang, Khan, & Iqbal, 2019; Sweidan & Elbargathi, 2022). The interconnectivity of the global economy has also manifested in the exchange of goods and services, capital mobility, population expansion, international migration, transportation, and communication. The sensitivity of stock returns to global uncertainties, and regional currencies makes it important to understand the connectivity of stock markets. Risk managers are usually interested in identifying markets that are susceptible to risks, as such information is essential for the smooth running of their investment activities. In addition, portfolio design and fund allocations will benefit greatly from the understanding of the spillover and interconnectivity of stock markets.

The African economic and financial systems have been experiencing tremendous growth over the last two decades, although, as expected, there were expected slowdowns in some years due to imminent crises, such as the COVID-19 pandemic. For example, between 2001 and 2010, the sub-region represented six out of the ten fastest-growing economies in the global rank (Adekoya et al., 2022). The AFDB (2020) puts in its economic outlook that the region's growth for 2019 was 3.4%, which is in concordance with the 2018 figure. Africa's economic growth varies from region to region. More importantly, the region is faced with regional differences in economic performance. The GDP growth rates of Western and Central Africa were estimated at 3.7% in 2022, while Eastern and Southern Africa grew by approximately 3.5% in the same year. South Africa is expected to drop by about 0.5% due to the deepening energy crisis, while the growth recovery for Nigeria in 2023 will be about 2.8% if oil production in the country remains subdued.[1] Moreover, the 10 largest economies in Africa represent up to three-quarters of the region's GDP, and eight countries, Sudan, Nigeria, Angola, and Ethiopia are growing at rates lower than their long-term average growth. The Southern part of the continent experienced the least growth, even slowing down from 1.2% to 0.7% (AFDB, 2020), while East Africa experienced the strongest growth overall, with an expected growth rate of 5% in 2019.

Given that economic performance has implications for the financial system, it is not surprising to also observe that African stock markets are increasingly developed, but at different levels. As of 2022, South Africa has the largest stock market in Africa with the Johannesburg Stock Exchange having a total capitalization of $1,356 trillion (€1,226 trillion), making it the 17th largest in the world. The Nigerian Exchange Group (NGX) is Africa's second-largest stock market with a market capitalization of $45.9 billion. The NGX also emerged as the 4th best-performing stock index in the world, in 2022 with a 19.99% investment return, according to the Morgan Stanley Capital International (MSCI) All-Country World Index that tracks some 3,000 stocks around the world. Next is Morocco's Bourse de Casablanca, with 76 listings, having a total market capitalization of $63.6 billion. The Egyptian Stock Exchange in Egypt and the Nairobi Stock Exchange in Kenya are ranked fourth and fifth, respectively. The African stock markets are also becoming more integrated. Nyakurukwa and Seetharam (2022) reported a low but increasing integration among the African markets, as they continue to undergo some level of development, including the automation of trade, demutualization of the markets, the introduction of the US-dollar-dominated trade, and the Exchange Traded Funds. The fact that the African economy has the world's largest free-trade area seems to be contributing to this integration.[2]

While the approach in this present paper is at variance with Adekoya et al. (2022), the need to investigate economic growth through market interdependencies is of paramount importance to the global community. In sum, Africa had eight stock exchanges in 2002 and currently has 29 stock exchanges with a combined market capitalization of about $1.6 trillion.[3] Global investors are now increasingly placing their bets on emerging economies to increase the size of their portfolios as the US and European stock markets

[1] https://dailypost.ng/2023/04/05/africas-growth-low-world-bank/
[2] https://www.worldbank.org/en/region/afr/overview
[3] https://www.afsic.net/stock-market-stocks-in-africa/

are in serious bubble territories. Some observers believe that the African economy has the greatest unrealized potential.[4]

This paper is motivated by the recent performance of African stocks and the recent proposition of the African Exchanges Linkage Project (AELP) which considers the linkage of seven African stock exchanges: South Africa, Nigeria, Morocco, Egypt, Kenya, Côte d'Ivoire, and Mauritius for easy access to diversified assets, particularly stocks of the largest African companies. There is a need to investigate African stock connectivity in terms of market drivers and spillovers, hence the need for this study. In addition, the African markets are still in their early stages of development, making them vulnerable to exogenous shocks that fluctuate overall market performance and integration. This implies that the African markets tend to behave and connect differently across different market conditions. While the finance literature has witnessed enormous studies that account for diverse market states in their examination of the connectedness among financial markets, such is scarce for the African markets.

Therefore, this paper investigates the linkage of stock markets in Africa using the Quantile Vector Autoregressive (QVAR) dynamic connectedness framework of Chatziantoniou et al. (2021). This approach allows connectedness to be investigated at bearish, bullish, and normal market phases, unlike the connectedness method of Diebold and Yilmaz (2012) and other related connectedness measures. Our findings indicate that selected African stocks are connected and that stocks in South Africa, Nigeria, Morocco, and Kenya played dominant roles at the two market extremes. Under normal market conditions for these six stock markets, the Nigerian, South African, and Egyptian stock markets are net shock transmitters of shocks. The portfolio management strategy rendered at the end will inform market participants on ways to combine portfolios to maintain profits amid underperforming African stocks.

The rest of the paper is therefore structured as follows: Section 2 presents a review of the literature. Section 3 presents the quantile VAR framework used to analyze the data. Section 4 presents the data and the empirical results, and Section 5 concludes the paper.

2. Literature review

The literature on global stock market connectedness is rich and vast and is grouped into different categories. The first category of studies considered within-group connectivity of stocks (Pan, et al, 2023; Bouras et al., 2019; Yang et al., 2021; Salisu et al., 2022). Another group of studies analyzed the connectedness of equities with other assets (Jain et al. 2023; Mensi et al. 2023; Dakhlaoui & Aloui, 2016; Wang et al., 2023). Yet another group of empirical papers on stock market connectedness considered the religious dimension, that is, Islamic stocks with conventional (Bossman, Junior, & Tiwari, 2022; Hassan, et al. 2022; Haddad et al. 2020). Other studies have examined the dynamic connectedness of South African stocks with other countries' stocks (Nyakurukwa & Seetharam, 2023; Khalfaoui et al., 2023; Chang et al., 2023). The papers have reported different results regarding the net receivers and transmitters of stock returns. The results obtained depended on the method adopted and the category of analysis.

Studies examining the dynamic linkages of African stock markets are scarce. Daryl and Biekpe (2002) found evidence of the 1997 Asian crisis spilling stock markets in South Africa, Egypt, Namibia, and Morocco, thus, these African stocks were considered as African market drivers. Louis et al. (2009) also showed that the financial markets in Africa were impacted by the global financial crisis of 2007-2009 and that the effects were exacerbated by overpriced stocks and insufficient diversification in the run-up to the crisis while the South African stock market seemed unaffected (Forbes & Rigobon, 2002). According to Giovannetti and Velucchi (2013), South Africa turns out to be a "net absorber" of volatility spillovers from global markets to Africa, whereas Kenya and Tunisia are "net creators" of these spillovers. Boako and Alagidede (2017) concentrated on

[4] https://www.dw.com/en/africas-stock-market-boom/a-66375522

estimating and evaluating the effects of extreme downside movements in developed stock markets and foreign exchange rates on the extreme downside risks in African stock markets. These findings are consistent with the hypothesis that global shocks may initially spread slowly to developing countries before accelerating after a crisis. Using dynamic conditional correlations, Bello, Guo, and Newaz (2022) investigated contagion effects in specific stock markets and from a regional viewpoint during global financial crises, and from a regional standpoint, they only discovered substantial evidence of contagion during the crises.

3. Statistical method

The QVAR dynamic connectedness framework of Chatziantoniou et al. (2021) uses quantile values $\tau \in (0,1)$ to mimic multivariate dynamics in the financial markets at different market phases, particularly at the bull, bear, and normal market conditions, corresponding to lower, middle, and upper quantile, respectively. The corresponding VAR(p) model for the econometric framework is,

$$X_t = \mu(\tau) + \sum_{j=1}^{\rho} \varphi_j(\tau) X_{t-j} + \varepsilon_t(\tau) \tag{1}$$

where X_t and $X_{t\text{-}j}$ are the K × 1-dimensional endogenous variable vectors; $\mu(\tau)$ defines the conditional mean vector of $K \times K$ dimensions, $\Phi_j(\tau)$ is the $K \times K$ dimensional matrix coefficients of the VAR model, $\varepsilon_t(\tau)$ are the K × 1-dimensional error vector with a $K \times K$ dimensional variance-covariance matrix, $\sum(\tau)$. It is often necessary to apply the Wold's representation in re-expressing the QVAR(ρ) model in (1) to a Quantile Vector Moving Average $[QVMA(\infty)\}$. Thus, one has,

$$X_t = \mu(\tau) + \sum_{i=0}^{\infty} \Psi_i(\tau) \varepsilon_{t-1} \tag{2}$$

and by using the approach contained in Koop et al. (1996) and Pesaran and Shin (1998), the Hstep ahead Generalized Forecast Error Variance Decomposition (GFEVD) is obtained as,

$$\Psi_{ij}^{\tau}(H) = \frac{\sum(\tau)_{ii}^{-1} \sum_{h=0}^{H-1} \left(e_i' \Psi_h(\tau) \sum(\tau) e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_i' \Psi_h(\tau) \sum(\tau) \Psi_h'(\tau)\, e_j'\right)}, \tag{3}$$

which is scaled as,

$$\widetilde{\Psi}_{ij}^{\tau}(H) = \frac{\Psi_{ij}^{\tau}(H)}{\sum_{j=1}^{k} \Psi_{ij}^{\tau}(H)}, \tag{4}$$

where e_i in (3) is a zero vector that equates to unity on the i-th position. From (4), the denominator, $\sum_{j=1}^{k} \widetilde{\Psi}_{ij}^{\tau}(H) = 1$, and $\sum_{i,j=1}^{k} \widetilde{\Psi}_{ij}^{\tau}(H) = k$, which are two necessary conditions here. Thus, $\widetilde{\Psi}_{ij}^{\tau}(H)$ renders the influence of variable j on all other variables i in terms of its share of forecast error variance/shocks. This is also defined as the total directional connectedness TO others, i.e. $C_{i\leftarrow j}^{\tau}(H) = \sum_{i=1, i\neq j}^{k} \widetilde{\Psi}_{ij}^{\tau}(H)$. The directional spillovers received by variable j from all other variables i is now the total directional connectedness FROM others, given as$C_{i\leftarrow j}^{\tau}(H) = \sum_{i=1, i\neq j}^{k} \widetilde{\Psi}_{ij}^{\tau}(H)$.Thus, the net directional connectedness is the difference between TO and FROM, i.e.,

$$\mathrm{NET}_i^{\tau} = C_{i\rightarrow j}^{\tau}(H) - C_{i\leftarrow j}^{\tau}(H) \tag{5}$$

Thus, NET_i^{τ}gives the net connectedness for variable i in the network of variables (i, j), and if NET_i^{τ}>0 in any variable, it implies that such a financial variable i transmits more shocks than it receives from other variables j. Thus, variable i influences the other variables in the network more than being influenced by them. If on the other way, NET_i^{τ}<0, it means that the variable is a net receiver of shocks, as it is being influenced by shocks from other variables j more than the shocks it transmits in the network. The Total Connectedness Index (TCI) is given in (6) as

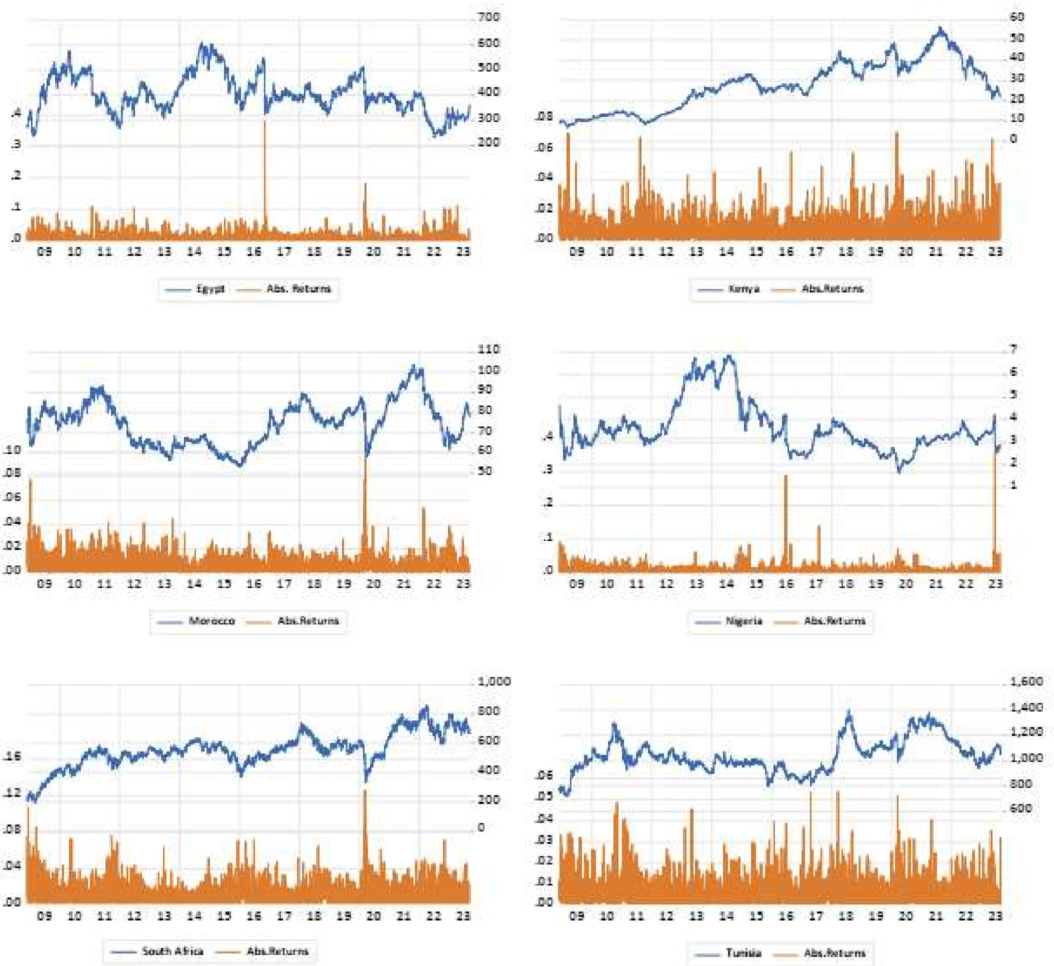
$$TCI^{\tau} = \frac{\sum_{i,j=1,i\neq j}^{k} \widetilde{\Psi}_{ij}^{\tau}(H)}{k-1} \tag{6}$$

which indicates the strength of the connectedness between a variable i and other variables j, and higher TCI implies high risk between (i, j) variable set and low TCI implies low market risk among the variables.

4. Data and empirical implementation

Daily Morgan Stanley Capital International (MSCI) stock indices of highly traded African stocks in US dollars were analyzed. The data are retrieved from DataStream, and span November 25, 2008, to September 18, 2023, covering 3865 data points, which were obtained based on data availability and relevance. The listed country stock indices are those of Egypt, Kenya, Morocco, Nigeria, South Africa, and Tunisia. The plots of these stocks, over the historic period are given in Figure 1 with the corresponding absolute log-returns. The absolute returns series allows for cross-checking of the volatility clustering with price dynamics, and it is appropriate on stock price plots. Recall, that stock prices have been reported in the current US dollar values because these allow for easier country-country comparison, and the weak US dollars in these countries will make plots of stock indices in local currencies entirely different from the ones given in Figure 1.

Figure 1. Plots of stock indices and absolute returns



The Kenyan stock index gained value from its inception until the third quarter of 2021 when prices started dropping significantly. South Africa and Tunisia have experienced price gains since 2008. The remaining three stocks (Egypt, Morocco, and Nigeria) have been performing poorly over time. The main focus of this paper is to analyze the volatility connectedness among these six stock markets using absolute log returns. Thus, corresponding log returns were obtained for each stock as

$$x_{it} = 100 * (\frac{p_{it} - p_{it-1}}{p_{it-1}}) \quad (7)$$

where p_{it} is the current price index of stock i at time t; and the previous price of the stock at time t - 1 is given as $p_{it\text{-}1}$. Table 1 presents the descriptive measures of log returns. In the upper part of Table 1, we observe negative average returns in the stock of Nigeria, and a large returns variance, implying high volatility in her stock markets. Egyptian stock has highest the volatility, followed by South Africa, and then Nigeria. The least variance was observed in the Tunisia stock market. All countries except Tunisia also showed negative asymmetry, which indicates that negative returns were more frequent than positive ones among these African countries' stock markets. Excess kurtosis estimates indicated leptokurtic distribution for each return series as an indication of heavy tails, and more frequent abnormal returns compared to the normal distribution. The ERS unit root test by Elliott, Rothenberg, and Stock (1996) [ERS hereafter] rejected the null hypothesis of no unit root in all the six series implying that log returns for these stocks are stationary as expected. Next, we checked for heteroscedasticity which informs volatility modeling using the serial autocorrelation Q test on log returns, $Q2$ on squared returns, and the ARCH test. Rejections of the null hypothesis of no serial correlations on log-returns and squared log-returns were observed, pointing to the possibility of heteroscedasticity in the log-return series. The significance of the ARCH LM test, as reported in the results table further supports the investigation of the interrelationships among the volatilities of African stocks using the QVAR connectedness approach.

Table 1. Descriptive Statistics and Correlations

	Kenya	Morocco	Nigeria	South Africa	Egypt	Tunisia
Mean	0.0666	0.0048	-0.0532	0.1556	0.1583	0.0665
Variance	1.2423	0.9240	2.3867	2.8896	3.1162	0.8305
Skewness	-0.275***	-0.514***	-5.313***	-0.244***	-3.357***	0.082**
Ex. Kurtosis	4.326***	7.566***	114.350***	3.550***	64.728***	3.401***
JB	3061.922***	9385.693***	2123405.151***	2067.826***	681795.603***	1866.541***
ERS	-22.788***	-28.009***	-11.229***	-28.711***	-7.824***	-21.284***
Q (20)	431.993***	79.680***	203.654***	29.356***	54.197***	20.848**
Q2(20)	596.951***	1334.724***	11.449	1421.160***	69.507***	459.624***
			Correlations coefficients			
	Kenya	Morocco	Nigeria	South. Africa	Egypt	Tunisia
Kenya	-					
Morocco	0.081***	-				
Nigeria	0.113***	0.042***	-			
South. Africa	0.070***	0.255***	0.039**	-		
Egypt	0.073***	0.136***	0.059***	0.141***	-	
Tunisia	0.026	0.184***	0.029	0.192***	0.028	-

** p < .05, *** p < .01

Since interconnectedness requires the dependency of one return variable on at least one or more variables, Pearson's correlation coefficients among the markets are reported in the lower panel of Table 1. The results were significantly positive but weak correlations were found generally among all the African stock markets considered. The highest correlation coefficient, r = .255, was found between the stock returns of South Africa and Morocco. The following pairs of country stock returns did not indicate any correlations: Kenya and Tunisia; Nigeria and Tunisia; and Egypt and Tunisia. The least significant correlation coefficient, r = .039, was found between Nigeria and South Africa. These weak correlations further supported our interest in possible checks on the connectedness of stocks in Africa in terms of volatility spillovers. Thus, the overall tests conducted in Table 1 support the assumptions and empirical strategy of connectedness employed using the QVAR framework of Chatziantoniou et al. (2021).

4.1. Results of quantile connectedness of African stocks

Following the preliminary test results in Table 1, the results of connectedness for the six African stock markets are discussed here for the lower quantile, upper quantile, and middle quantile.

4.1.1. Connectedness at the lower quantile, $\tau = 0.05$

The lower quantile represents the bearish side of the stock market. In Table 2, the results of the average connectedness of stock volatility at the lower quantile are presented. With a TCI of 56.22, the own-variance share spillovers for each stock are about 40-50% in the lower quantile case which further explains the strength of the connectedness. Kenya reported a 42.93% own variance share of volatility spillovers at the bearish market phase and it transmitted 11.5% of market shocks to Morocco, 11.97% to Nigeria, 12.27% to South Africa, 10.19% to Egypt, 11.7% to Tunisia, implying that Kenyan stocks transmitted a total of 57.62% spillovers to the remaining five stocks in the network. In terms of the number of volatility shocks received, Kenyan stocks received 11.67% shocks from Moroccan stocks, 11.58% from Nigerian stocks, 12.91% from South African stocks, 9.28% from Egyptian stocks, and 11.63% from Tunis stocks, with a total of 57.07% shock variations received by Kenyan stocks from the other five stocks. Thus, Kenyan stock is a net shock transmitter in the bear market among African stock networks. South African stock with NET = 4.53 was the strongest net shock transmitter in the network, followed by Moroccan and Kenyan stocks. The Egyptian stock was the weakest stock that received the highest shock (NET = - 4.85).

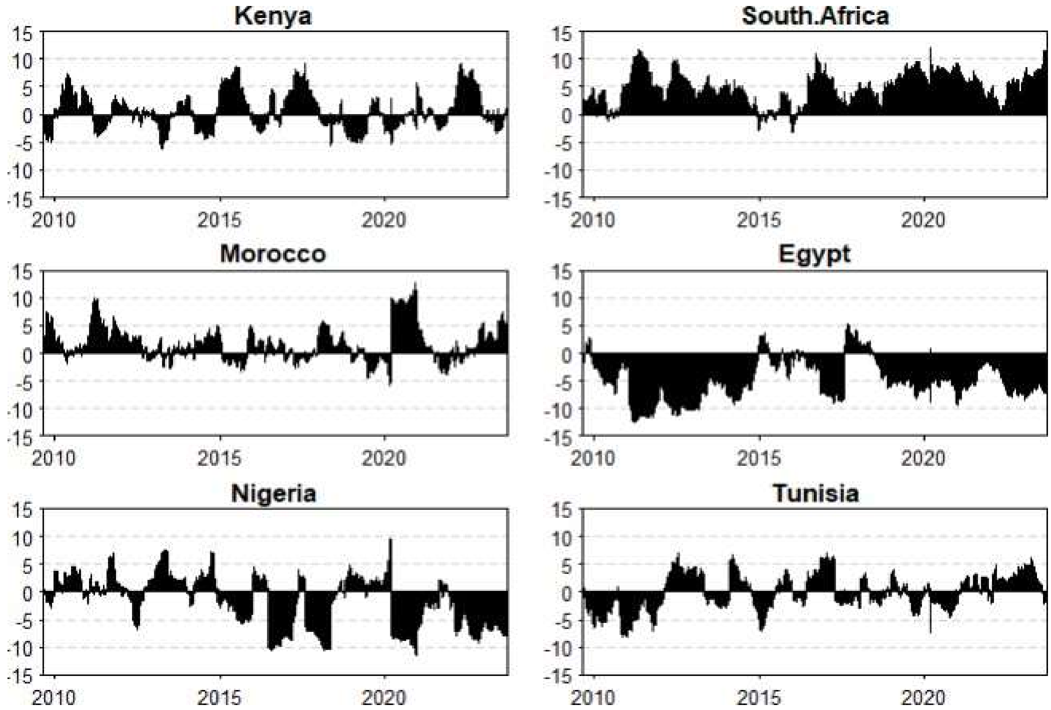
Table 2. Average connectedness at the lower quantile

	Kenya	Morocco	Nigeria	South Africa	Egypt	Tunisia	FROM
Kenya	42.93	11.67	11.58	12.91	9.28	11.63	57.07
Morocco	11.5	42.24	10.37	13.94	9.7	12.25	57.76
Nigeria	11.97	10.85	45.45	12.01	8.95	10.77	54.55
South Africa	12.27	13.4	10.99	40.49	10.22	12.64	59.51
Egypt	10.19	10.83	9.45	11.78	48.35	9.41	51.65
Tunisia	11.7	12.55	10.49	13.4	8.67	43.2	56.8
TO	57.62	59.31	52.88	64.04	46.81	56.7	337.35
Inc.Own	100.54	101.55	98.33	104.53	95.15	99.9	TCI
NET	0.54	1.55	-1.67	4.53	-4.85	-0.1	56.22

Further, we investigate the net connectedness abilities of the stocks over the sampled period, which is given as net directional connectedness. Recall that the NET values in

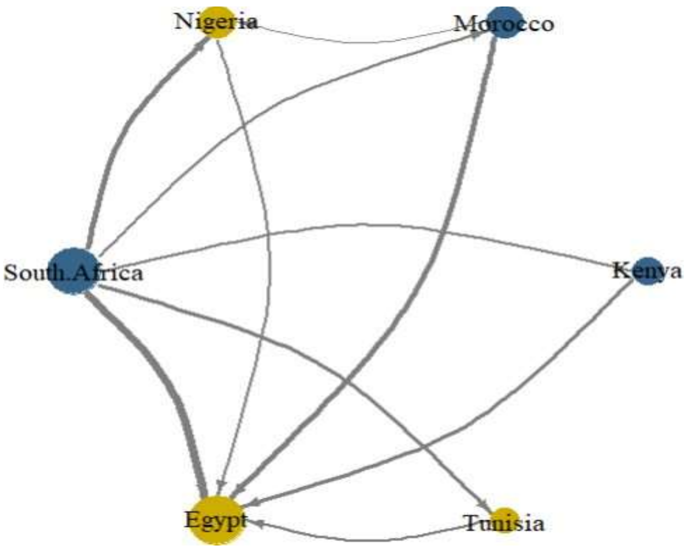
Table 2 give average value from the time series of NET values computed for each stock index from 2018 until the end of the sample, while this average value only indicates the overall direction of spillovers. Figure 2 shows that the South African and Moroccan stock markets have consistently maintained their net shock transmitting ability to other stock markets in Africa, while the Egyptian stock market has consistently become a net shock receiver over time. In late 2015, the Nigerian stock market was a net shock receiver, partly due to its weak US exchange rate. Thus, South African, and Moroccan stocks strongly drive the remaining four markets to a bearish market state.

Figure 2. Net Total Directional Connectedness at the lower quantile



From the net directional connectedness results, we examine pairwise directional connectedness, that is how shocks are transmitted between two stocks and how they are connected. In the network plots in Figure 3, the BLUE node indicates that the stock market is a net transmitter, while the ORANGE node indicates that the stock market is a net shock receiver, and in each case, the size of the node implies the transmitting (or receiving) strength of the market in the network. In Figure 3, the South African stock dominates the remaining five stocks in its shock-transmitting ability in the bear market phase. This transmitted the largest shock to the Egyptian stock market. It transmitted a fairly small shock to the Nigerian stock market next to the Tunisian market. It further transmitted shock of similar magnitude to the Moroccan and Kenyan stock markets. The Moroccan stock market severely transmitted shock to the Egyptian market and transmitted a very light volatility shock to the Nigerian market. Kenya transmitted the largest shock to Egypt than to South Africa. Obviously, Egyptian stock received shocks from all five stock markets, making Egyptian stock the strongest net shock receiver.

Figure 3. Network plots based on NPD for the lower quantile



4.1.2. Connectedness at the upper quantile, $\tau = 0.95$

The results in Table 3 are for the upper quantile, which connotes bullish market behavior for African markets, which became more integrated as they were found to move closely as revealed by the TCI value of 80.1. Thus, at the bull phase, African stocks move closer than at the bear state. Further, the Nigerian stock market emerged as the dominant market in the network with a NET value of 9.09, making the stock market the strongest net shock transmitter in the network. Next are the South African and Kenyan stock markets with NET values of 2.02 and 1.21, respectively. Thus, these three markets are the net shock transmitters at the bull market phase of African stocks. Egyptian stock maintained its position in this bull phase, as it was in the bear phase, as the strongest net receiver with an average NET value of -6.33 and joined the group by the Kenyan stock market with an average NET value of -5.44, and Morocco with an average NET value of -0.56. Thus, the South African stock market maintained its position as a net transmitter of shocks in the bull phase, as it did in the bear phase.

Table 3. Average connectedness at the upper quantile

	Kenya	Morocco	Nigeria	South Africa	Egypt	Tunisia	FROM
Kenya	19.95	15.94	17.6	16.43	15.16	14.92	80.05
Morocco	16.36	19.59	17.3	16.43	15.06	15.26	80.41
Nigeria	16.33	15.72	21.98	16.07	14.8	15.1	78.02
South Africa	16.14	16.11	17.4	20.11	15.04	15.2	79.89
Egypt	16.15	16.05	17.13	16.79	18.79	15.1	81.21
Tunisia	16.28	16.04	17.67	16.19	14.82	19	81
TO	81.26	79.85	87.11	81.91	74.88	75.57	480.58
Inc Own	101.21	99.44	109.09	102.02	93.67	94.56	TCI
NET	1.21	-0.56	9.09	2.02	-6.33	-5.44	80.1

Looking at the net directional connectedness plots in Figure 4 for the upper quantile's case, markets have become more volatile as the risk is higher in the network, as observed in the plots. Spillovers have become more sporadic and short-lived. The case of the

Nigerian stock market was obvious with this stock market consistently maintaining its stance as a net shock transmitter from 2015 to 2018. By looking at the network plot in Figure 5, Nigerian stock could transmit larger shocks to Egypt and Tunisia, while the stock market could also transmit shocks of similar magnitude to South Africa, Kenya, and Morocco. Egypt only received shocks from South Africa, Nigeria, Morocco, and Kenya, with the largest share received from Nigeria, whereas Tunisia received shocks received the largest shock from Nigeria and received a smaller amount of shocks from South Africa, Kenya, and Morocco. Morocco only received a shock from Nigeria.

Figure 4. Net Total Directional Connectedness at the upper quantile

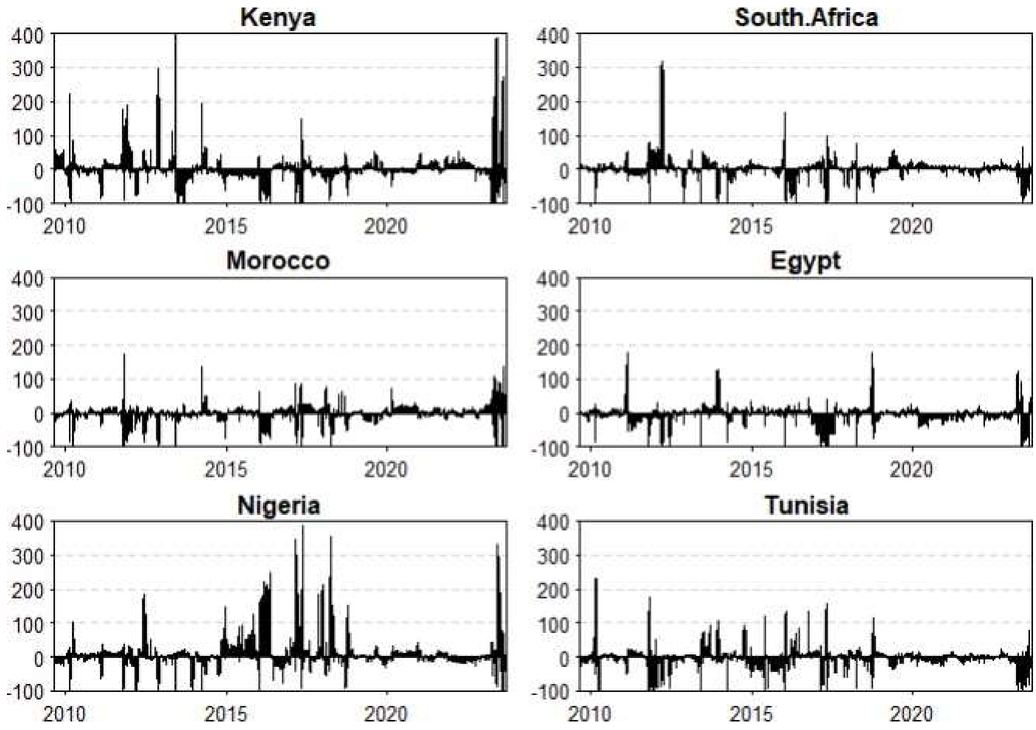
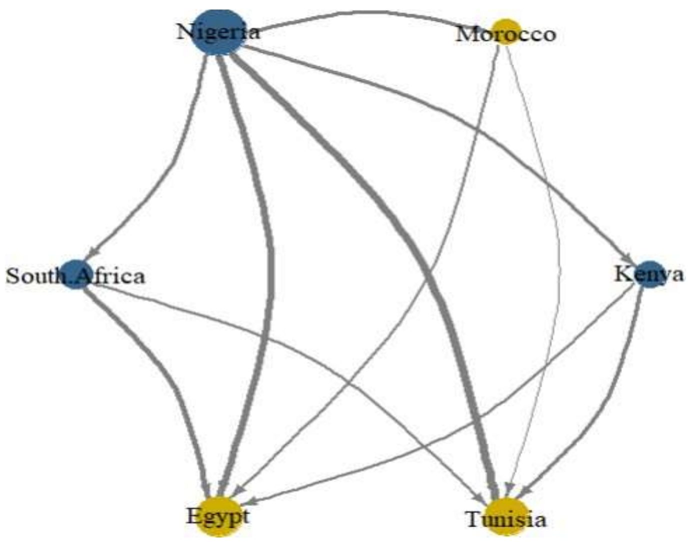


Figure 5. Network plots based on NPDC at the upper quantile



4.1.3. Connectedness at the middle quantile, $\tau = 0.5$

The middle quantile connotes normal market conditions where the stock market is calm and this is likened to the case of an efficient market where markets are not likely to be predicted due to low risk in holding an asset (Gil-Alana et al., 2018). In Table 4, under normal market conditions for stocks in Africa, each stock takes a large proportion of variance as its variance share of volatility spillovers, that is, above 80%. Further, stocks are less influenced by spillovers because the proportions of variance interconnectedness measures to and from other variables are very low. Thus, stock pricing is more stable and the market becomes less risky. The TCI is 16.33, which is lower than that of the bearish and bullish market phases. Due to low market interconnections, the Kenyan stock market emerged as the strongest net shock receiver while the South African, Nigerian, and Egyptian stocks emerged marginally as net shock transmitters. Moroccan and Tunis stock markets also emerged marginally as net shock receivers.

Table 4. Average connectedness at the middle quantile

	Kenya	Morocco	Nigeria	South Africa	Egypt	Tunisia	FROM
Kenya	85.28	2.56	3.13	3.46	2.98	2.6	14.72
Morocco	2.4	82.21	3.67	4.87	3.28	3.57	17.79
Nigeria	2.83	3.46	83.96	2.93	3.93	2.89	16.04
South. Africa	2.66	4.4	3.22	81.99	4.2	3.52	18.01
Egypt	3.01	3.52	3.27	3.93	83.83	2.43	16.17
Tunisia	2.17	3.56	3.41	3.72	2.42	84.73	15.27
TO	13.08	17.5	16.7	18.9	16.81	15.01	98
Inc.Own	98.35	99.71	100.67	100.89	100.64	99.74	TCI
NET	-1.65	-0.29	0.67	0.89	0.64	-0.26	16.33

The plots of net total directional connectedness at the middle quantile in Figure 6 further show that Kenyan stocks have been a persistent net receiver of shocks since 2010, while other stock markets have oscillated between being net transmitters or net receivers of shocks over the historical years. Figure 7 shows that there is a strong market bond between the Nigerian and Egyptian stocks, while the Nigerian stock market transmits shocks to the Kenyan and Tunis markets, and the Egyptian stock market transmits shocks to South African, Moroccan, Kenyan, and Tunisia markets. The Kenyan stock market received the most shocks.

Figure 6. Net Total Directional Connectedness at middle quantile

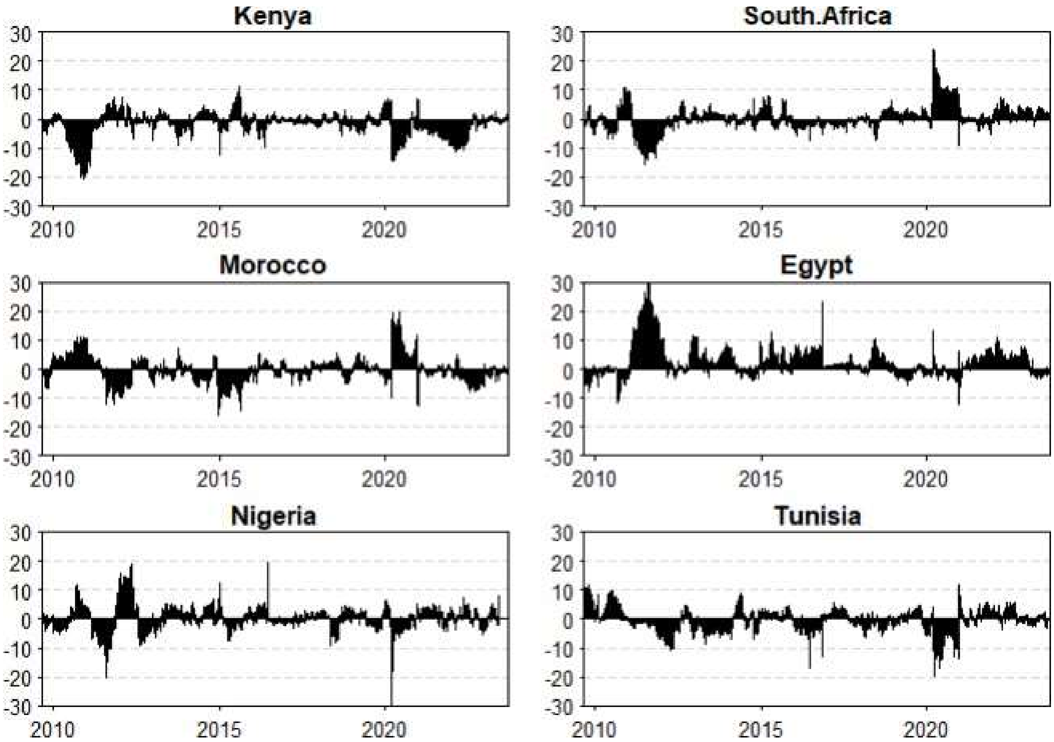
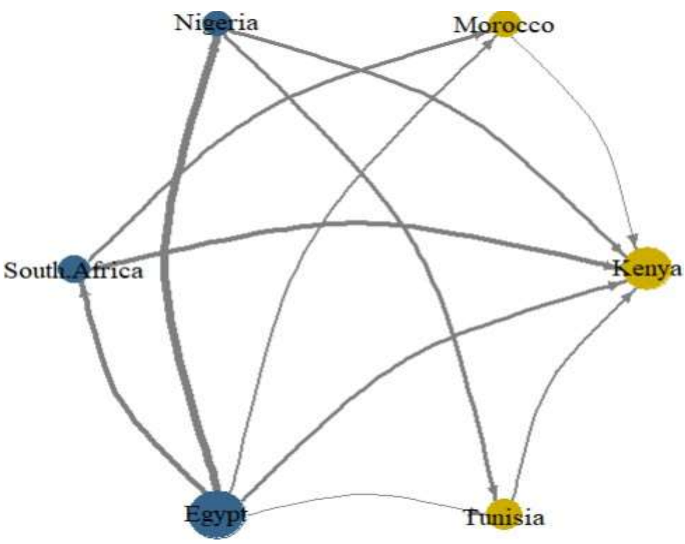


Figure 7. Network plots based on NPDC at the middle quantile



4.2 Portfolio management strategy based on optimal portfolio weights

The analysis is based on the dependence on estimates of time-varying variance-covariances and time-varying conditional correlations from the DCC-GARCH-t-Copula model of Antonakakis, et al. (2020) since conditional variance and conditional covariance series give the dynamic portfolio weights. The optimal weights for a portfolio were proposed by Kroner and Ng (1998). Given that investors prefer to minimize risk (variance) over reduce expected returns, this dynamic measure depends on estimations of variance-covariances. The following formula is suggested by Kroner and Ng (1998) to determine the weights of the two assets held concurrently in a portfolio:

$$W_{l,m,t} = 100 * (\frac{h_{llt} - h_{lmt}}{h_{mmt} - 2h_{lmt} + h_{llt}}) \quad (8)$$

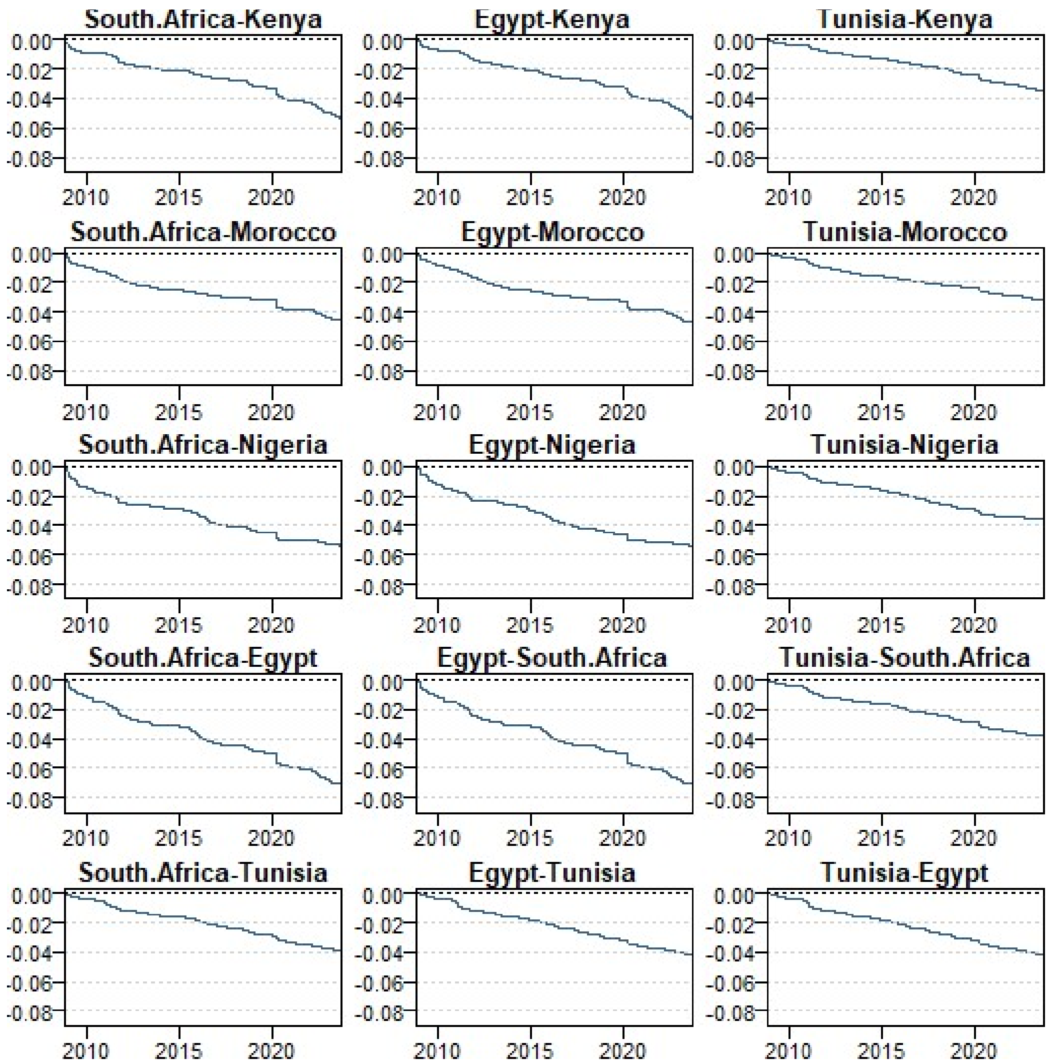
where the weight of asset l in a \$1 portfolio of the two assets (l, m) at time t is $w_{l,m,t}$. The corresponding weight of asset m is then given as $w_{m,,t}$ = (1 - $w_{l,m,t}$). In, the case of African stocks, two stocks are paired in the portfolio at lower, upper, and median quantile of log-returns of stock indices (see Table 5). Average optimal hedge ratios are reported in the results table with Hedging Effectiveness (HE) tests. The HE test results are obtained by comparing the performance of the hedged portfolios with those of the unhedged portfolios. In Table 5, HEs are found to be significant for the lower, upper and median quantile connectedness results implying the success of portfolio risk minimizing strategy in minimizing risk incurred during the trading of portfolios. Average optimal portfolio measures in the results table suggest a very high proportion of Moroccan stock to be combined with South African and Egyptian stocks in the same portfolio to maximize market returns. That is, at the lower quantile of returns, in the Moroccan stocks – South African stock, 74% proportion of Moroccan stock of a \$1 price is required to be combined with the balance of 26% of South African stocks in the same portfolio. At the upper and middle quantiles, it is expected that the proportions of Moroccan stocks in Moroccan stocks – South African, and Moroccan stocks – Egyptian stock portfolios should increase more than the proportions for the lower quantile. The proportion of South African stock in the South African stock – Egyptian stock portfolio is expected to be about 28% while the corresponding proportion for Tunis stocks will be about 72%. Also, that of South Africa in South African stock – Tunis stock portfolio is low, about 27%.

Table 5. Average cumulative portfolio return for optimal portfolio weights

Portfolio pairs	Lower quantile			Upper quantile			Middle quantile		
	Mean	HE	p-value	Mean	HE	p-value	Mean	HE	p-value
Kenya/Morocco	0.43	0.66	0.00	0.40	0.59	0.00	0.44	0.56	0.00
Kenya/Nigeria	0.57	0.50	0.00	0.57	0.45	0.00	0.60	0.39	0.00
Kenya/South Africa	0.64	0.44	0.00	0.68	0.30	0.00	0.73	0.29	0.00
Kenya/Egypt	0.66	0.46	0.00	0.75	0.30	0.00	0.72	0.30	0.00
Kenya/Tunisia	0.45	0.67	0.00	0.40	0.71	0.00	0.43	0.62	0.00
Morocco/Nigeria	0.64	0.38	0.00	0.65	0.45	0.00	0.65	0.35	0.00
Morocco/South Africa	0.74	0.26	0.00	0.78	0.20	0.00	0.81	0.13	0.00
Morocco/Egypt	0.74	0.32	0.00	0.85	0.19	0.00	0.78	0.20	0.00
Morocco/Tunisia	0.50	0.55	0.00	0.48	0.64	0.00	0.48	0.48	0.00
Nigeria/South Africa	0.58	0.49	0.00	0.58	0.73	0.00	0.63	0.54	0.00
Nigeria/Egypt	0.59	0.53	0.00	0.67	0.72	0.00	0.62	0.54	0.00
Nigeria/Tunisia	0.36	0.75	0.00	0.33	0.89	0.00	0.34	0.77	0.00
South Africa/Egypt	0.51	0.53	0.00	0.61	0.44	0.00	0.50	0.47	0.00
South Africa/Tunisia	0.27	0.77	0.00	0.24	0.82	0.00	0.19	0.76	0.00
Egypt/Tunisia	0.28	0.79	0.00	0.17	0.88	0.00	0.23	0.80	0.00

Plots indicating accrued returns during the trading of each paired portfolio at the lower, upper, and middle quantile of returns are given in Figures 8, 9, and 10. Expectedly, at the lower extreme negative stock returns over the sampled period, the paired portfolios of stocks are underperforming (Figure 8), and these are underperforming at the upper quantile (Figure 9). We are very concerned about the performance of stocks' portfolios at the median quantile where stock markets are operating at normal conditions. Here in Figure 10, we see that some portfolios are not gaining returns over the years.

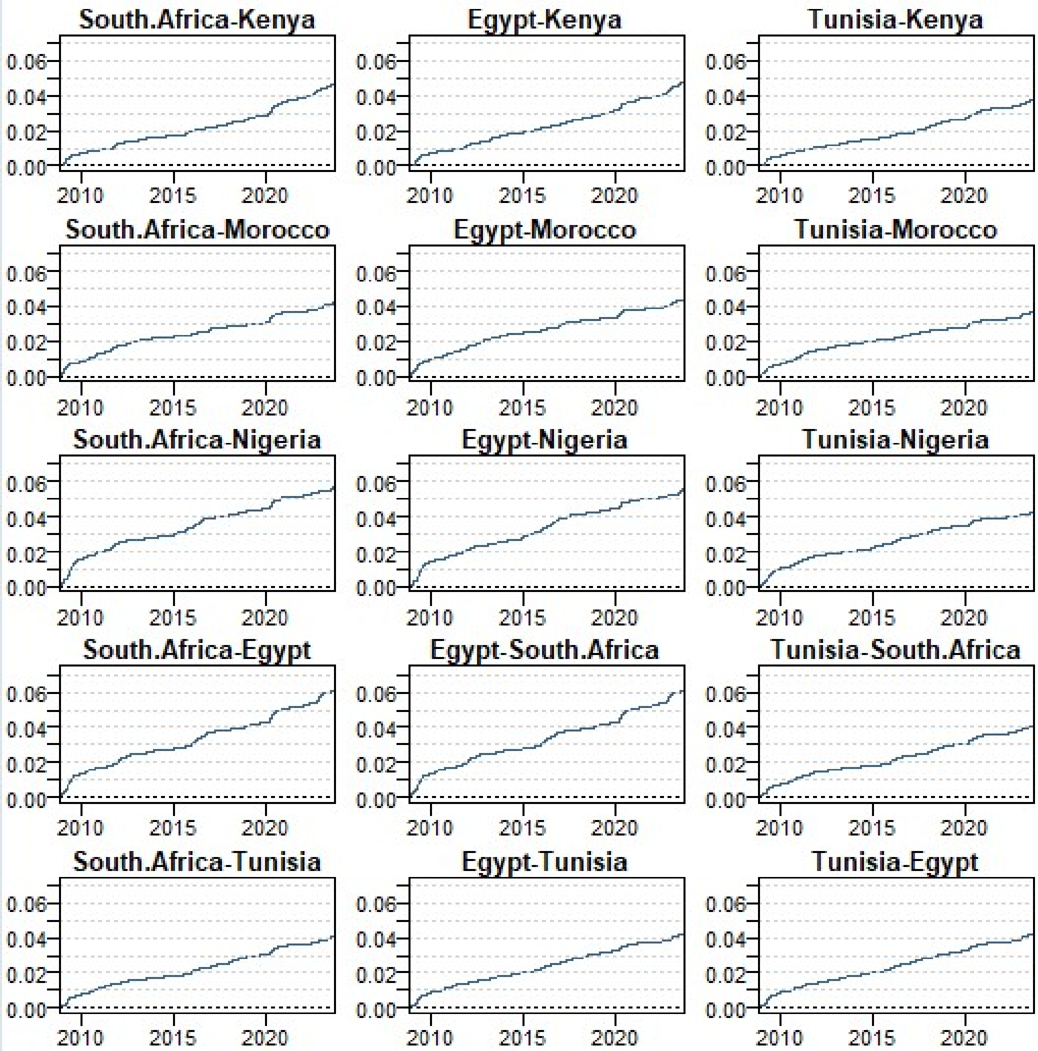
Figure 8. Cumulative portfolios return for optimal portfolio weight at lower quantile



5. Conclusion

Motivated by the unexplored opportunities in African stocks, and the recent proposition to link seven African stock exchanges, (i.e. South Africa, Nigeria, Morocco, Egypt, Kenya, Côte d'Ivoire, and Mauritius) together for easy access to diversify assets, the present paper therefore considers the linkage among African stock markets via the recently developed quantile dynamic connectedness of Chatziantoniou et al. 2021. This approach allows the investigation of the performance of markets at the bear, bull, and normal market phases. Daily MSCI stock indices for Egypt, Kenya, Morocco, Nigeria, South Africa, and Tunisia were considered with data spanning November 25, 2008, to September 18, 2023.

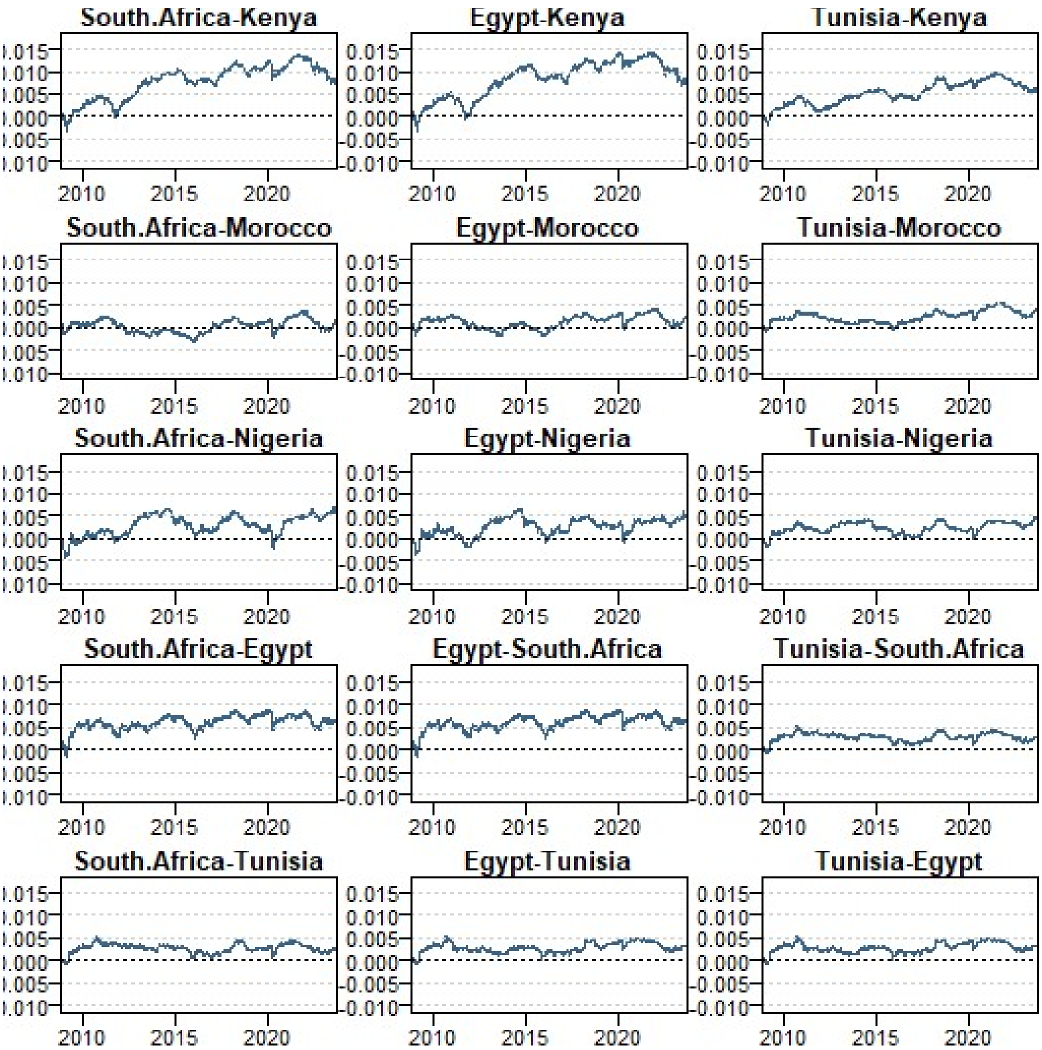
Figure 9. Cumulative portfolios return for optimal portfolio weight at upper quantile



At the extremely lower quantile value, which connotes a bearish market condition of African stocks, South Africa emerges as the dominant stock market in the connectedness network as it transmits volatility shocks to the remaining five stock markets, while the Moroccan and Kenyan stock markets also played similar role mildly. On the bullish side with high extreme quantile value, the Nigerian stock market dominated the African stock network as a major net transmitter of shocks, with South African and Kenyan stock markets also playing the role of net shock transmitters. At the bear and bull market phases, Egyptian and Tunis stock markets are more vulnerable as they remain the net shock receivers. At the median quantile points, which connotes a normal market condition for African stock markets, stock markets become less risky and the connectedness index is low. The Kenyan stock market was the most hit stock in this market phase, followed by the Tunis and Moroccan stock markets. The portfolio management strategy rendered at the end shows the importance of Moroccan stock in some portfolios. The strategy of optimum portfolio weighing rendered in the paper further shows the low performance of portfolios of African stocks.

The policy implications of the findings are that as a result of globalization, it is worthwhile for African stock exchanges to be linked together because of the mutual benefits that accrue to them as well as the reduction in risk as a result of the interconnectivity of stock markets. However, the reform should be planned with an appropriate regulatory body since countries respond to shocks emanating from stock markets, or other global shocks differently.

Figure 10. Cumulative portfolios return for optimal portfolio weight at middle quantile



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References

Acheampong A. O., Dzator J. and Savage D. A. (2021). Renewable energy, CO2 emissions and economic growth in sub-Saharan Africa: Does institutional quality matter? *Journal of Policy Modeling*, 43(5), 1070-1093. ttps://doi.org/10.1016/j.jpolmod.2021.03.011

Adekoya, O. B., Yaya, O. S., Oliyide, J. A. and Posu, S. M. A. (2022). Growth and growth disparities in Africa: Are differences in renewable energy use, technological advancement, and institutional reforms responsible? *Structural Change and Economic Dynamics*, 61, 265-277. https://doi.org/10.1016/j.strueco.2022.02.020

AFDB (2020). *African Economic Outlook 2020: Developing Africa's workforce for the future*. African Development Bank.

Antonakakis, N., Cunado, J., Filis, G., Gabauer, D. and de Gracia, F. P. (2020). Oil and asset classes implied volatilities: Investment strategies and hedging effectiveness. *Energy Economics*, 91, 104762. https://doi.org/10.1016/j.eneco.2020.104762

Bello J, Guo J., and Newaz M. K. (2022). Financial contagion effects of major crises in African stock markets. *International Review of Financial Analysis*. 82, 102128. https://doi.org/10.1016/j.irfa.2022.102128

Boako G. and Alagidede P. (2017). Examining evidence of 'shift-contagion' in African stock markets: A CoVaR-copula approach. *Review of Development Finance*, 7, 142-156. https://doi.org/10.1016/j.rdf.2017.09.001.

Bossman, A., Agyei, S.K., Owusu Junior, P., Agyei, E.A., Akorsu, P.K., Marfo-Yiadom, E., Amfo-Antiri, G., (2022). Flights-to-and-from-quality with Islamic and conventional bonds in the COVID-19 pandemic era: ICEEMDAN-based transfer entropy. *Complexity*, 2022 (1027495), 1-25. https://doi.org/10.1155/2022/1027495

Bouras C., Christou, C., Gupta R., and Suleman T. (2019). Geopolitical Risks, Returns, and Volatility in Emerging Stock Markets: Evidence from a Panel GARCH Model. *Emerging Markets Finance and Trade*, 55(8), 1841-1856. https://doi.org/10.1080/1540496X.2018.1507906

Chang, H. W., Chang, T., Ling, Y. H., and Yang, Y. L. (2023). Dynamical linkages between the Brent oil price and stock markets in BRICS using quantile connectedness approach. *Finance Research Letters*, 54, 103748. https://doi.org/10.1016/j.frl.2023.103748

Chatziantoniou, I., Gabauer, D., & Stenfors, A. (2021). Interest rate swaps and the transmission mechanism of monetary policy: A quantile connectedness approach. *Economics Letters*, 204, 109891. https://doi.org/10.1016/j.econlet.2021.109891

Coskun, Y., Akinsomi, O., Gil-Alana, L. A. and Yaya, O. S. (2023). Stock market responses to COVID-19: The behaviors of mean reversion, dependence, and persistence. *Heliyon*, 9, e15084. https://doi.org/10.1016/j.heliyon.2023.e15084

Dakhlaoui I., and Aloui, C. (2016). The interactive relationship between the US economic policy uncertainty and BRIC stock markets. *International Economics*, 146, 141-157. https://doi.org/10.1016/j.inteco.2015.12.002

Daryl, C. and Biekpe, N. (2002). Contagion: a fear for African markets? *Journal of Economics and Business*, 55, 285-297. https://doi.org/10.1016/S0148-6195(03)00020-1

Deev, O. and Lyócsa S. (2020). Connectedness of financial institutions in Europe: A network approach across quantile. *Physica A: Statistical Mechanics and its Applica*tions, 550, 124035. https://doi.org/10.1016/j.physa.2019.124035

Diebold, F.X. and Yilmaz, K. (2012). Better to give than to receive: predictive directional measurement of volatility spillovers. International *Journal of Forecasting*, 28 (1), 57-66. https://doi.org/10.1016/j.ijforecast.2011.02.006

Elliott, G., Rothenberg, T. J., & Stock, J. H. (1996). Efficient Tests for an Autoregressive Unit Root. *Econometrica*, 64(4), 813-836. https://doi.org/10.2307/2171846

Forbes, K.J. and Rigobon, R. (2002). No contagion, only interdependence: measuring stock market co-movements. *Journal of Finance*, 57, 2223-2261. https://doi.org/10.1111/0022-1082.00494

Gil-Alana, L. A., Gupta, R., Shittu, O. I. and Yaya, O. S. (2018). Market Efficiency of Baltic Stock Markets: A Fractional Integration Approach. *Physica A, Statistical Mechanics, and its Applications*, 511, 251-262. https://doi.org/10.1016/j.physa.2018.07.029

Giovannetti, G. and Velucchi, M. (2013). A Spill-over analysis of shocks from U.S, UK and China on African financial markets. *Review of Development Finance*, 3, 169-179. https://doi.org/10.1016/j.rdf.2013.10.002

Gourène, G. A. Z., Mendy P., and. Ake, G. M. N. (2022). Multiple time-scales analysis of global stock markets spillovers effects in African stock markets. *International Economics* 157 (2019) 82-98. https://doi.org/10.1016/j.inteco.2018.09.001

Haddad, H. Ben, Mezghani, I., Al Dohaiman, M. (2020). Common shocks, common transmission mechanisms and time-varying connectedness among Dow Jones Islamic stock market indices and global risk factors. *Economic Systems*, 44 (2), 100760. https://doi.org/10.1016/j.ecosys.2020.100760

Hassan, K., Hoque, A., Wali, M., Gasbarro, D. (2019). Islamic stocks, conventional stocks, and crude oil: directional volatility spillover analysis in BRICS. *Energy Economics*, 92, 104985. https://doi.org/10.1016/j.eneco.2019.02.016

Hassan, K., Hoque, A., Wali, M., Gasbarro, D. (2020). Islamic stocks, conventional stocks, and crude oil: directional volatility spillover analysis in BRICS. *Energy Economics*, 92, 104985. https://doi.org/10.1016/j.eneco.2020.104985

Jain P., Maitra D., McIver R. P. and Hang S. H. (2023). Quantile dependencies and connectedness between stock and precious metals markets. *Journal of Commodity Markets*, 30, 100284. https://doi.org/10.1016/j.jcomm.2022.100284

Khalfaoui, R., Hammoudeh, S., and Rehman, M. Z. (2023). Spillovers and connectedness among BRICS stock markets, cryptocurrencies, and uncertainty: Evidence from the quantile vector autoregression network. *Emerging Markets Review*, 54, 101002. https://doi.org/10.1016/j.ememar.2023.101002

Koop, G., Pesaran, M. H., and Potter, S. M. (1996). Impulse response analysis in nonlinear multivariate models. *Journal of Econometrics*, 74 (1), 119-147. https://doi.org/10.1016/0304-4076(95)01753-4

Kroner, K. F. and Ng, V. K. (1998). Modelling asymmetric co-movements of asset returns. *Review of Financial Studies*, 11(4): 817-844. https://doi.org/10.1093/rfs/11.4.817

Louis, K., Leonce, N., and Taufic, R., (2009). Impact of global financial and economic crisis on Africa. Working Paper Series, No. 96. African Development Bank, Tunis, Tunisia. 36.

Mensi, W., Aslan, A., Vo, X., and Kang, S.H. (2023). Time-frequency spillovers and connectedness between precious metals, oil futures and financial markets: Hedge and safe haven implications. *International Review of Economics and Finance*, 83, 219-232. https://doi.org/10.1016/j.iref.2022.08.015

Nyakurukwa K. and Seetharam Y. (2022). Stock market integration in Africa: Further evidence from an Information-Theoretic Framework. *International Finance*, 26 (1), 1-11. https://doi.org/10.1111/infi.12419

Nyakurukwa, K., and Seetharam, Y. (2023). Quantile and asymmetric return connectedness among BRICS stock markets. *The Journal of Economic Asymmetries*, 27, e00303. https://doi.org/10.1016/j.jeca.2023.e00303

Pesaran, M.H. and Shin, Y. (1998). Generalized Impulse Response Analysis in Linear Multivariate Models. *Economics Letters*, 58, 17-29. https://doi.org/10.1016/S0165-1765(97)00214-0

Salisu A. A., Ogbonna A. E., Lasisi L., and Olaniran A. (2022). Geopolitical risk and stock market volatility in emerging markets: A GARCH - MIDAS approach. *The North American Journal of Economics and Finance*, 62, 101755. https://doi.org/10.1016/j.najef.2022.101755

Sweidan O. D. and Elbargathi K. (2022). The effect of oil rent on economic development in Saudi Arabia: Comparing the role of globalization and the international geopolitical risk. *Resources Policy*, 75, 102469. https://doi.org/10.1016/j.resourpol.2021.102469

Tabak B. M. and Silva T. C. (2018). A Sensory, Financial networks. *Complexity*, 2018(7802590). https://doi.org/10.1155/2018/7802590

Wang, G.-J., Wan, L., Feng, Y., Xie, C., Uddin, G. S., and Zhu, Y. (2023). Interconnected multilayer networks: Quantifying connectedness among global stock and foreign exchange markets. *International Review of Financial Analysis*, 86, 102518. https://doi.org/10.1016/j.irfa.2023.102518

Yang T., Zhou F., Du M., Du Q., and Zhou S., (2021). Fluctuation in the global oil market, stock market volatility, and economic policy uncertainty: A study of the US and China. *The Quarterly Review of Economics and Finance*, 87, 377-387. https://doi.org/10.1016/j.qref.2021.08.006

Yaya, O. S., Gil-Alana, L. A., Vo, X. V. and Adekoya, O. B. (2021). How fearful are Commodities and US stocks in response to Global fear? Persistence and Cointegration analyses. *Resources Policy*, 74, 102273. https://doi.org/10.1016/j.resourpol.2021.102273

Zhang, Wu, H., Li H., Zhong B., Fung I. W. H., and Lee Y. Y. R. (2023). Exploring the adoption of blockchain in modular integrated construction projects: A game theory-based analysis. *Journal of Cleaner Production*, 408, 137115. https://doi.org/10.1016/j.jclepro.2023.137115