

## Research Article

# Exchange Rate, COVID-19, and Stock Returns in Africa: Insights from Time-Frequency Domain

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We examine the co-movement between exchange rate (EXR) returns and stock (STK) returns in Africa amid COVID-19 in a time and frequency domain. Therefore, we employ the bi- and partial wavelet and the wavelet multiple correlation techniques using daily data from 13 February 2013 to 6 May 2021. Our findings divulge that COVID-19's effect does not increase the intensity of the relationship between EXR and STK returns in Africa but causes a significant difference in the lead-lag relationship between the two assets. We find a strong likelihood for a high market integration between African markets in the long run, regardless of market conditions. Under general market conditions, South African (Namibian) equities have the lead/lag potential in the short and long run (intermediate term). Namibian stocks are the first to respond to shocks before all other remaining variables in the intermediate term, while in the long term, the South African EXR market is the last variable to experience shocks. Owing to the recently intensified alliances between African markets, investors should be wary of the specific African equities they include in their portfolios in the periods ahead. Policymakers are required to have an in-depth understanding of the nature of the co-movement between the variables to ensure timely and operative policy responses are rolled out to minimise adverse fluctuations in stocks and the local currencies.

## 1. Introduction

Undoubtedly, the role of an operational financial system in the attainment of financial stability, economic growth, and development is inevitable [1, 2]. This is evidenced by the far-reaching consensus that has been reached on the subject over the past few decades [1]. Fundamentally, the financial system consists of the markets for stocks (STK) and foreign exchange (EXR). Thus, these markets need to be “up and running” to facilitate consumption, capital investments, aggregate demand [3], savings, and overall macroeconomic performance and affluence. He et al. [1] noted that the co-movement between the markets for STK and EXR presents critical consequences to economies.

In high volatility periods, the financial system could be destabilised [4] because, through contagious conduits,

distinct market shocks are diffused across several markets [5], causing economic instability. Furthermore, the co-movement between the two markets is critical for an efficient allocation of scarce resources since it influences portfolio management [6–9]. Certainly, the views shared and decisions made by economic agents as well as policy implementation rely on the strong connection between the stock (STK) and foreign exchange (EXR) markets. The consequences account for the intense analysis by researchers on the co-movement between the two markets—EXR and STK. Volatility in these markets may usually be different across periods and depends on the prevailing market conditions. Following these, studies on the subject matter have yielded inconclusive results [1].

Since the declaration of coronavirus disease 2019 (COVID-19) as a pandemic, several sectors have had a fair

share of the detrimental effects imposed by the pandemic [10, 11]; X. [12–14]. Financial markets (Asafo-Adjei, [15–18]), supply chains [19], tourism (Wu et al. [20]), energy, communication [21], real estate [17] just to mention a few are notable sectors that have been unfavourably affected by the pandemic. Although scholars, such as [22–25], have identified that the stock market has not been spared by the pandemic, particular attention has not yet been paid to the EXR-STK returns nexus in a time-frequency spectrum in Africa. Therefore, insights into the relationship between the two markets are essential [26] as investors and fund managers would rely upon them in constructing a minimum-variance portfolio.

Given that the stochastic properties of the stock and exchange markets may differ across time and frequency, it is relevant that studies consider the time-variant connection between these markets. Owing to this, the adaptive market hypothesis (AMH) engineered by Lo [27] posits that markets evolve—due to events and structural changes—and market efficiency changes in degree at diverse times. The COVID-19 pandemic could bring about changes in market dynamics as a result of the shocking consequence it poses on financial markets ([18, 28–31]), leading to various states of market efficiency. Also, the frequencies (multiscales) are important to illustrate stock market participants' diverse investment timescales, which corroborate the heterogeneous markets hypothesis (HMH), as indicated by Müller et al. [32].

Therefore, we employ an edifying method, an analysis by wavelet coherence, to examine the co-movement between the exchange rates and stock market returns during the COVID-19 pandemic in Africa, a segmented market of the international financial market [33]. The socioeconomic consequences of the pandemic on the African economy may be lifelong despite its survival from the anticipated health implications [19]. In addition, African markets are not well integrated with international stock markets [9]. Therefore, it follows that the effect of the pandemic on financial markets in Africa may differ from that of global markets. To aid policy implementation and optimal investor decisions in the uncertain times of the pandemic, a study of the co-movement of the two fundamental components of the financial system from the perspective of the time-frequency domain is essential [8]. Hence, observing how market dynamics evolve across investment or trading horizons of short-, medium-, and long-term periods (i.e., frequency domain) is as important as envisaging such dynamics across calendar times (i.e., time-domain).

The application of wavelet transforms helps to decompose time-series observations into a time-frequency domain. Unlike other techniques, wavelet analysis also facilitates the evaluation of the localised variations of power in data series. Furthermore, given that time series are characterised by nonlinearity and disorder, wavelet analysis is capable of revealing concealed irregularities [1] between variables relative to other techniques. The characteristics of a given time-series data are preserved in the course of wavelet analysis, making it appropriate for this study.

With recourse to the HMH [32] and the AMH [27], the COVID-19 pandemic could cause a change in market

dynamics, leading to the possible creation of new markets in which investor behaviour is expected to be different from normal markets—due to changes in market dynamics such as varying market efficiencies and structural changes. Just like other asset classes, both the stock and exchange rate markets have been proven to be impacted by the pandemic. Studies [23–25] have revealed that the stock market has not been spared by the COVID-19 pandemic, as it has intensified the level of risk aversion in the stock market. Likewise, Agyei et al. [19] identified that the COVID-19 pandemic has not been favourable to supply chains.

According to Dornbusch and Fischer [34] and Rai and Garg [35], the balance of trade and global competitiveness is induced by fluctuations in the exchange rate and, consequently, affect real output and stock price. Meanwhile, Arouna et al. [36] observed that one of the direct channels through which the COVID-19 pandemic affects global economic activities is input cost fluctuations resulting from inflation, crude oil prices, and exchange rates, leading to distortions in aggregate consumption. Given that policy implementation decisions warrant a strong interrelation between the EXR and STK markets [1], there is the need to revisit the stock-exchange rate relationship during the COVID-19 pandemic. Furthermore, as Blau [4] noted, during high volatility eras, a destabilisation of the financial system could be envisaged. The possible destabilisation of the financial system in high volatility periods could occur through contagious conduits, in which unique market shocks are transmitted across several markets [5].

Following this, it is expected that the shocks in either the EXR or STK market resulting from the impact of the COVID-19 pandemic would transmit to the other, causing a change in the standing EXR-STK nexus. To the best of our knowledge, no existing study has analysed the COVID-19 effect on EXR and STK returns co-movement in Africa. As Owusu Junior et al. [6–8] and Tweneboah et al. [9] posit, the co-movement between exchange rate and stock market returns is critical for an efficient allocation of scarce resources since it influences portfolio management. As contended by Heimonen et al. [3] and He et al. [1], the fundamental constituents of the financial system are stocks and exchange rates.

The United States Dollar, USD, is widely accepted as an international currency for trade across the globe. The USD exchange rate is utilised in this study because it is the most acceptable and tradable legal tender for most international transactions (Salisu & Mobolaji, 2013) irrespective of high interdependencies with other currencies (see [8]). There is a need to ensure the efficient running of these markets to facilitate a sound financial system [3] since decisions made by economic agents and policy implementation [1] heavily require a strong connection between the EXR and STK markets. Additionally, Heimonen et al. [3] suggested that a strong connection between the two markets facilitates consumption, capital investments, aggregate demand, savings, and overall macroeconomic performance.

Thus, in devising measures to overcome the unprecedented shocks of the COVID-19 pandemic [28], a study of the two markets is indispensable. With several sections (e.g.,

tourism, supply chains, energy, and communication) of the global economy being affected by the COVID-19 pandemic, we believe that it is not empirically a misplaced focus to reassess the connection between the key constituents (exchange rate and stock markets) of the financial system. Several international transactions are undertaken in respect of the USD. Thus, a common measure of the exchange rate is the local currency to the USD, the widely accepted currency for international trade.

By way of extension, we provide substantial evidence on the effect of the COVID-19 pandemic on the correlations between asset classes. The study's focus on the exchange rate and stock index is motivated by the relevance of optimal portfolio creation by investors during market stress, for example the unfavourable market conditions brought about by the COVID-19 pandemic. As indicated by Frimpong et al. [38], asset correlations offer a significant contribution in areas such as risk administration, analysis of risk transmission across assets, and asset allocation decisions. In addition, the smooth running of the markets for exchange rates and stocks facilitates consumption, capital investments, aggregate demand [3], savings, and overall macroeconomic performance. Therefore, re-examining the correlations between asset classes during the COVID-19 pandemic cannot be overlooked—this would enable investors and fund managers to make optimal portfolio decisions, taking into consideration the relative risks associated with each asset class across different timescales. Specifically, we provide fresh evidence on the EXR-STK return co-movement by adjusting for the possible influence of the COVID-19 pandemic through the application of partial wavelet coherence, which is yet to be attended to by scholars.

By employing the wavelet coherence analysis, we provide novel insights into the EXR-STK market returns nexus in Africa. We employ the partial wavelet transform to show the co-movements between two variables relative to a common interdependence. In this case, we examine the COVID-19 pandemic's (total cases returns) influence on the co-movement between EXR and STK returns to establish how the relationship between these markets covary across varying time and frequencies [9, 18].

Furthermore, new alliances (e.g., the African Continental Free Trade Area (AfCFTA), the stipulated West-African Monetary Zone, etc.) are now common to the African continent. Also, with the recent increases in the international agreements with countries such as the UAE, China, and India, the chances of market integration are now higher. Thus, we maintain that an assessment of the level of integration and the fundamental co-movement dynamics in a time-frequency paradigm is timely. Hence, supplementary to the bi-wavelet approach, the use of the wavelet techniques (wavelet multiple correlations (WMC) and cross-correlations (WMCC)) becomes important. For any given country or markets, the correlation between EXR and STK returns is revealed by the bi-wavelet analysis, whereas the use of WMC and WMCC reveals the coherence between multiple countries or markets [18, 39].

Under the bi-wavelet analysis, we report that the diversification prospects of African stocks and EXR returns may be inconsistent during the short term in turbulent

trading periods like the one introduced by the COVID-19 pandemic, specifically within the sample period. Results from the WMC indicate that African markets stand the chance of getting highly integrated into the long term, be it tranquil or exuberant market conditions. Through the WMCC analysis, we document that in general market conditions, South African (Namibian) stocks possess the lead/lag potential in the short and long term (intermediate term). In stress periods, the stock market of Botswana and the exchange rate market of South Africa possess the lead/lag potential in the short and intermediate term.

The rest of the article is organized as follows: Section 2 covers the literature review. Section 3 discusses the methods. Section 4 presents the data and preliminary results. Section 5 details the results. Practical implications are provided in Section 6. And the conclusion is given in Section 7.

## 2. Literature Review

Theoretically, the link between the markets for stocks and foreign exchange is premised on Dornbusch and Fischer's [34] flow-oriented theory and Frankel's [40] portfolio balance theory. The flow-oriented theory also referred to as the "goods market hypothesis" [41] holds that in an economy, the movement in the exchange rate is accompanied by a corresponding movement in asset prices. The foremost determination of the exchange rate is brought about by the asset market at a given point in time [34]. The theory presents that an economy's balance of trade and current account are significantly influenced by a movement in the exchange rate, which sequentially affects the real sector of that economy, particularly aggregate productivity [41]. From a macroeconomics outlook, a firm's stock price is worth, in today's terms, future cash flows, which in line with the hypothesis of efficient markets, must incorporate all available information relevant for determining firm performance (provided the market is characterised by efficiency).

Thus, stock prices are expected to behave in line with the prevailing economic conditions at any point in time, suggesting a co-movement of exchange rate and stock returns. Empirically, a devaluation (appreciation) of the local currency of an export-dominated economy stimulates (suppresses) exports as foreign demands for domestic goods increase (reduce). This economic boom (downturn) causes a rise (fall) in stock prices. On the contrary, foreign inputs are rendered expensive (cheaper) in import-dominated economies when their local currency devalues (appreciates)—production costs escalate (de-escalate) and both production and profits are reduced (enhanced), causing a fall (rise) in stock prices. Generally, the effect of movements in the exchange rate is hooked on the nature of the economy, be it an import- or export-dominated one.

Also known as the "stock-oriented" model, the portfolio balance theory (PBT), propounded by Frankel [40], suggests a reverse direction of causality established by the flow-oriented theory. Rather than movements in exchange rate causing a change in stock prices, the PBT proposes that oscillations in stock prices in an economy could influence the exchange rate through the inflow and outflow of foreign

capital. Frankel's [40] PBT classifies the exchange rate as the same as goods and services whose prices are established by market forces, implying that flourishing (low-performing) stock markets, determined by the returns they offer, attract (discourage) foreign investors, causing more capital inflows (outflows) as a result of the increased (decreased) demand for local currency and that would strengthen (weaken) the local currency. Generally, the PBT proposes an inverse connection between stock prices and interest rates on the premise that a reduction in wealth is caused by a reduction in stock prices, and that it results in capital outflows and currency devaluation since the demand for money falls and interest rates also follow suit.

Although the two theories offer a strong backing to explain the co-movement of stocks and exchange rates, their influence could simultaneously [42] occur in a given market. Under such a condition, any of the theories may be inadequate to draw inferences about the co-movement between the two markets [1], and hence, a pragmatic inquiry is relevant. In the era of the COVID-19 pandemic, where mixed relationships between variables could be revealed (especially in "not so well" developed or robust economies), the relationship between the two variables could be established by both theories. The nature of this co-movement needs to be examined in African markets.

Studies have found support for both theories (flow-oriented theory and stock-oriented theory). The majority of techniques employed by previous studies to examine the relationship between the stock and foreign exchange markets are simple linear regression models [41] and linear time-series approaches [1]. Empirical works on the relationship between the two markets do not commensurate with each other. Although Patra and Poshakwale [43] did not reveal a significant result, some works (see, e.g., [44–46]) have claimed a positive relationship between stock prices and exchange rates, whereas others (see [47–49]) have suggested a negative relationship. Moreover, some studies [50] claim a long-run stable positive co-movement between stock prices and exchange rates; others reveal either a minimal indication [51] or no indication [52, 53] of any connection between the two markets. As a result, Bahmani-Oskooee and Saha [54] opine that scholars have a greater chance of uncovering indications of short-term impacts.

Variations in findings could be attributed to differences in methods or techniques, differences in geographical regions, and data collection periods. Katechos [55] advances that a strong co-movement of the two markets is expected during unfavourable market conditions. In Nigeria, Okorie et al. [56] revealed a weak direct relationship between exchange rate and stock market returns when they examined the connection between the variables including inflation. Bahmani-Oskooee and Sohrabian [57] employed an autoregressive model to examine the connection between the US stock indices and the US exchange rate and found a bi-causal relationship between the two variables. Meanwhile, among the G7 economies, Nieh and Lee [58] reported that in the long term, there exists no relationship between the markets for stocks and foreign exchange. Upon conducting a study involving the largest economies in the world, Ferreira et al.

[59] discovered a significant connection between stock and foreign exchange markets in India but no significant connection was discovered between the two markets in Europe.

With the BRICS economies, Mroua and Trabelsi [60] analysed the connection between stock market indices and exchange rates between the period 2008 and 2018 and found that movements in exchange rates have a direct and significant influence on stock returns, both in the short term and in the long term. On the contrary, when Rai and Garg [35] studied the effect of the COVID-19 pandemic on the dynamic relationship and volatility between the two variables in the BRIICS economies, they found a negative dynamic connection between exchange rates and stock returns in most of these economies. Furthermore, Singhal et al. [61] employed the ARDL technique to investigate cointegration to test the relationship between the markets for stocks, foreign exchange, global oil prices, and global gold prices in Mexico. Their findings resulted in the conclusion that there is no significant connection between stocks and exchange rate markets in Mexico, yet they discovered that crude oil could drive a significant link between the variables. A firm-level analysis conducted by Salisu et al. [62] revealed a positive connection between exchange rate and stock returns for firms listed on the S&P500 index.

Wavelet analysis is increasingly gaining attention in the finance literature that focuses on two-sided relationships between variables. By employing this technique, Afshan et al. [42] investigated the connectedness of exchange rates and stock prices in Pakistan and discovered that across a long timescale, there is coherence and a bidirectional connection between the variables. When the technique was used in the BRICS economies to re-examine the stock-exchange rate relationship, Dahir et al. [63] found no evidence for China. A negative co-movement led by stock returns was revealed for India, while a positive co-movement was led by the exchange rate for Brazil and Russia. In South Africa, the relationship was proven to be bidirectional.

To add to the finance literature on the COVID-19 pandemic, the study employs the wavelet analysis to assess the EXR-STK returns nexus in Africa to allow for the generation of relationships for separate markets rather than some average results that would be obtained using other panel data analysis techniques. Our study differs substantially from prior empirical studies on the nexus between exchange rates and stock markets in Africa via the wavelet techniques in three folds. First, we carefully delineate the co-movements between EXR and STK returns of Africa for the full and subsamples. Second, we examine the pandemic's impact on the nexus between EXR and STK returns from a time and frequency perspective through the partial wavelet. This analysis divulges how the pandemic has distorted the fundamental relationship between EXR and STK returns as espoused by existing studies. The principles of portfolio diversification suggest that highly co-moving assets may not be viable candidates for a given portfolio [64]. Therefore, findings from our analysis, which detail how returns on stocks and exchange rate co-move, are essential to asset allocation and portfolio diversification. Third, we employ the "wavelet multiple" technique to investigate the

possible interactions between EXR and STK returns in Africa simultaneously. These contributions make our study stand out in the midst of the numerous empirical studies on the co-movements between EXR and STK returns in Africa.

### 3. Methods

**3.1. Bi-Wavelet Coherence.** We employ the continuous wavelet transform (CWT), which does well in revealing mixed-scale localisations [65]. To examine the dependence between exchange rate returns (i.e.,  $x(t)$ ) and stock returns (i.e.,  $y(t)$ ) in Africa, the covariance in the time-frequency domain—from a complex conjugate described by the CWT is given by the following expression:

$$W_{xy} = W_x(i, s)W_y^*(i, s), \quad (1)$$

where the CWT of the two series are shown as  $W_x(i, s)$  and  $W_y^*(i, s)$  (as in [66]).

In line with [67], the square of the wavelet coherence (SWC) defining the degree of co-movement between  $x(t)$  and  $y(t)$  is defined as

$$R_{(x,y)}^2 = \frac{|\rho(s^{-1}W_{xy}(i, s))|^2}{\rho(s^{-1}|W_x(i, s)|^2)\rho(s^{-1}|W_y(i, s)|^2)}, \quad (2)$$

with  $\rho$  being a smoothing factor ensuring a resolutionary balance and significance. Note that  $0 \leq R_{xy}^2(i, s) \leq 1$  and can be interpreted as follows. Weak (strong) co-movements have  $R_{xy}^2$  near 0 (1). For a given scalogram, hotter (mild) colours imply stronger (weaker) correlations.

**3.2. Partial Wavelet Coherence (P-WC).** The contribution of time series  $z(t)$  (in our case, COVID-19 cases), which may influence the correlation between  $x(t)$  and  $y(t)$ , amid the era of the COVID-19 pandemic can be eradicated through the use of wavelet (Wu et al. [68]). In line with Wu et al. [68], we express the P-WC as

$$R_p^2(x, y, z) = \frac{|R(x, y) - R(x, z) \bullet R(x, y)^*|^2}{[1 - R(x, z)]^2 [1 - R(x, z)]^2}, \quad (3)$$

where  $0 \leq R_p^2(x, y, z) \leq 1$  and follows the interpretation for  $R^2(x, y)$ .

**3.3. Phase Relationship.** As a limitation of the SWC, positive and negative correlations cannot be distinguished. Hence, to probe into the directional co-movements, we follow [66] to employ the wavelet coherence phase difference (WC-PD), which is expressed as

$$\varnothing_{xy}(i, s) = \tan^{-1} \left( \frac{\Im\{S(s^{-1}W_{xy}(i, s))\}}{\Re\{S(s^{-1}W_{xy}(i, s))\}} \right), \quad (4)$$

where  $\Im$  is an imaginary operator and  $\Re$  is a real operator of a smoothed CWT. From a given scalogram, the WC-PD effects are shown by dimensional phase patterns with positioning arrows distinguishing the varying phase patterns.

Accordingly, right (left)-directional arrows indicate an in-phase condition for  $x(t)$  and  $y(t)$  and down (up)-pointed directional arrows means a leading position for either  $x(t)$  or  $y(t)$ .

**3.4. Wavelet Multiple (WM).** From a multivariate stochastic process with variables  $X_t = x_{1t}, x_{2t}, \dots, x_{nt}$  and given that  $W_{jt} = w_{1jt}, w_{2jt}, \dots, w_{njt}$  is the outcome scale,  $\lambda_j$  wavelet coefficients are obtained from the application of maximal overlap discrete wavelet transform (MODWT)<sup>1</sup>. In line with [69], and recent works such as [18, 70, 71], we additionally analyse the estimations from multiple wavelets (WMC and WMCC) from the multivariate series  $X_t$ .

### 4. Data and Preliminary Analysis

The datasets for the study comprised daily stock returns and exchange rate returns for 11 African countries—Botswana, Egypt, Ghana, Kenya, Namibia, Nigeria, Morocco, Rwanda, South Africa, Tunisia, and Zambia from February 2013 to May 2021. Stock market data were retrieved from EquityRT and exchange rate data from Yahoo Finance (<https://finance.yahoo.com/>). Relative to monthly data, we employ daily data, which make use of rich information [39] and are capable of standing the wavelet technique.

In addition, COVID-19 cases ranging between 31 March 2020 and 6 May 2021 were employed as a control variable in the partial wavelet estimations. Two major datasets were used where one covered data from 13 February 2013 to 6 May 2021 and the other dataset contained data from the day all countries with stock and exchange rate data had recorded at least a case of COVID-19 (31 March 2020) up to 6 May 2021. Our sample was determined by available data, yet all relevant markets in Africa were involved. Exchange rates were measured as the USD (US\$) equivalent per unit of local currency in the various countries. COVID-19 case returns represent the log returns of the total cases recorded by African countries over the period.

**4.1. Descriptive Statistics.** Table 1 summarises the descriptive statistics of the datasets. Panel A (Panel B) details the descriptive statistics for STK (EXR) returns.

The distribution of the data in Table 1 depicts non-normality. Botswana, Ghana, Nigeria, Rwanda, Tunisia, and Zambia had negative mean returns over the period, whereas all other countries (Egypt, Kenya, Morocco, Namibia, and South Africa) experienced positive stock market returns. With 0.0972%, Namibia recorded the highest average return on stocks and Rwanda recorded the lowest at  $-0.0000272\%$ . Namibia recorded the highest deviation (6.73%) in STK returns and Botswana recorded the lowest (0.66%) over the period. Apart from Kenya, Namibia, and Zambia, which had positive EXR returns, all other countries had negative average EXR returns during the period. Zambia recorded the highest mean EXR returns with 0.0664% and Rwanda recorded the lowest at  $-0.000549\%$ . The country with the highest deviation in EXR returns was Ghana (20.01%) and Kenya recorded the lowest deviation (0.52%).

TABLE 1: Descriptive summary (all-period).

Variable	Mean	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	ADF	PP	Obs
<i>Panel A: stock returns</i>								
Botswana	-0.00011	0.006643	-0.42413	10.322	2517.344**	-34.0669**	-34.0687**	1112
Egypt	0.000225	0.018431	-9.53678	212.6719	2053776**	-19.1354**	-31.2289**	1112
Ghana	-0.00054	0.00919	-7.08319	148.417	989067.6**	-19.3273**	-34.8441**	1112
Kenya	0.000275	0.008871	-0.22984	7.406	909.252**	-29.4316**	-29.4536**	1112
Morocco	0.000195	0.007716	-1.34451	24.77084	22295.61**	-29.2354**	-29.0749**	1112
Namibia	0.000972	0.067305	0.756796	449.5509	9239329**	-23.6422**	-79.6683**	1112
Nigeria	-0.00035	0.016341	-11.06666	244.3892	2722483**	-33.3016**	-33.3016**	1112
Rwanda	-2.72E-05	0.007062	13.93219	302.2134	4184136**	-35.3782**	-35.5429**	1112
South Africa	0.000915	0.016216	-0.39357	6.568224	618.633**	-32.5236**	-32.8506**	1112
Tunisia	-0.00014	0.008292	-0.2695	7.049443	773.234**	-37.0159**	-36.8769**	1112
Zambia	-0.00077	0.010532	-0.8919	18.50629	11288.05**	-22.6803**	-26.2775**	1112
<i>Panel B: exchange rate returns</i>								
Botswana	-0.0002	0.006539	-0.84168	9.468508	2069.955**	-34.3328**	-34.3313**	1112
Egypt	-0.00033	0.008516	-6.83366	121.6327	660736.7**	-32.3295**	-32.8055**	1112
Ghana	-0.00135	0.200131	-0.30106	510.2315	11920834**	-22.7566**	-116.155**	1112
Kenya	0.000264	0.00518	0.583386	7.923884	1186.411**	-41.2969**	-40.383**	1112
Morocco	-0.00183	0.013711	-0.23176	4.260012	83.51485**	-42.8527**	-41.847**	1112
Namibia	0.000362	0.067024	2.396701	402.3345	7389749**	-26.3548**	-61.5719**	1112
Nigeria	-0.00267	0.31821	-0.32183	171.1569	1310174**	-24.4834**	-107.836**	1112
Rwanda	-5.49E-06	0.167321	0.871755	180.9036	1466577**	-11.6347**	-39.1527**	1112
South Africa	-8.73E-05	0.009935	-0.36228	4.065072	76.88448**	-34.506**	-34.5974**	1112
Tunisia	-7.13E-05	0.013237	0.240461	14.05535	5673.612**	-42.8457**	-42.5017**	1112
Zambia	0.000664	0.009974	0.410479	18.36896	10975.39**	-28.3397**	-28.0884**	1112

Note. The significance levels are given as 1% (\*\*), 5% (\*), and 10% (\*).

Moreover, at first difference, the augmented Dick–Fuller and Philips–Perron tests confirm the stationarity of the datasets. Trajectories of the datasets are presented in Figure 1.

Table 2 details the descriptive summary for only the COVID-19 period from 31 March 2020 to 6 May 2021. From the summary, several changes were spotted—all countries except for Rwanda and Zambia recorded positive average returns. Namibia and Rwanda recorded the highest (16.11%) and lowest (0.1032%) deviations, respectively. Egypt, Ghana, Kenya, and Nigeria recorded negative EXR returns, while all other countries had positive EXR returns over the period. The lowest EXR return was recorded by Ghana ( $-0.00000137\%$ ) and the highest by South Africa (0.1536%). The highest (48.8953%) and lowest (0.1907%) deviations in EXR returns were witnessed by Ghana and Egypt, respectively.

## 5. Empirical Results and Discussion

Using the wavelet coherence technique, the plots in Figure 2 were generated. The plots display the co-movement dynamics between STK returns of African countries and their respective EXR (the US\$ equivalent of a unit of local currency) returns. The nature of the co-movement between the returns on the two assets was analysed from three perspectives. First, the “all-period” (February 2013 to May 2021) reactions between the two markets were analysed for each country. Second, the focus was shifted to the era of the COVID-19 pandemic. Third, P-WC analysis was undertaken to control for the pandemic’s effect on the fundamental nexus between EXR and STK returns in African markets.

### 5.1. Bi-wavelet Analysis

**5.1.1. Full Sample.** Figure 2 shows the EXR-STK nexus over the entire sample period. The results indicate that in the short term, around 0–16 days (intraday-to-fortnightly), there exists no strong and significant co-movement between EXR and STK returns in Africa, except for South Africa where there exists a positive and significant co-movement with most right-pointing arrows directed downwards, driven by stock returns. This finding is in line with the findings of Mroua and Trabelsi [60], who revealed that in the short term, there exists a direct relationship between the EXR and STK markets among BRICS.

We notice strong co-movements in the medium and long term with a mixture of upward and downward right-pointing arrows, highlighting the potential for exchange rate and stock returns to drive each other. This reveals that the dynamics of exchange rate and stock returns are rather interconnected in the medium and long term with a bidirectional causality outcome demonstrating a high degree of integration in Africa, except for Zambia. Generally, it can be observed that the right-pointing arrows are mostly downwards at all time frequencies. This indicates that stock returns play a dominant driving capacity in the exchange rate and stock returns nexus for most African economies, but positively. Since we are employing the US\$ equivalent of a local currency, the finding implies that stock prices

influence the behaviour of domestic and international investors thereby causing fluctuations in money demand which in turn impact the exchange rate. Thus, following an increase in stock prices in the respective countries will attract an inflow of foreign capital. This induces excess demand for local currency thereby leading to its appreciation (i.e., depreciation of the US\$). However, it is worth noting that due to the relative ineffective regulatory structures in African markets, this observation may be impracticable for the sampled stock markets.

Intuitively, in the short term, in South Africa, portfolio diversification may fail. Diversification may be relatively advantageous in countries such as Botswana, Egypt, Ghana, Kenya, Namibia, Nigeria, Morocco, Rwanda, Tunisia, and Zambia, in the short term. The situation in South Africa follows the flow-oriented theory (i.e., the “goods market hypothesis”) such that the movement in the exchange rate is accompanied by a corresponding movement in asset prices, as posited by Zhang [41]. Generally, in Botswana, Egypt, Ghana, Kenya, Namibia, Nigeria, Morocco, Rwanda, Tunisia, and Zambia, international investors could benefit from portfolio diversification due to the absence of correlation or inverse relationship (as in the case of Zambia) between stock and exchange rate returns. This finding lies well with the conclusion made by Owusu Junior et al. [7] that the USD could be considered by investors when making investment decisions that involve diversification. The finding is also consistent with the general observation made about the reliability of African stocks for diversification [71].

The co-movement between the two markets in Zambia is also an exception in the short term even though it was revealed to be inconsistent throughout the period. For a few moments in 2015/16, 2018, and 2020, there was a significant negative stock-led co-movement between EXR and STK returns, contrary to the situation in South Africa. From day 16–64 (fortnightly-to-quarterly), around the medium term, a significant co-movement is spotted in Zambia in 2015 and 2020 where the relationship was antiphase (negative). This means that the relationship between exchange rate and stock returns was negative. Impliedly, stock prices in Zambia negatively influence the exchange rate through the inward and outward movements of foreign capital. Particularly for Zambia in the short and medium terms, upsurges in stock prices will rather lead to depreciation of the local currency (a fall in the US\$ equivalent of the local currency leading to its appreciation). Hence, potential investors might consider stock prices in Zambia expensive and would not encourage the inflow of foreign capital. When this occurs for a very long time, the local currency becomes cheaper to induce local demand for goods. This finally occasions appreciation of the local currency which drives the cost of export to enterprises to reflect a fall in stock returns (Yuan et al., 2020) as can be found in the long term between 2013 and 2016 for Zambia.

This observation is consistent with the portfolio balance theory (PBT) propounded by Frankel [40]. The PBT suggests that rather than movements in exchange rate causing a change in stock prices, the PBT proposes that oscillations in stock prices in an economy could influence the exchange rate through the inflow and outflow of foreign capital. Thus,

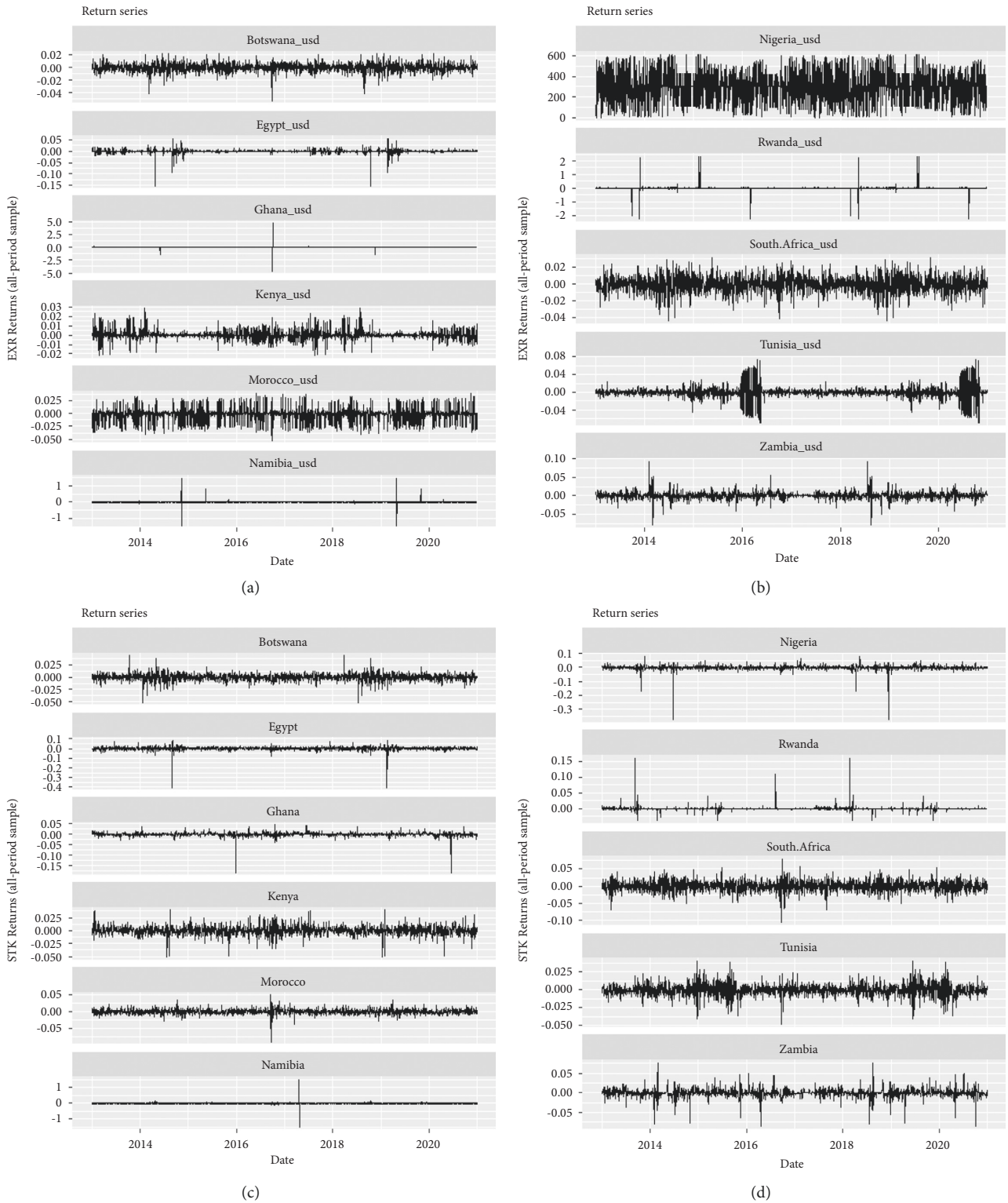


FIGURE 1: Time-series plots of EXR and STK returns. (a, b) Exchange rate returns and (c, d) stock returns.

following Frankel [40], the exchange rate is classified as the same as goods and services whose prices are established by market forces, implying that flourishing (low-performing) stock markets, determined by the returns they offer, attract (discourage) foreign investors, causing more capital inflows

(outflows) as a result of the increased (decreased) demand for local currency and that would strengthen (weaken) the local currency.

Therefore, per the PBT, the inverse connection between stock prices and exchange rate in Zambia in the short term



TABLE 2: Descriptive summary (in-pandemic).

Variable	Mean	Std. Dev.	Skewness	Kurtosis	Jarque-Bera	ADF	PP	Obs
<i>Panel A: stock returns</i>								
Botswana	0.000122	0.005547	-0.451	3.171952	6.288743***	-14.3534***	-14.3283***	179
Egypt	8.56E-06	0.009939	0.161053	3.540566	2.953231***	-11.0713***	-10.9969***	179
Ghana	0.000199	0.01022	0.131518	9.697635	335.0843***	-3.33244***	-16.6311***	179
Kenya	0.001628	0.010566	-0.05567	4.093364	9.008475**	-12.5648***	-12.5802***	179
Morocco	0.001375	0.007777	-0.51839	8.502871	233.8674***	-12.4004***	-12.4308***	179
Namibia	0.002632	0.0161099	0.309161	85.85493	51203.86***	-12.2849***	-55.358***	179
Nigeria	0.001874	0.01105	1.1002	11.35024	556.1548***	-10.6723***	-10.6612***	179
Rwanda	-0.00022	0.001032	1.48443	33.06706	6808.28***	-13.3091***	-13.4204***	179
South Africa	0.003361	0.017655	-0.44674	4.546518	23.79226***	-14.5887***	-14.7316***	179
Tunisia	0.000738	0.006507	-0.07514	6.728737	103.8652***	-12.7152***	-12.7088***	179
Zambia	-0.00041	0.005707	0.597057	5.667759	63.71539***	-10.7072***	-10.7215***	179
<i>Panel B: exchange rate returns</i>								
Botswana	0.000513	0.005641	-0.67505	4.336424	26.9157***	-16.1943***	-16.2308***	179
Egypt	-0.00012	0.001907	-1.76596	16.36703	1425.676***	-17.0088***	-16.5255***	179
Ghana	-1.37E-06	0.488953	-0.02375	89.49023	55792.52***	-39.9553***	-31.7519***	179
Kenya	-0.0003	0.005348	0.173191	3.402774	2.104796***	-16.862***	-16.7197***	179
Morocco	-0.00126	0.013698	-0.26811	5.655417	54.73506***	-12.8678***	-18.7082***	179
Namibia	0.000901	0.010545	-1.26331	8.794952	298.0745***	-14.7146***	-14.7292***	179
Nigeria	-0.00096	0.018976	-0.51842	12.70733	710.8336***	-15.116***	-15.2424***	179
Rwanda	4.84E-06	0.008584	0.14599	4.274751	12.75555***	-13.0769***	-20.731***	179
South Africa	0.001536	0.010166	-0.59282	4.432993	25.79992**	-12.0576***	-79.5436***	179
Tunisia	0.000199	0.003916	-0.15178	3.854719	6.135901**	-16.1382***	-16.1382***	179
Zambia	0.000192	0.004947	-0.95181	7.167933	156.5907***	-2.53392**	-11.6371***	179
<i>Panel B: COVID-19 cases returns</i>								
Botswana	0.026606	0.067792	5.483864	42.96344	12808.7***	-12.6283***	-12.6311***	179
Egypt	0.013955	0.021595	2.261811	8.2539	358.4969***	-5.03298***	-4.10002***	179
Ghana	0.01468	0.033627	4.137287	22.45428	3333.409***	-7.34583***	-9.1469***	179
Kenya	0.020236	0.037854	5.592923	41.22813	11832.74***	-3.48187***	-4.61491***	179
Morocco	0.015963	0.019548	2.47985	10.80759	638.1132***	-3.09357***	-4.48749***	179
Namibia	0.016474	0.035403	4.876873	32.66233	7271.797***	-2.21248**	-9.29663***	179
Nigeria	0.018567	0.03617	4.293197	25.96695	4484.003***	-10.7922***	-6.97144***	179
Rwanda	0.014379	0.017247	2.628798	11.00481	684.0726***	-2.48826**	-6.19568***	179
South Africa	0.015909	0.021241	1.280628	3.30507	49.62106***	-4.24794***	-26.3344***	179
Tunisia	0.016366	0.026689	4.052797	27.60951	5006.994***	-4.56013***	-10.9857***	179
Zambia	0.018054	0.049913	7.443926	66.14494	31391.62***	-2.668***	-13.4998***	179

Note. The significance levels are given as 1% (\*\*\*), 5% (\*\*), and 10% (\*).

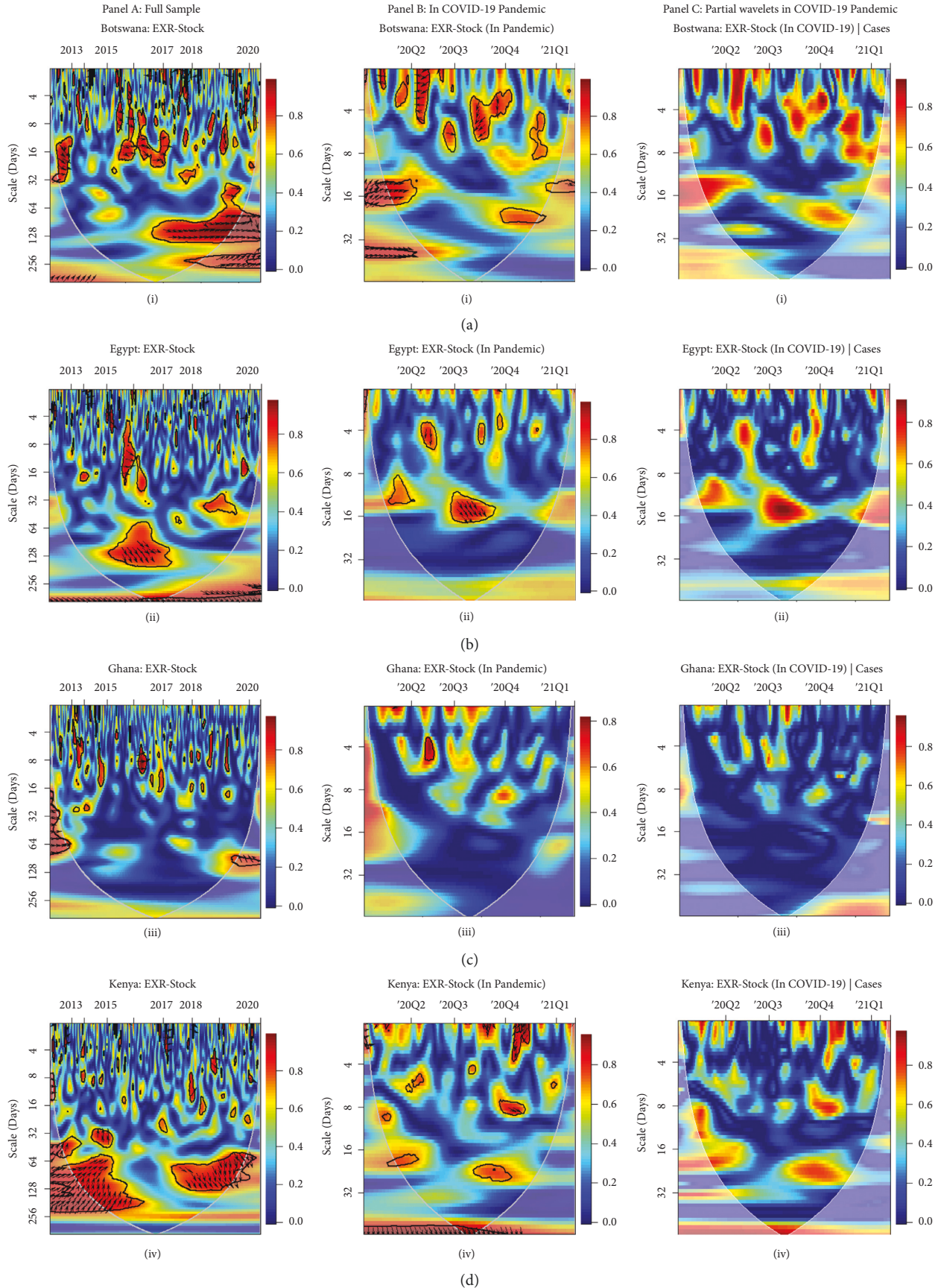


FIGURE 2: Continued.

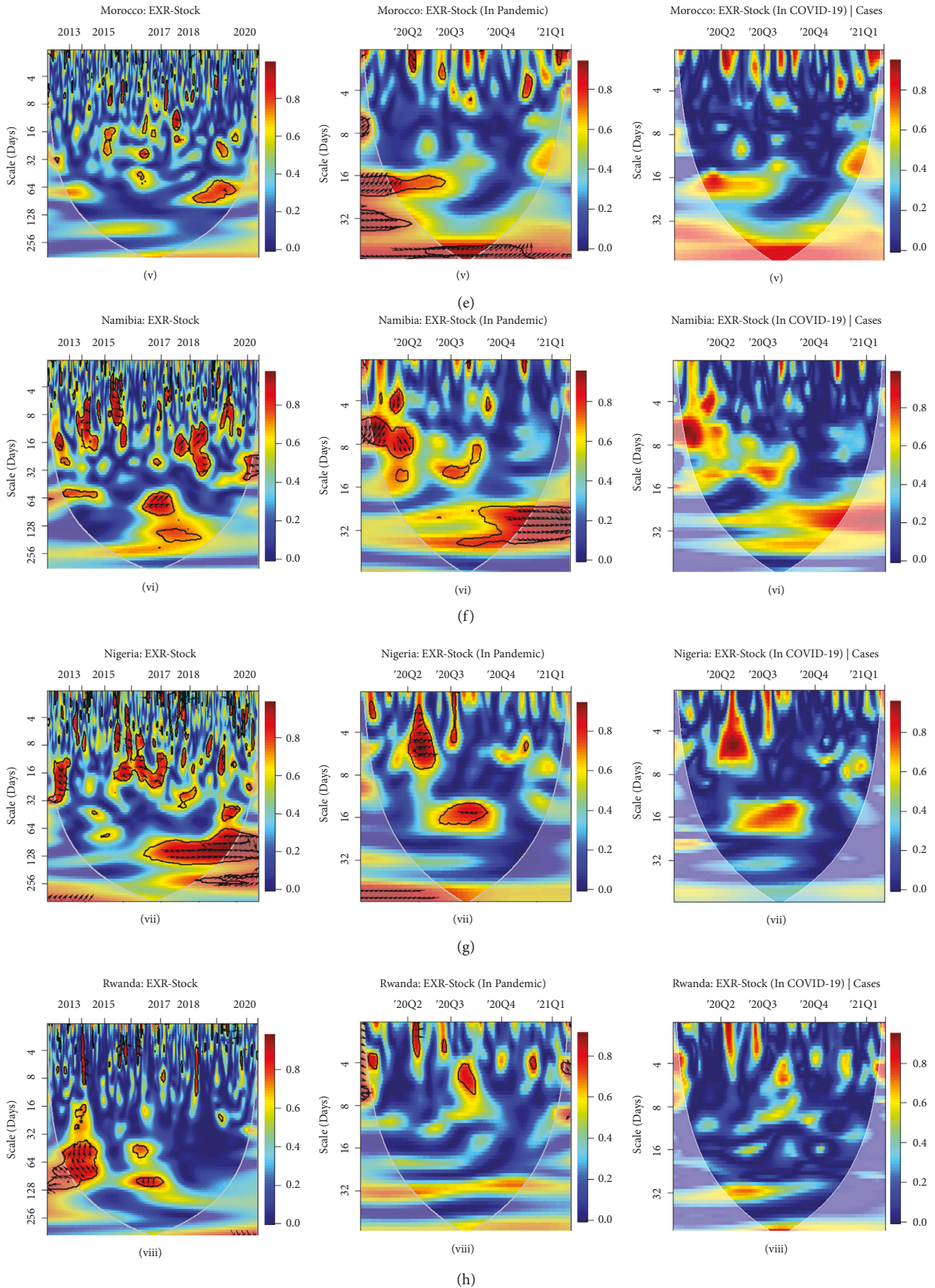


FIGURE 2: Continued.

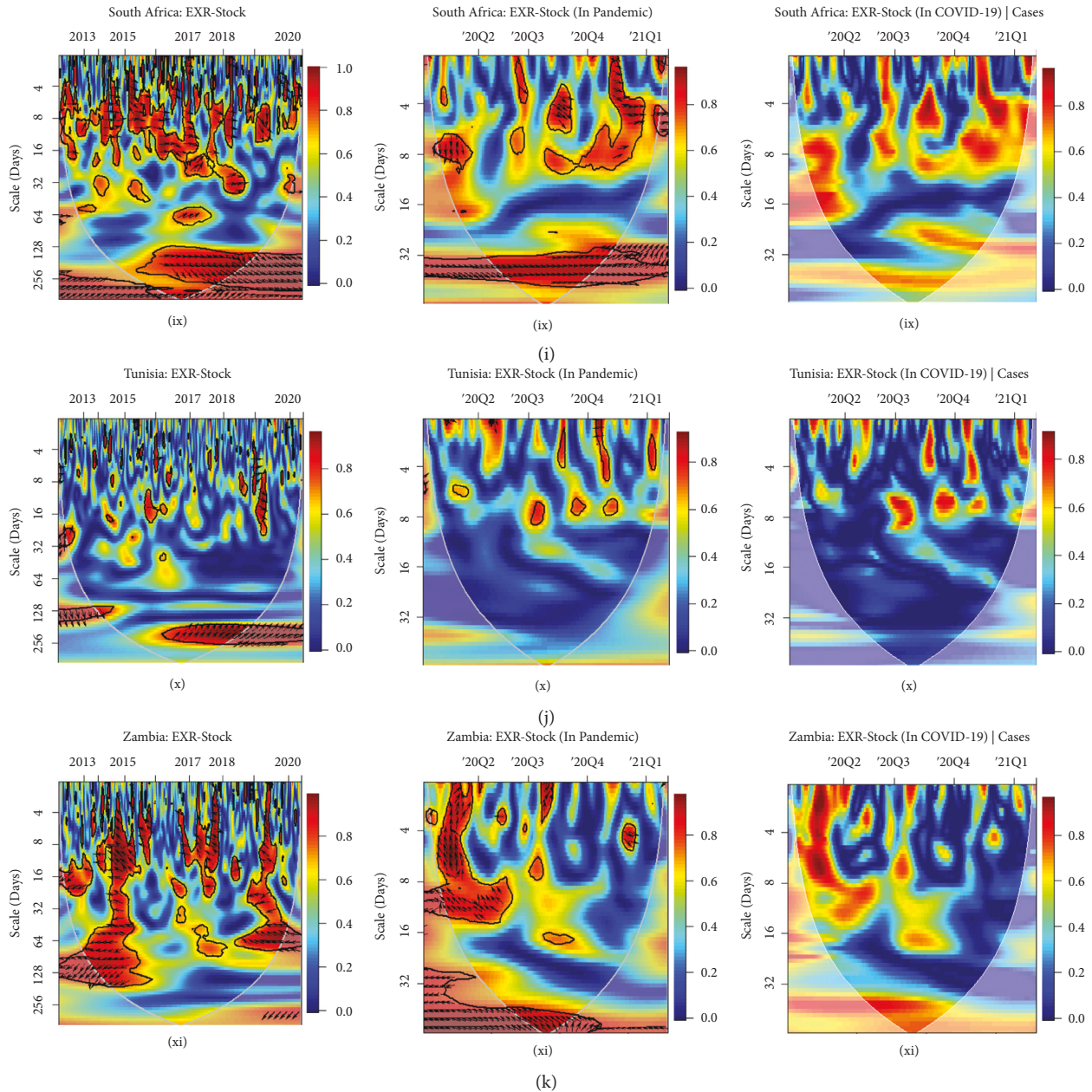


FIGURE 2: Co-movements between EXR and STK returns. Note: the bivariate wavelet coherence plots for the full sample are shown in Panel A; the bivariate wavelet coherence plots for the COVID-19 pandemic sample are shown in Panel B, and the partial wavelet coherence plots in the COVID-19 pandemic era in Panel C.

could be justified on the premise that a reduction in wealth is caused by a reduction in stock prices, and that it results in capital outflows and currency devaluation since the demand for money falls and interest rates also follow suit. The study found pieces of evidence suggesting a co-movement between EXR and STK returns in Kenya but was bidirectional in the medium term. Among many countries, however, in the medium term, there exists a weak co-movement between the EXR and STK markets.

In the long term, a few African countries experience a significant co-movement between the two markets. In Botswana, the co-movement is positive and driven by EXR returns, as indicated by the rightward pointing arrows from 2018 to 2020, similar to Nigeria and Tunisia. In Egypt, a positive “stock-driven” co-movement was spotted in 2017. Between 2014 and 2016 in Kenya, the co-movement was positive and caused by EXR returns but turned otherwise in 2019/2020 where EXR returns (STK returns) lagged (led). The co-movement between EXR and STK returns in Zambia was

found to be largely a relative phase relationship, as evidenced by the left-pointing arrows, suggesting that changes in STK returns cause a change in EXR returns. In South Africa, there was a predominant positive co-movement led by EXR returns between 2017 and 2019, even though around days 245–256 (biannual-to-annual) in the stipulated period, the relationship was induced by STK returns.

*5.1.2. COVID-19 Pandemic Sample.* Panels B and C of Figure 2 reveal, in pairs, the bivariate and partial wavelet coherences between EXR and STK returns in the studied COVID-19 pandemic period, respectively. The analysis was done in quarters to unveil the co-movement dynamics between the returns of EXR and STK in Africa during a “black swan” period. It was found that the co-movement of EXR and STK returns in Botswana, Egypt, Morocco, Namibia, South Africa, and Zambia existed across distinct scales and frequencies. The bivariate wavelet coherence plots highlight the interrelations between EXR and STK returns during the COVID-19 pandemic. The essence of the P-WC is to investigate whether the pandemic, measured by COVID-19 cases returns, drives the co-movement between exchange rate and stock returns in Africa.

The P-WC plots suggest that except for South Africa, the area of significance in the bivariate wavelet coherence for other countries has not experienced any significant reduction. Yet, the findings are suggestive that during the COVID-19 pandemic, different market dynamics, are observed across African markets—implying that the COVID-19 pandemic drives a change in the lead-lag interrelations between EXR and STK returns in Africa. In Botswana, a positive EXR-led relationship was found around the first 6 days (intraday-to-weekly) of the second and fourth quarter of 2020 and between days 12 and 18 of the second quarter. This observation is found to be consistent with the goods market hypothesis. During the studied COVID-19 period, the exchange rate (local currency to the USD) return movements in Botswana are accompanied by a corresponding movement in stock returns, liaising well with Zhang’s [41] observation. In the all-period sample, the bivariate coherence plot suggested that in the short term, stock returns rather led its co-movement with EXR, with justifications from the PBT [40].

In effect, through Lo’s [27] AMH, the COVID-19 pandemic presents a change in market dynamics for EXR and STK returns in Botswana. Therefore, it is expected that per the HMH of Müller et al. [32], investors may develop different investment patterns during this period. This observation is no different from the situation in South Africa, where there continued to be a positive EXR-led co-movement both in the short term and the long term of the COVID-19 pandemic. Thus, a consistent EXR-STK co-movement is observed in South Africa both before and during the COVID-19 pandemic. In Egypt, a stock-led co-movement was found around days 12–18 (fortnightly-to-monthly) of the fourth quarter of 2020, suggesting that movements in stock returns drive the movement in exchange rate returns. There was a similar observation in

Kenya but during the first 4 days (weekly) of the first quarter of 2021.

This observation lies within the tenet of the PBT [40], indicating that the inverse connection between stock and exchange rate returns in Egypt and Kenya in the short term could be substantiated on the premise that flourishing stock markets, determined by the returns they offer, attract foreign investors, causing more capital inflows as a result of the increased demand for local currency and that would strengthen the local currency. Intuitively, an appreciation in wealth is caused by an appreciation in stock prices, which results in capital outflows and currency devaluation since the demand for money falls and interest rates also follow suit. There was a bidirectional co-movement between EXR and STK returns in Namibia within the first 8 days (weekly) of the pandemic but in the medium term, around 32–64 days, the co-movement was in-phase, depicted by the right-pointing arrows. A bidirectional co-movement was also found in Zambia during the first 12–14 days (fortnightly) of the pandemic (in the second quarter of 2020), but in the long term, stock returns induced its co-movement with exchange rate returns. These findings, again, are indicative of the fact that the AMH [27] has resulted in the diverse market dynamics for some STK and EXR markets in Africa and, therefore, through the HMH [32], investors are expected to adopt or develop new investment patterns during the COVID-19 pandemic.

*5.2. Analysis of Wavelet Multiple Correlations.* The WMC between the studied African STK and EXR returns is pictorially denoted by Figure 3 and supported numerically by the results in Table 3. Across the short- to long-term dynamics, these results—achieved from MODWT’s frequency localisation [18]—establish the extent of integration between the studied variables. Despite not revealing the leading and/or lagging variable, the general interrelations between the studied variables are portrayed by the results. It can be seen that EXR and STK returns in Africa were more integrated prior to the COVID-19 pandemic as shown in Figure 3(b). As provided in Figure 3(a) (full sample), the less integration in the short term is accounted for by the adverse impact of the COVID-19 pandemic which can be observed from Figure 3(c) with less integration, especially in the short term. Notwithstanding, drawing insights from theoretical and empirical positions, due to the strong interactions between EXR and STK returns, our findings evidence strong long-term convergence. The intense integration between the variables in the long term is partly due to the significant integration of African stock markets (Boateng et al., 2021, [33, 39, 71]) as well as among African exchange rates [6, 8].

The results suggest a high degree of integration between African STK and EXR returns, as the correlation approximates unity. In the all-period sample, a 99.998% correlation coefficient (99.99% at the lower panel and approximately 100% at the upper panel) is revealed. In the pre-COVID-19 sample, the correlation approximates 100%, confirmed by both the lower and upper bounds. The degree of integration, in the presence of COVID-19 cases, witnessed a slight drop

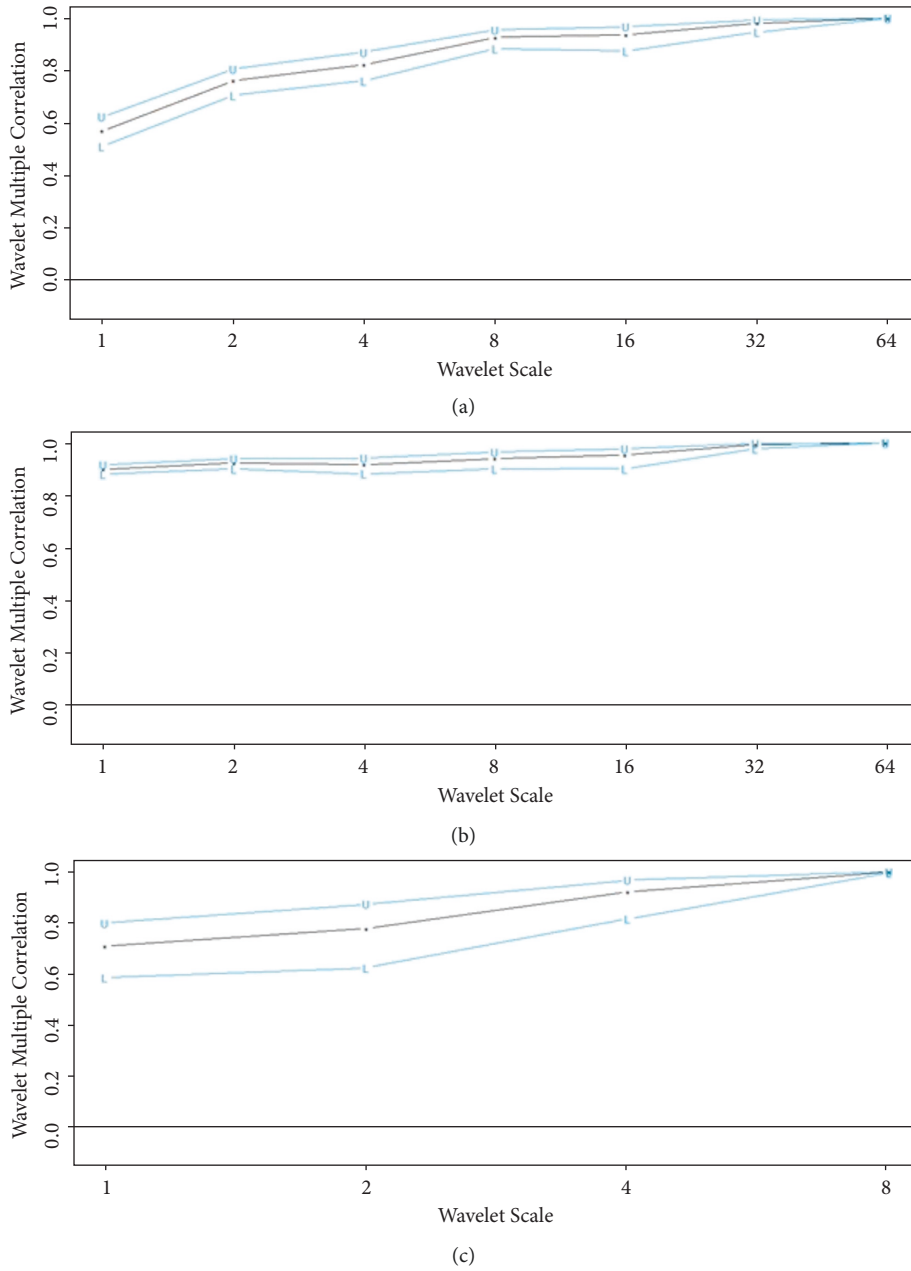


FIGURE 3: Wavelet multiple correlations among selected African STK and EXR returns. (a–c) All-period (13 February 2013 to 6 May 2021), pre-COVID-19 (13 February 2013 to 30 March 2020), and COVID-19 period (31 March 2020 to 6 May 2021). Given a 95% confidence interval, L and U denote the lower and upper limits.

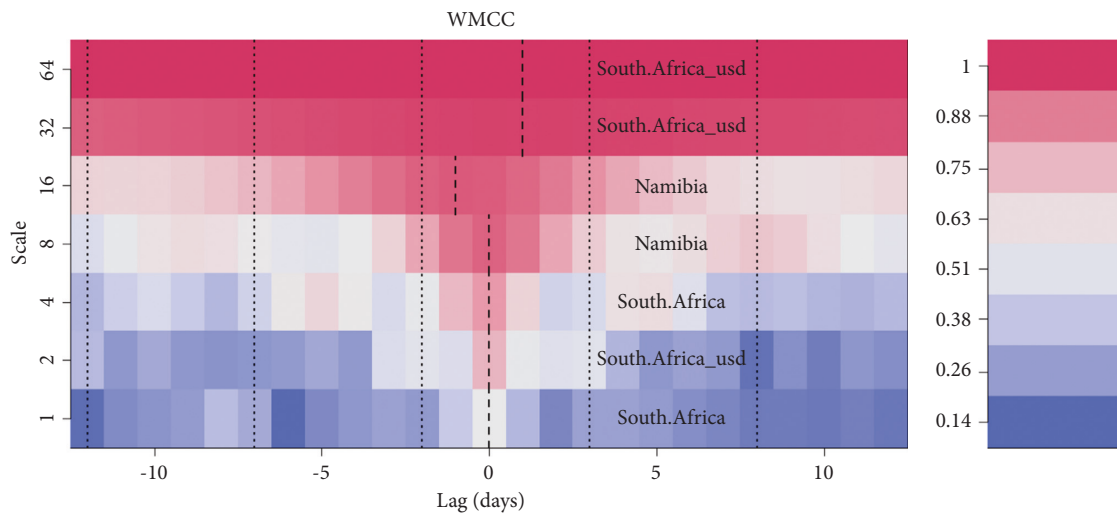
to 99.90% (lower bound: 99.62% and upper bound: 99.98%), confirming the earlier observation that the COVID-19 pandemic has yet to increase the general connectedness among African STK and EXR daily returns. Therefore, on average, at scale 64 (quarterly) interdependence, over 99% of the daily returns of one variable are explained by the remaining variables in both all-period and pre-COVID-19. During the studied COVID-19 era, however, this is achievable at scale 8 (fortnightly). Although the individual correlations have yet to be affected, the overall market correlations are impacted to some extent. Chances of high

integration are observed at a lower scale in the COVID-19 period relative to the pre-COVID-19 and all-period samples. We reiterate Bahmani–Oskooee and Saha’s [54] conclusion that there is a greater chance of uncovering indications of short-term impacts in the stock-exchange rate nexus. Diversification in the short term may not be viable, as a result.

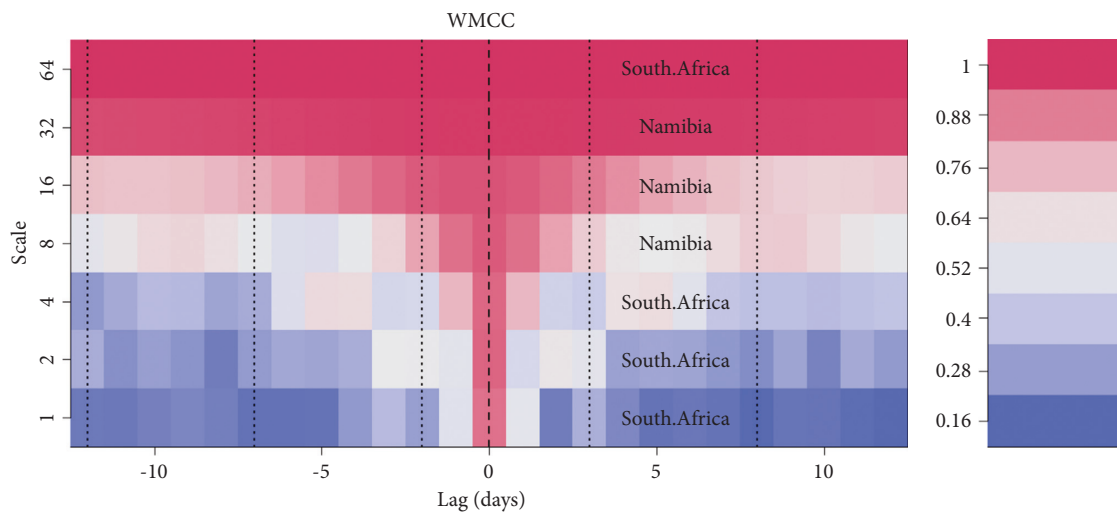
5.3. *Wavelet Multiple Cross-Correlations.* The WMCC for the studied variables is presented pictorially (numerically) in Figure 4 (Table 4). In the all-period and pre-COVID-19

TABLE 3: Wavelet multiple correlations among selected African STK and EXR returns.

Wavelet scale	WMC “lower”	Correlation	WMC “upper”
<i>All-period</i>			
1	0.513711031	0.572311907	0.625597674
2	0.708177502	0.762220988	0.807384562
3	0.762702971	0.824499981	0.871378082
4	0.885561457	0.927783161	0.954800727
5	0.876071158	0.936725244	0.968196833
6	0.947080129	0.981113222	0.993334352
7	0.999904389	0.999983435	0.99999713
<i>Pre-COVID-19</i>			
1	0.882489354	0.901055334	0.916817615
2	0.903076065	0.9242762	0.940983041
3	0.884224816	0.91834824	0.942719917
4	0.902204462	0.941173342	0.964900698
5	0.903765223	0.954204794	0.978505934
6	0.978340012	0.993306742	0.99794244
7	0.999997207	0.99999607	0.999999945
<i>COVID-19 period</i>			
1	0.590181	0.711044	0.800729
2	0.627563	0.779259	0.873953
3	0.817639	0.921563	0.967327
4	0.996188	0.999045	0.999761



(a)



(b)

FIGURE 4: Continued.

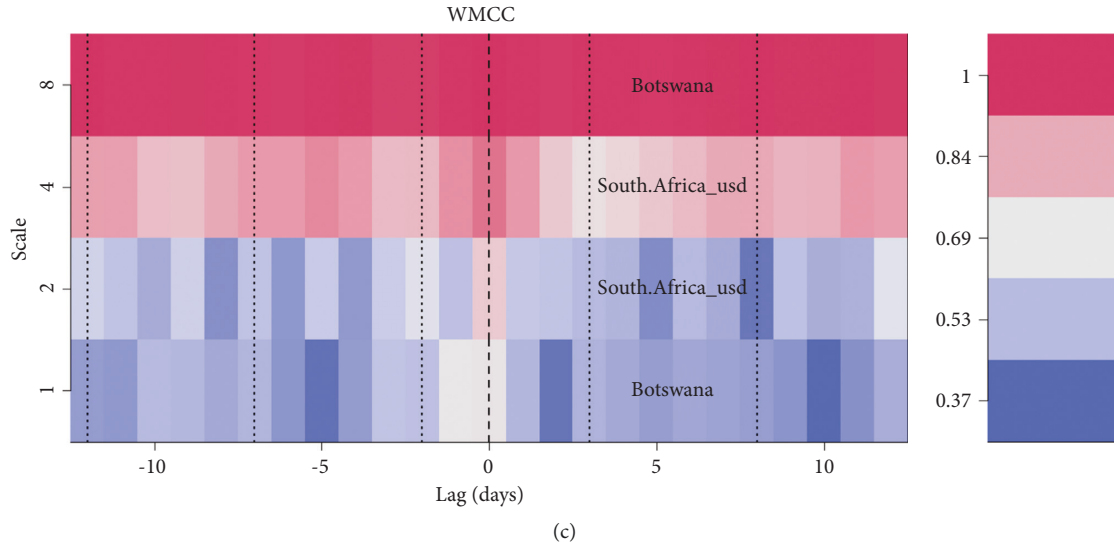


FIGURE 4: WMCC among selected African STK and EXR returns. (a–c) All-period (13 February 2013 to 6 May 2021), pre-COVID-19 (13 February 2013 to 30 March 2020), and COVID-19 period (31 March 2020 to 6 May 2021).

TABLE 4: Wavelet multiple cross-correlations among selected African STK and EXR returns.

Wavelet scale	Localisations	Time lag (months)	Leading/lagging variable
<i>All-period</i>			
1	0.572311907	0	South Africa
2	0.762220988	0	South Africa_usd
3	0.824499981	0	South Africa
4	0.927783161	0	Namibia
5	0.940101392	-1	Namibia
6	0.981578795	1	South Africa_usd
7	0.999990049	1	South Africa_usd
<i>Pre-COVID-19</i>			
1	0.901055334	0	South Africa
2	0.9242762	0	South Africa
3	0.91834824	0	South Africa
4	0.941173342	0	Namibia
5	0.954204794	0	Namibia
6	0.993306742	0	Namibia
7	0.999999607	0	South Africa
<i>COVID-19 period</i>			
1	0.711044297	0	Botswana
2	0.779258862	0	South Africa_usd
3	0.92156319	0	South Africa_usd
4	0.999045368	0	Botswana

samples, there are 7 scales, but 4 scales for the COVID-19 sample. The  $x$ -axis represents the lag length—12 daily periodicities—of the return series. The potential leading/lagging variable is indicated by positive/negative shocks. Note that localisations are represented by dashed lines. For positive (negative) lags, localisations signify the lagging (leading) variable at respective scales. No leading or lagging variable is spotted at localisations with zero lag. A given wavelet scale’s localisation is reflected by the highest value in a linear combination of all return series. These are denoted by dashed lines accompanied by dotted lines across the lags. On a given scale, a listed variable is the potential lead or lag relative to all other variables in the sample.

From the all-period results, South African STK and EXR returns present themselves as latent lead or lag series (at 0 lag) within scale 1~4, representing intraweek-to-weekly, that is, the short term. In the mid-term scale, 4~8 (weekly-to-fortnightly), the Namibian STK returns take on the potential to be the lead or lag variable but become an actual lead variable (at lag -1) in the 8~16 (fortnightly-to-monthly) scale. In the long term, the South African EXR market (South Africa\_usd) becomes the lag variable (at lag 1), specifically at the 32~64 (monthly-to-quarterly) scale, indicating that the South Africa\_usd is the last variable to be hit by shocks.

Turning to the pre-COVID-19 era, we find the STK returns of South Africa (Namibia) to be the potential lead or



lag variable in the short term (intermediate term), as represented by the zero lags. The South African STK returns serve as the potential leading variable in the long term, suggesting that the stock market of South Africa is likely to be the first to fall (rise) during stress (tranquil) trading periods. The short and medium terms—of the COVID-19 pandemic sample era—are dominated by the STK returns of Botswana and the EXR returns of South Africa. Thus, the STK (EXR) market of Botswana (South Africa) stands the chance of leading or lagging all other variables across all timescales in the studied COVID-19 era.

## 6. Practical Implications

Overall, a careful study of the bivariate wavelet coherence and the P-WC shows that there is little or no impact of the COVID-19 cases on the EXR-STK co-movement, although it could influence the nature of the co-movement. The established correlation between EXR and STK returns in Africa during normal market conditions suggests that African stocks could be diversified with USD [7], this study reveals that the diversification prospects of African stocks and EXR returns may be inconsistent during the short term in black swan conditions such as the prevailing market conditions introduced by the COVID-19 pandemic, specifically within the sample period. Therefore, risk administration, analysis of risk transmission across assets, and asset allocation decisions should be carefully approached, especially in the creation of diversified portfolios. Also, policy measures that extend into the long term should be regularly monitored and reassessed since the cone of influence does not cover all horizons in the long term.

The wavelet coherence analysis during the pandemic revealed a weak relationship between several African countries and this was unchanged after controlling for the influence of COVID-19 total cases returns. Thus, among African countries, increases in total reported cases of COVID-19 cause no significant effect on the co-movement between the two assets, despite a change in the lead-lag relationship between the two assets in the studied COVID-19 period. With the high degree of interrelations revealed by the WMC, international investors and policymakers should be wary about the degree of potential integration among African markets. Generally, findings from the WMCC partly communicate the power of the South African market relative to all the others. This could be attributed to its relatively high market capitalisation. Despite the prospective resilience of the South African market, it still stands the chance of being the first to experience shocks in turbulent periods, and this should be noted by portfolio managers and investors alike.

## 7. Conclusions

We use bivariate and partial wavelet coherence analysis to examine and provide novel insights into the nexus between exchange rate and stock returns in Africa amid the COVID-19 pandemic. Specifically, we employ the partial wavelet transform to assess the pandemic's (total cases returns) impact on the co-movement between exchange rate and

stock returns to investigate how the lead-lag relationship between these markets varies across the time-frequency domain. The WMC and WMCC are further utilised to assess the coherence between several variables, which aids in examining the extent of market integration between the studied African countries. The findings from the bi-wavelet show that in the short term, there is a weak co-movement between the variables among African countries except for South Africa and Zambia but the relationship is country dependent.

We found time- and frequency-varying significant co-movement between EXR and STK returns in Africa. A positive co-movement led by EXR returns was evident in Botswana, Kenya, Nigeria, South Africa, and Tunisia in the long term but negative in Zambia. There was no significant co-movement spotted in countries like Ghana and Morocco. The relationship between the variables was largely weak across these countries. In Egypt, Namibia, and Rwanda, there was an inconsistent co-movement between the variables in the medium- to long-term period. Our findings divulge that among African countries, increases in total reported cases of COVID-19 cause no significant effect on the co-movement between the two assets, despite a change in the lead/lag dynamics between the two assets in the sampled COVID-19 era.

Thus, the co-movement between EXR and STK returns in Africa is not significantly influenced by the adverse impact of the COVID-19 pandemic, but the changes in the lead-lag relationship are driven by the COVID-19 total cases returns. Specifically, the findings divulge that different market dynamics are observed across African markets, suggesting that the COVID-19 pandemic drives a change in the lead-lag interrelation between EXR and STK returns in Africa. Furthermore, a pre-COVID-19 pandemic analysis showed that in the short term, stock return leads its co-movement with EXR, with justifications from the portfolio balance theory (PBT) [40]. Conversely, during the COVID-19 period under study, the study discloses findings that are rather consistent with the goods market hypothesis—oscillations in the exchange rate (local currency to the USD) are accompanied by a corresponding movement in stock returns [41]. In effect, under the AMH [27], the COVID-19 pandemic presents varying market dynamics for EXR and STK returns in Africa (e.g., Botswana).

Consequently, through the HMH, it stands to reason that, investors may develop different investment patterns during the COVID-19 pandemic. In addition, in Egypt and Kenya, for instance, the EXR and STK interrelation dynamics in the COVID-19 pandemic period follow the PBT, which supposes that foreign investors are attracted to flourishing stock markets, causing more capital inflows from the increased demand for local currency, which would strengthen the local currency. This may cause an inverse connection between exchange rate and stock prices in the short term. We observe that as rightly indicated by Afshan et al. [42], even though the PBT and the flow-oriented theory offer a strong backing to explain the co-movement of stocks and exchange rates, their influence could simultaneously occur in a given market, as generally revealed in Africa. He et al. [1] submitted that under such a condition, any of the

theories may be inadequate to draw inferences about the co-movement between the two markets. Hence, suffice to say, that attribution could be made to the only significant variable—the COVID-19 pandemic that has brought changes to global economic activity since the year 2020.

With our WMC analysis, the high WMC revealed across all scales and especially in the long term (which approximates unity) imply that integration between African economies is more likely in recent periods. This is substantiated by the increasing regional and international alliances in Africa. Resultantly, we predict a high chance of market integration between African economies in the coming years. The Namibian stock market is the first to respond to shocks in the medium term, according to the WMCC analysis. Over time, particularly at the 32–64 (monthly–quarterly) scale, the South African EXR market shifts from the leading variable (at lag 1) to the lag variable (at lag 1). This implies that the South African EXR market is the last to experience shocks.

Our findings provide novel intuitions to the literature and treasured information to investors, portfolio and risk managers, and policymakers. The novel market dynamics presented by this study are expected to be relevant to investors and portfolio managers in constructing diversified portfolios. These market dynamics would also enable policymakers to devise measures for ensuring the smooth running of the two fundamental constituents (EXR and STK markets) of the financial system. Notwithstanding, we offer vigorous economic insinuations. In the long term, there exist few indications of strong co-movement between EXR and STK returns. Consequently, a complete and all-encompassing understanding of the nature of the co-movement between the variables is required of policymakers to ensure that timely and operative policy responses are rolled out to prevent excessive unfavourable returns on stocks or depreciation of local currencies.

Thus, any intervention tactic towards the stabilisation of stock returns or exchange rate fluctuations should be at irregular periods since the co-movement between the variables vary across both time and frequency spectrums. With portfolio and risk managers, reliance could be placed on the findings of the study to shield investible funds from excessive fluctuations and benefit from any diversification opportunity present in the markets for EXR and STK. Therefore, individual investors could also embark on optimal decision-making aimed at achieving diversified portfolios, while considering the high chances of market integration between African markets in the periods ahead. Furthermore, export and import-induced corporations' managers could better manage and hedge forex risks, as the lead-lag relationship between the variables is established to vary over time and at different frequencies.

Even though the study employed a novel technique, wavelet coherence analysis, in examining the EXR-STK nexus, critiques of the approach contend that it only considers two variables. Notwithstanding, rather than just the bivariate analysis, the application of several wavelet approaches (like the WMC and WMCC) helped overcome this limitation. Besides, the advantages associated with the technique far outweigh the limitations. In any case, further

studies are recommended to apply other econometric models to test for the relationship between exchange rates and stocks. Other macroeconomic variables such as external uncertainty shocks could be included in future studies to determine their effect on the co-movement between the two markets. In addition, further studies may consider the implications of wavelet techniques in other fields of study.

## Data Availability

The stock market data were provided by EquityRT, and the data on exchange rates were obtained from Yahoo Finance (<https://finance.yahoo.com/>).

## Conflicts of Interest

The authors declare no conflicts of interest.

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