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## Article

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# Interconnectedness and idiosyncratic risks in sub-Saharan forex markets: Implications for investment, portfolio management, and policy formulation

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## ABSTRACT

This study examines the interconnectedness and idiosyncratic risks in sub-Saharan forex markets from 1999 to 2023. Using the TVP-VAR extended joint connectedness technique, we measure both the static and dynamic extended joint connectivity. Our analysis reveals that sub-Saharan forex markets are significantly influenced by self-induced shocks, with the South African and Namibian Dollars being notable exceptions. It is also observed that the joint total connectedness index for volatility spillovers consistently exceeds that for return spillovers. Additionally, we investigate the drivers of extended joint connectedness and identified mixed effects. Our analysis suggests that GPR, USEPU, MCI, VIX, and OVX asymmetrically influence return and volatility connectedness among sub-Saharan African forex markets. These findings have important implications for policy management and coordination across emerging sub-Saharan African markets.

## 1. Introduction

Is the instability of the monetary and economic environment in Africa, particularly in its sub-regions, primarily attributable to events in the global financial markets? By modeling the interconnectedness and idiosyncratic risks in sub-Saharan African forex markets, our study challenges this notion. We present empirical evidence that aligns with the findings from various contexts, demonstrating that the foreign exchange ecosystems of sub-Saharan African economies are only marginally influenced by global events. This holds even as their interconnectedness intensifies in response to significant occurrences in the global financial market. Our results underscore the need for policymakers in sub-Saharan Africa to focus on country-level shocks. These self-induced factors pose a greater threat to market connectivity than do global events. In essence, owing to the deteriorating performance and high-risk nature of African FX markets and similar emerging markets,

global economic events should not be the primary narrative around sub-Saharan economies. Rather, conversations should revolve around strategies to mitigate the impact of self-induced risk factors. This is the unequivocal conclusion drawn from the present study. From this perspective, we not only align with but also contribute to, extend, and enrich the growing body of literature on international financial markets, their institutions, and monetary matters (Ahmed, 2016; Anwer et al., 2022; Atenga & Mougoué, 2021; Guney et al., 2017; Lu et al., 2022; Tian et al., 2023).

Understanding exchange rate spillovers among sub-Saharan African countries is crucial for several reasons. Exchange rate fluctuations can significantly affect inflation, trade balances, and overall economic growth. By determining the sources and extent of exchange rate spillovers, our study provides insights that are essential for maintaining economic stability in these countries.

By focusing on domestic factors rather than on external shocks,

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policymakers can design more effective monetary and fiscal policies that enhance economic resilience and stability. Our study's results will also help policymakers understand the dynamics of their forex markets, enabling them to develop strategies that focus on domestic factors and lead to more stable and predictable economic environments. Investors can use our findings to make informed decisions regarding their investments in the SSA forex markets. Understanding interconnectedness and idiosyncratic risks helps optimize investment portfolios and manage risks more effectively. Regional institutions such as economic communities and central banks benefit from a deeper understanding of regional market dynamics, aiding in the coordination of policies and interventions to stabilize forex markets across the region.

Our results can help formulate exchange rate policies by highlighting the importance of focusing on domestic shocks, leading to more targeted and effective policy measures that enhance exchange rate stability. Understanding interconnectedness and idiosyncratic risks allows financial regulators to better anticipate and mitigate potential market disruptions, contributing to the overall financial stability in the region. This study provides valuable insights for risk-management practitioners. Investors and portfolio managers can develop strategies to minimize their exposure to idiosyncratic risks and enhance returns.

Mitigating investment risks in emerging and frontier markets is a popular topic in applied and fundamental research (Emenike, 2021, 2022; Gubareva, 2021; Gubareva & Borges, 2018; Gubareva et al., 2024; Gubareva & Keddad, 2022; Rigana et al., 2023; Yang et al., 2024). In particular, this concerns the investigation of forex markets in sub-Saharan Africa, addressing their interconnectedness and idiosyncratic risks and proving relevant implications for investment, portfolio management, and policy formulation (Emenike, 2018; Huang et al., 2024). The real-world importance of such research cannot be overestimated, as it allows for improving evidence-based policymaking, especially regarding the politics of poverty in low- and lower-middle-income economies in sub-Saharan Africa (Kaltenbrunner et al., 2022). Empirical studies of forex markets have uncovered the practical influence of financial regulations on exchange rates (Perez-Reyna & Villamizar-Villegas, 2019). Furthermore, a better understanding of the interconnectedness and idiosyncratic risks in forex marketplaces may result in better investment decision-making for forex investors (Aziz et al., 2022).

Regarding investment decisions, the mechanisms at play that shape the interconnectedness of forex markets should be carefully addressed, considering important factors such as geopolitical risk (GPR), economic policy uncertainty (EPU), returns and volatility of stocks and crude oil markets, and the impacts of major risk events transversal to global financial markets among others (Bossman, Gubareva, & Teplova, 2023; Umar & Bossman, 2023; Umar & Gubareva, 2020; Usman et al., 2023). These factors aid investors in anticipating potential changes in the forex market, allowing for a better comprehension of FX rate dynamics. Thus, investors can make informed decisions and amend their investment strategies in a timely manner. Moreover, forex-related insights contribute to the efficient diversification of investment portfolios (Huang et al., 2024; Usman et al., 2023). Advanced knowledge of the interlinkages between the sub-Saharan African forex markets and an understanding of the drivers affecting their connectivity allow portfolio managers to improve risk management and return optimization. Considering the mechanisms at play that shape forex markets, portfolio managers can design more resilient and profitable asset allocation strategies. Market regulators and policymakers may also benefit from an advanced knowledge of FX rate dynamics. Understanding the drivers of FX market connectedness helps market regulators anticipate market disruptions and design policies to mitigate their effects on the value of the domestic currency. Furthermore, the return and volatility connectedness between sub-Saharan African forex markets is expected to be highly asymmetric (Huang et al., 2024). Thus, robust market regulation mechanisms are critical in order to mitigate the idiosyncratic risks inherent in such asymmetric patterns.

Since the beginning of the 21st century, the forex markets in sub-Saharan Africa have undergone remarkable changes (Huang et al., 2024; Kaltenbrunner et al., 2022; Opoku et al., 2023). Several states liberalized their capital accounts and forex markets, progressing to flexible, non-pegged forex rate policies. Furthermore, several states have adopted monetary regimes that prioritize inflation and resort to interest rates as the principal tool of monetary policy. Such shifts have provided relevant inferences for the structure of forex markets and forex rate behavior. For example, in a few prominent forex markets, non-resident investors have become increasingly prominent and have expanded their influence on the behavior of forex rates. Notably, these changes in FX markets evolved in close interaction with historically established export and import patterns, exhibiting a high concentration of mining and agricultural commodity products (Agyei & Bossman, 2023). Such interlinkages affect the stability of forex rate dynamics and may result in risky macroeconomic consequences. In fact, central banks in sub-Saharan Africa have been unwilling to abandon forex rate management, leaving forex rate management to the free market as sub-Saharan central banks have largely intervened in forex rate management despite the officially declared policies of floating forex rates (Kaltenbrunner et al., 2022; Opoku et al., 2023).

Recent literature on African forex markets has outlined the critical importance of studying forex rate behaviors and their interconnectedness (Huang et al., 2024; Opoku et al., 2023). This study conceptualizes the essential interdependencies between these markets and their association from an export perspective with the production of chosen heavily predominant commodities. Therefore, the specificity of sub-Saharan African forex markets resides in their strong dependence on a stringent sample of highly volatile commodity products predestined for export and their feeble position in the global monetary system. The latter makes them potentially vulnerable to volatile and potent foreign financial inflows and outflows vis-à-vis rather shallow and not sufficiently liquid domestic financial markets. Our research addresses the interconnectedness of and idiosyncratic risks in sub-Saharan African forex markets and provides important implications for investments, portfolio management, and policy formulation.

Based on insights from the Time-Varying Parameter Vector autoregression (TVP-VAR) extended joint connectedness approach (Balcilar et al., 2021), we reveal substantial idiosyncratic risks in the sub-Saharan African forex markets.

The TVP-VAR extended joint connectedness metric (Balcilar et al., 2021) is an advanced econometric technique that has been widely applied in recent years (Chen et al., 2022; Ha & Nham, 2022; Lu et al., 2023; Thanh et al., 2023). Notably, the joint spillover index designed by Lastrapes and Wiesen (2021) helps surmount the row-sum normalization limitation. Following this, Balcilar et al. (2021) have introduced the TVP-VAR extended joint connectedness metric. This methodology is based on the findings of Antonakakis et al. (2020) and Lastrapes and Wiesen (2021). In general, the connectedness methodology is widely used in diverse scientific investigations to provide empirical evidence of the relationships among forex rates and explore the influence on FX rates of forex market drivers such as stock and crude oil prices, economic policy uncertainty (EPU), geopolitical risk (GPR), and the COVID-19 media coverage index (MCI), among others.

As concluded in previous research (see, e.g., Lu et al., 2023), the TVP-VAR extended joint connectedness technique consistently outperforms the generalized connectedness approach proposed by Diebold and Yilmaz (2012). Notably, Balcilar et al. (2021) outline several advantages of the TVP-VAR extended joint connectedness methodology. In this study, we conduct advanced analyses on the time-varying connectedness among the forex rates of sub-Saharan African countries from two perspectives: performing a sensitivity analysis of the results to forecast horizons and comparing the extended joint connectedness results with those from the traditional TVP-VAR approach. This comparative analysis confirms the superiority of the TVP-VAR extended joint connectedness technique over the traditional generalized connectedness

method (Diebold & Yilmaz, 2012), thus confirming the appropriateness of the chosen methodology.

Our study contributes six-fold to state-of-the-art research. First, we expand the application of the TVP-VAR extended joint connectedness technique by applying it to the complex context of the sub-Saharan African forex markets. Second, we add to the extant studies on the relationship between forex rates and markets and important drivers such as the VIX (stock market volatility), OVX (oil price volatility), EPU, GPR, and MCI. Given the contradictory landscape that lacks robust conclusions, we are motivated to explore the unresolved issues of forex rate dynamics by employing an advanced econometric technique, which is the TVP-VAR extended joint connectedness approach, capable of dealing with diverse methodological shortcomings inherent to less sophisticated methodologies previously applied in this field. Third, our study provides evidence of bidirectional pairwise causation within a framework comprising nine sub-Saharan African forex markets. Fourth, as our sample spans the COVID-19 pandemic period, we can investigate how connectedness in the system was affected throughout the COVID-19 period. Interestingly, we demonstrate that there is strengthening connectivity among the sub-Saharan African forex markets during the times of COVID-19. Fifth, the inclusion of the ongoing Russia-Ukraine military conflict in our dataset allows us to scrutinize how the returns and volatility connectedness of the sub-Saharan African forex markets are impacted by this regional conflict with an elevated geopolitical relevance. It is shown that both the return and volatility dynamic joint total connectedness indices (JTTCI) experience substantial increases with the escalation of the military conflict, whereas the magnitude of the time-varying volatility JTTCI remains consistently higher than its return counterpart. These findings highlight the importance of analyzing volatility spillovers in addition to return spillovers. Sixth, our average connectedness results reveal that self-induced shocks profoundly impact a substantial portion of the SSA forex markets. This finding emphasizes the need for policymakers in sub-Saharan Africa to concentrate on domestically generated market innovations when formulating their forex policies. As a conclusion, our paper presents several important contributions to a better comprehension of interdependence within the system comprising the sub-Saharan African forex markets, being, thus, of potential use for both investors and policymakers.

The remainder of this paper is organized as follows. Section 2 provides a brief review of recent literature. Section 3 describes the econometric techniques used in this study. Section 4 provides a brief overview of the data metrics and presents the preliminary analyses. Section 5 presents the empirical results and discusses their implications. The main conclusions are presented in Section 6.

## 2. Literature review

Forex markets, in general and the ones in sub-Saharan Africa, in particular, receive extensive attention from investors because of their relatively low entry barriers and decentralized nature (Aziz et al., 2022; Emenike, 2018; Huang et al., 2024; Huynh et al., 2023; Kaltenbrunner et al., 2022; Lu et al., 2023; Nekhili et al., 2021; Okot et al., 2022; Opoku et al., 2023; Usman et al., 2023; Wang et al., 2023; Wen & Wang, 2020). Enormous trading volumes and non-ceasing operations underline the sensitivity of the FX market to alterations in the financial and political landscape (Bossman, Gubareva, & Teplova, 2023; Rigana et al., 2023). Government interventions and geopolitical news substantially impact the returns and volatility in forex markets. In this context, interconnectedness, spillovers, and idiosyncratic risks in sub-Saharan African forex markets require special consideration, especially in terms of the influence of the recent crisis of forex rates, as this knowledge is arguably relevant for asset allocation strategies and the betterment of risk management. The most advanced econometric techniques, such as the TVP-VAR extended joint connectedness metric (Balcilar et al., 2021), are widely employed to explore the connectivity of forex markets within themselves and with other financial assets.

Therefore, the first strand of the literature addressed in this brief literature review is focused on the TVP-VAR extended joint connectedness methodology utilized in studies on spillovers between diverse asset classes, including forex rates (Chen et al., 2022; Ha & Nham, 2022; Lu et al., 2023; Thanh et al., 2023). The second strand of the literature addresses the most recent studies on connectedness and idiosyncratic risks in sub-Saharan forex markets, focusing, among other aspects, on the macroeconomic drivers of spillovers within systems encompassing forex rates. To correctly consider the ever-increasing complexity of progressively integrated forex markets, several drivers such as geopolitical risk (GPR), economic policy uncertainty (EPU), and crude oil price, have been introduced in recent research on forex markets (Bossman, Gubareva, & Teplova, 2023; Huang et al., 2024; Okot et al., 2022; Wang et al., 2023; Xu et al., 2023).

Below, we review the most recent studies in the knowledge domain of our research along the two aforementioned strands of literature.

### 2.1. TVP-VAR extended joint connectedness approach

In this subsection, we survey the most relevant recently published papers on the TVP-VAR extended joint connectedness approach employed in our investigation.

We trace the TVP-VAR extended joint connectedness metric in Balcilar et al.'s (2021) seminal work, which explored the connectedness between crude oil futures contracts and commodity markets. Their data sample extended from 2005 to 2020. Balcilar et al. (2021) investigated the return spillover mechanisms between crude oil and 11 agricultural commodities. It is found that crude oil, grains, livestock, sugar, and soybean oil were the main net emitters of shocks, whereas corn, lean hogs, soybeans, cattle, and wheat consistently acted as principal recipients of innovation. Moreover, Balcilar et al. (2021) show that crude oil affects commodities and is receptive to shocks as well. Their results demonstrate that systemic connectedness is time-varying and economic event-dependent. Furthermore, the authors demonstrate the importance of the normalization method used in the connectedness network, as their conclusions provide relevant insights into the design of strategies for portfolio optimization and lessening downside risk based on advanced hedge techniques.

Chen et al. (2022) apply the extended joint connectedness of the TVP-VAR model to examine whether financial stress wreaks havoc on oil, banking, insurance, and gold markets. The authors used a daily data set from July 2011 to June 2021 and resorted to the TVP-VAR extended joint connectedness metric of Balcilar et al. (2021). They attempt to provide empirical evidence on whether the traditional association between financial stress, oil, and gold has changed throughout the study period. The traditional determinants of financial stress in the USA are time-varying and change in response to the 2019 monetary injections. Despite the apparent relevance of the COVID-19 pandemic, the results highlight the significance of US monetary injections in driving joint connectedness within this framework. Furthermore, the authors report that oil and gold possess attractive and diversifying attributes in US equity and financial sector portfolios. Furthermore, relevant insights into policy design and investment strategy structuring are provided, which are potentially useful for enhancing the overall financial stability and risk management practices.

Ha and Nham (2022) apply the TVP-VAR extended joint connectedness methodology to investigate the interrelations between crude oil, stocks, gold, and cryptos throughout the COVID-19 pandemic. Their dataset spanned the period from January 2018 to August 2021. The study shows that health shocks affect dynamic network connectedness, which is strongest during the COVID-19 pandemic. From an analysis of the net total directional connectedness results, Ha and Nham (2022) conclude that equities and gold predominantly act as net recipients of innovation spillovers. Oil was as a crucial net emitter of innovation for nearly the entire pre-COVID-19 period. However, crude oil became a significant net recipient throughout the COVID-19 crisis. Crypto markets

alternate their roles as emitters and recipients. The Pairwise connectedness indicates that equities and oil typically absorb spillovers from other markets. In addition, the study finds that gold, like cryptocurrencies, alternates its emitter/recipient role contingent on the considered markets. Moreover, crypto is found to be a highly volatile asset.

Lu et al. (2023) also use the generalized connectedness methodology and the TVP VAR extended the joint connectedness model to study the interrelationship between the forex rates of six oil-importing and five oil-exporting economies and oil futures. The analyzed sample spanned from March 2000 to March 2022. The authors demonstrate the dynamic nature of the pairwise and overall linkages. The magnitude of the connectedness metrics, as a rule increases during episodes of severe financial and economic stress, such as the European sovereign debt crisis, Brexit, and the coronavirus-caused health crisis. The Russian Ruble and Japanese Yen are the most prominent net innovation receivers, as implied by both the joint connectedness approach and the generalized technique. Regarding other currencies, the authors obtain inconclusive outputs. Lu et al. (2023) provide empirical evidence of dynamic bidirectional innovation spillovers between forex rates and crude oil. Lu et al.'s (2023) study offers relevant insights for investors and market regulators.

Thanh et al. (2023) employ the TVP-VAR extended joint connectedness methodology to study the time-varying spillovers between equities and cryptocurrencies in Vietnam. The dataset covers four years, namely, 2018–2021. The authors demonstrate that COVID-19-driven innovations affect dynamic network connectedness, showing that maximum levels are attained within the COVID-19 timeframe. In addition, the total net directional connectedness analysis suggests that crypto assets with elevated market capitalization levels, such as Bitcoin and Ethereum, substantially influence domestic stock prices. They argue that cryptocurrencies may help explain the high volatility of the domestic equity market. During the initial COVID-19 outbreak, the impact of the cryptosphere was reduced. Nonetheless, since late 2020, cryptocurrencies have recovered their role as net innovation emitters absorbed by domestic equities.

## 2.2. Interconnectedness in sub-Saharan forex markets

Among the recent papers addressing sub-Saharan foreign exchange rates, Wen and Wang's (2020) research on volatility connectedness in global forex markets is notable. The authors compute the static and dynamic metrics of total and directional volatility connectedness in 65 major forex markets. Using the variance decomposition technique, they employ the LASSO-VAR and volatility spillover index methodologies to build a volatility connectedness framework encompassing the forex rates considered. The authors provide empirical evidence that the Euro and United States dollar act as principal emitters of volatility innovations. In contrast, other currencies, including the British pound and the Japanese yen, largely behave as net volatility recipients. Using the volatility connectedness framework, they show that currencies lean towards clustering according to their geographical location. It is also found that total volatility connectedness provides sensitive responses to alterations in global economic and financial conditions, increasing during crises. In particular, directional connectedness in the volatility domain of the Renminbi decreases substantially because of the reformulation of the Chinese exchange rate regime, shifting from a USD-pegged regime to a floating, albeit regulated, regime. In general, the study concludes that foreign exchange regimes, oil export dynamics, and changes in monetary policies are the most important factors influencing volatility spillovers across foreign exchange markets.

Kaltenbrunner et al. (2022) focus specifically on sub-Saharan forex rates and present a structural analysis of forex markets in the sub-Saharan region of the African continent. Their research provides extensive knowledge on the microstructure of forex markets in several low- and lower-middle-income African economies. The authors discuss

their insights into the design of regulatory policies thoroughly. The authors interview seventeen fore experts from Ghana, Kenya, Malawi, Sierra Leone, Uganda, and Zambia. It is demonstrated that forex inter-bank markets are functional in most of the examined countries. However, these markets frequently reveal highly volatile, shallow, and time-clustered liquidity patterns. The authors argue that such liquidity attributes and elevated uncertainty about the feasibility of future forex operations cause eventual forex hoarding among market players, exacerbating the lack of liquidity in the studied forex markets. Furthermore, it is reported that the traders with access to forex liquidity gain substantial market power and the possibility to influence the behavior of forex rates considerably. The authors also find that central banks in the studied African economies represent principal agents in forex markets, helping market players deal with volatile and shallow liquidity. However, their regulatory power to ensure continuous forex availability is impaired by microstructural weaknesses, including pressure related to domestic currency depreciation issues. Kaltenbrunner et al. (2022) conclude that their findings reveal important obstacles toward floating regimes of forex rates in the African economies considered. The main obstacles are exports, which are heavily concentrated on a few commodity products, the weak confidence of investors and traders in domestic currencies, and the shallow liquidity of African financial markets in general.

Okot et al. (2022) investigate the determinants of forex rates, their volatility, and the crash risk of domestic currencies in low- and lower-middle-income African economies. This study uses macro panel estimations for 15 African economies with casually regulated floating forex rates. This study highlights a relevant role in discovering the export and productive structures of African economies, concentrated in a few mineral-based and agricultural commodity products. The recent financial integration of African markets also represents an important driver of forex. In particular, export concentrations, terms of trade, and export prices substantially affect the ranges of forex rates and volatility. Moreover, the financial aspects encompassing the differential between interest rates, global economic conditions, and short-run financial flows play an important role in the probability of domestic currencies suffering from strong and unexpected movements in forex rates.

In their study, Opoku et al. (2023) examine the dynamic connectedness and contagion between exchange rates and commodity prices in Sub-Saharan African countries. The authors employ the Barunik and Krehlik (2018) spillover index, which uses a monthly frequency dataset spanning 1990–2019 to explore the time-varying connectedness in the time and frequency domains. This spillover index can capture the nonstationary, nonlinear, time-dependent, and asymmetric co-movements of the considered variables. Their outcomes imply that the interrelationship between forex rates and commodity prices in Sub-Saharan Africa is both frequency- and time-dependent and becomes more pronounced at shorter investment horizons. The authors report that oil is the only consistent spillover transmitter among the examined commodities. However, the forex rate of South Africa produces dominant spillovers to metal-producing economies, whereas the forex rate of Cote d'Ivoire produces dominant spillovers to - economies producing agricultural goods. Additionally, they reveal considerable spillover transmission among forex rates and commodity products throughout crises, implying contagion across the forex and commodity markets. As uncertainty spillovers are stronger amidst market disorders, traders and investors must be aware of market behavior to keep their holdings safe from market downturns. Moreover, market regulators and policymakers should closely monitor return and volatility spillovers because spillover transmission may adversely affect market interrelations.

The most recent study by Huang et al. (2024) addresses the international transmission of shocks and their influence on African forex markets. The authors assess the effects of geopolitical risk and crude oil on innovation spillovers across African forex markets. To assess the time-varying spillovers of innovation transmission, they resort to the TVP-VAR connectedness approach and use a daily frequency dataset

covering the period from 2000 to 2023. The authors use foreign exchange rates, gauged against the UD dollar, from four major oil-importing African economies (Egypt, Ivory Coast, South Africa, and Tunisia) and four major crude oil exporters (Algeria, Angola, Libya, and Nigeria). It has been demonstrated that crude oil shocks and exporters considerably influence innovation spillovers between oil importers and changes in GPR levels. In addition, the authors clarify that return and volatility innovation spillovers between African foreign exchange rates, the GPR, and oil are contingent on economic stress episodes and are stronger during financial turmoil. Notably, such events may interchange the emitter-recipient roles of the analyzed network constituents. Moreover, the pairwise forex shock transmissions across and within Africa’s major oil importers and exporters are subject to GPR and oil innovation. This finding underscores the relevance of employing the partial connectedness methodology to gauge the interrelations across African foreign exchange rates against the backdrop of GPR levels and oil prices. Finally, the outcomes of this study provide important insights for regulators, traders, and investors active in foreign exchange markets.

Two major conclusions can be drawn from the literature review. On the one hand, academic researchers’ attention to sub-Saharan African foreign exchange markets is severely limited. However, several recent works on this subject have demonstrated that the topic is relevant and popular from both purely theoretical and applied perspectives. On the other hand, it can be inferred that an advanced econometric approach, namely the TVP-VAR extended joint connectedness methodology, has recently been gaining popularity and has been applied to connectedness studies across diverse financial markets. However, to the best of our knowledge, this approach has never been employed to study sub-Saharan forex rate dynamics and interdependencies. Therefore, this study strives to address the two gaps uncovered in our survey of the relevant literature. Our research, dedicated to the sub-Saharan African forex markets and resorting to the TVP-VAR extended joint connectedness approach, fills the above-identified voids. Thus, to conduct our research, we employ original data and apply an advanced econometric modelling technique, which we discuss in the following section.

### 3. Methodology

We integrated the TVP-VAR extended joint connectedness model into the classical TVP-VAR connectedness metric and the index of joint spillover, in line with Diebold and Yilmaz (2012) and Antonakakis et al. (2020). The econometric steps are described in the following three subsections.

#### 3.1. The TVP-VAR metric

Formulated in Equation (1), the TVP-VAR model stems from the Bayesian information criterion (BIC):

$$Y_t = \beta_t Y_{t-1} + \varepsilon_t; \varepsilon_t \sim N(0, S_t) \tag{1}$$

$$vec(\beta_t) = vec(\beta_{t-1}) + v_t; v_t \sim N(0, RV_t) \tag{2}$$

where,  $N \times 1$  vector variables regarded as endogenous are represented by  $Y_t$  and  $Y_{t-1}$ ; a vector of  $N \times N$  dimensions denote VAR slopes; a normally distributed error term with  $N \times 1$  dimension and  $N \times N$  covariance matrix is represented as  $\varepsilon_t$ ; both  $vec(\beta_t)$  and  $v_t$  are vectors with dimension  $N^2 \times 1$ , and  $RV_t$  is a vector with dimension  $N^2 \times N^2$ .

Following the Wold theorem, the TVP-VAR is modified to yield the TVP-VMA model, expressed as  $Y_t = \sum_{h=0}^{\infty} A_{ht} \varepsilon_{t-h}$ , where  $A_0 = I_N$  and  $E\varepsilon_t \varepsilon_t' = S_t$ . Consequently, the forecast error of the  $H$ - step is expressed as follows:

$$\zeta_t(H) = Y_{t+H} - E(Y_{t+H} | Y_t, Y_{t-1}, \dots) = \sum_{h=0}^{H-1} A_{h,t} \varepsilon_{t+H-h} \tag{3}$$

The forecast errors’ covariance matrix is denoted as:

$$E(\zeta_t(H) \zeta_t'(H)) = A_{h,t} S_t A_{h,t}' \tag{4}$$

#### 3.2. The TVP-VAR-based connectedness metric

The connectedness metric based on TVP-VAR results from an  $H$  = step ahead generalized forecast error variance decompositions (GFEVD), computed based on Equation (4). Hence, the GFEVD, captured as  $\phi_{ij,t}^g(H)$ , describing market  $i$ ’s influence on market  $j$ , is formulated as follows:

$$\phi_{ij,t}^g(H) = \frac{E(\zeta_{i,t}^2(H)) - E[\zeta_{i,t}(H) - E(\zeta_{i,t}(H) | \varepsilon_{j,t+1}, \dots, \varepsilon_{j,t+H})]^2}{E(\zeta_{i,t}^2(H))} \tag{5}$$

$$= \frac{\sum_{h=0}^{H-1} (\hat{e}_i A_{ht} S_t e_j)^2}{(e_j S_t e_j) \sum_{h=0}^{H-1} (\hat{e}_i A_{ht} S_t A_{ht}' e_i)} \tag{6}$$

$$\phi_{ij,t}^g(H) = \frac{\phi_{ij,t}^g(H)}{\sum_{j=1}^N \phi_{ij,t}^g(H)} \tag{7}$$

where an  $N \times 1$  zero selection vector that has a unit  $i_{th}$  element is denoted by  $e_i$ ; and proportional reductions in market  $i$ ’s  $H$  – step forecast error variance attributed to market  $j$ ’s prospective shocks is represented as  $\phi_{ij,t}^g(H)$ .

All other markets’ directional shocks to market  $i$  gauge their magnitude of effect on market  $i$  which can be formulated as

$$S_{i \leftarrow \bullet}^{g,from} = \sum_{j=1, j \neq i}^N \phi_{ij,t}^g(H) \tag{8}$$

#### 3.3. The TVP-VAR extended joint connectedness metric

The joint spillover index advanced by Lastrapes and Wiesen (2021) helps surmount the row sum normalization limitation. Following this, accompanied by the TVP-VAR model, Balcilar et al. (2021) introduce the TVP-VAR extended joint connectedness metric, under which the overall directional connectedness from all markets  $j$  to market  $i$  is formulated as follows:

$$S_{i \leftarrow \bullet}^{jnt,from} = \frac{E(\zeta_{i,t}^2(H)) - E[\zeta_{i,t}(H) - \zeta_{i,t}(H) | \varepsilon_{j,t+1}, \dots, \varepsilon_{j,t+H}]^2}{E(\zeta_{i,t}^2(H))} \tag{9}$$

$$= \frac{\sum_{h=0}^{H-1} \hat{e}_i A_{ht} S_t M_i (M_i' S_t M_i)^{-1} M_i' S_t A_{ht}' e_i}{\sum_{h=0}^{H-1} (\hat{e}_i A_{ht} S_t A_{ht}' e_i)} \tag{10}$$

Here, an identity matrix with an  $i_{th}$  eliminated column is denoted as  $M_i$  with  $N \times N - 1$  rectangular dimension.

The index of joint total connectedness (jTCI) takes the following expression:

$$jTCI_t = \frac{1}{N} \sum_{i=1}^N S_{i \leftarrow \bullet}^{jnt,from} \tag{11}$$

Balcilar et al. (2021) initiate the scaling factor  $\lambda$  to connect  $S_{i \leftarrow \bullet}^{jnt,from}$  and  $S_{i \leftarrow \bullet}^{g,from}$ , yielding:

$$\lambda_{it} = \frac{S_{i \leftarrow \bullet}^{jnt,from}}{S_{i \leftarrow \bullet}^{g,from}} \tag{12}$$

Resultantly, all markets’, i.e.,  $j$ ’s influence by virtue of shocks on market  $i$ , i.e.,  $\phi_{ij,t}^{jnt}(H)$ , and that of market  $i$  on all markets,  $j$ , are written as follows:

$$\varphi_{ij,t}^{int}(H) = \lambda_{it}\varphi_{ij,t}^g(H) \tag{13}$$

$$\varphi_{ji,t}^{int}(H) = \lambda_{it}\varphi_{ji,t}^g(H) \tag{14}$$

Finally, following Equations (13) and (14), the directional joint connectedness from  $i$  to  $j$ , net joint connectedness, and net joint pairwise connectedness can be formulated using Equations (15)–(17), respectively.

$$S_{i \rightarrow \bullet, t}^{int, to} = \sum_{j=1, i \neq j}^N \varphi_{ji,t}^{int}(H) \tag{15}$$

$$S_{j,t}^{int, net} = S_{i \rightarrow \bullet, t}^{int, to} - S_{i \leftarrow \bullet, t}^{int, from} \tag{16}$$

$$S_{ij,t}^{int, net} = \varphi_{ji,t}^{int}(H) - \varphi_{ij,t}^{int}(H) \tag{17}$$

In our analysis, the base models were estimated with a 20-step ahead GFEVD, lag of one (BIC), as per Antonakakis et al. (2020) and Balciilar et al. (2021). A sensitivity analysis was conducted under two and ten GFEVD in the section discussing robustness.

### 3.4. Data metrics and preliminary analyses

We use the daily foreign exchange (forex) rates of nine African economies from August 1999 to August 2023: Botswana, Ghana, the Ivory Coast, Kenya, Mauritius, Namibia, Nigeria, South Africa, and Zambia. These rates were measured against the United States dollar using all forex data sourced from Bloomberg. The selection of this 24-year timeframe was intentional and was done to capture a substantial historical span while also incorporating recent developments. This extensive study period allowed us to scrutinize the long-term trends, cyclical patterns, and effects of structural shifts in both global and African economic landscapes. Our choice to use daily data frequency in our analysis stems from our desire to capture the nuanced dynamics of forex markets. This is particularly relevant in African markets, which have recently attracted attention. The high temporal resolution of the daily data frequency enables us to observe and analyze intraday fluctuations and respond swiftly to sudden market changes. For each African forex rate, 5710 observations were made during the analysis period. The sample statistics for all the forex rates analyzed are listed in Table 1.

The mean forex rate returns range from 0.000 (Ivory Coast) to 0.067 (Ghana). The median returns are mostly around zero except for Kenya and Zambia, which have slightly higher median values (0.009 and

0.023, respectively). The maximum forex rate return observed was 35.037 for Nigeria, while the minimum return was –15.452 for Zambia. The standard deviation, which measures the dispersion of forex rates, varies across countries, with Ghana having the highest value (1.209), followed by Kenya (0.458). The skewness and kurtosis values indicate the degree of asymmetry and sharpness of the distribution peak, respectively. Nigeria shows a significantly high positive skewness of 8.934, indicating a long tail on the right-hand side of the distribution. On the other hand, Zambia has a negative skewness of –1.111, indicating a long tail on the left side. The Jarque-Bera test, which tests the null hypothesis of whether the data are distributed normally, shows significant results for all countries, suggesting that forex rates are not normally distributed. Meanwhile, the Augmented Dickey (ADF) and Phillips (PP) tests, which test for the presence of unit roots in the time-series data, show significantly negative values for all countries, suggesting that the forex rates are stationary. These tests are supplemented by the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test, which tests the null hypothesis that the data are trend stationary and show values greater than 0.05 for most countries, further confirming the stationarity of forex rate returns.

The Ljung (LB) and ARCH-LM tests, which evaluate the presence of autocorrelation and autoregressive conditional heteroskedasticity (ARCH) effects in the data, indicate significant results for most countries. This suggests that these effects are prevalent in forex rates. In conjunction with this, the volatility clusters, which can be qualitatively assessed from the trajectories of the returns of the forex rates (as shown in Fig. 1), and the peak distribution, as evidenced by the kurtosis statistics, provide strong motivation for us to extract the volatility series from the various forex rate return series. We employ the generalized autoregression conditional heteroskedasticity variant proposed by Glosten et al. (1993) to derive the GJR-GARCH volatility series. The first step involves capturing the conditional mean of the log-return series. This was achieved by employing an appropriate autoregressive and moving average (ARMA) model selected based on the Akaike Information Criterion. Subsequently, the GJR-GARCH model is used to fit the residuals derived from the ARMA models in the second step. Given the ability of the Student’s t-distribution to effectively capture the fat tails of variables, which is an advantage highlighted in our analysis, we opted to use this distribution to fit the standardized residuals during model estimation. This approach allowed us to account for the heavy-tailed nature of the distribution, which is a common characteristic of financial return series. The best-fitting models for each country’s forex rates, specifically the autoregressive moving average (ARMA) and

**Table 1**  
Sample statistics.

	Botswana	Ghana	Ivory Coast	Kenya	Mauritius	Namibia	Nigeria	South Africa	Zambia
Obs.	5710	5710	5710	5710	5710	5710	5710	5710	5710
Mean	0.019	0.067	0.000	0.013	0.010	0.020	0.036	0.020	0.036
Median	0.000	0.000	0.000	0.009	0.000	–0.019	0.000	–0.019	0.023
Max	11.977	17.007	4.342	8.729	8.116	15.496	35.037	15.496	14.098
Min	–8.832	–14.934	–6.870	–4.615	–5.694	–6.630	–8.751	–6.630	–15.452
Std. Dev.	0.870	1.209	0.697	0.458	0.731	1.109	1.074	1.109	1.188
Skewness	0.788 ***	0.778 ***	–0.301 ***	1.724 ***	0.289 ***	0.832 ***	8.934 ***	0.832 ***	–1.111 ***
Kurtosis	25.136 ***	40.711 ***	8.157 ***	48.488 ***	15.850 ***	12.440 ***	261.752 ***	12.440 ***	31.385 ***
Jarque-Bera	117173.3 ***	338926.1 ***	6413.1 ***	495114.7 ***	39364.4 ***	21862.3 ***	16005054.7 ***	21860.6 ***	192868.5 ***
ADF	–22.609 ***	–20.558 ***	–23.575 ***	–21.656 ***	–21.244 ***	–22.719 ***	–21.969 ***	–22.719 ***	–21.398 ***
PP	–88.299 ***	–96.363 ***	–84.976 ***	–80.311 ***	–119.702 ***	–76.867 ***	–89.304 ***	–76.866 ***	–76.935 ***
KPSS	0.034	0.228	0.123	0.243	0.083	0.061	0.406	0.061	0.081
Panel B: Tests for autocorrelation, ARCH effect, and best ARMA-GARCH models.									
LB	163.1 ***	167.4 ***	95.1 ***	96.2 ***	900.1 ***	14.555	190.7 ***	14.549	31.6 ***
LB <sup>2</sup>	674.8 ***	1134.1 ***	269.2 ***	690.4 ***	1989.3 ***	1408.2 ***	19.959	1408.2 ***	913.8 ***
ARCH-LM(10)	370.4 ***	1029.9 ***	185.8 ***	990.9 ***	955.1 ***	589.5 ***	13.652	589.5 ***	540.6 ***
ARMA(p,q)	(1,1)	(4,3)	(2,1)	(3,2)	(2,3)	(3,3)	(2,1)	(1,1)	(2,2)
GJR – GARCH(p,q)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)	(1,1)

Notes: The table presents the sample statistics for the daily forex rates of nine African economies—Botswana, Ghana, Ivory Coast, Kenya, Mauritius, Namibia, Nigeria, South Africa, and Zambia—measured against the U.S. dollar from August 27, 1999, to August 22, 2023.

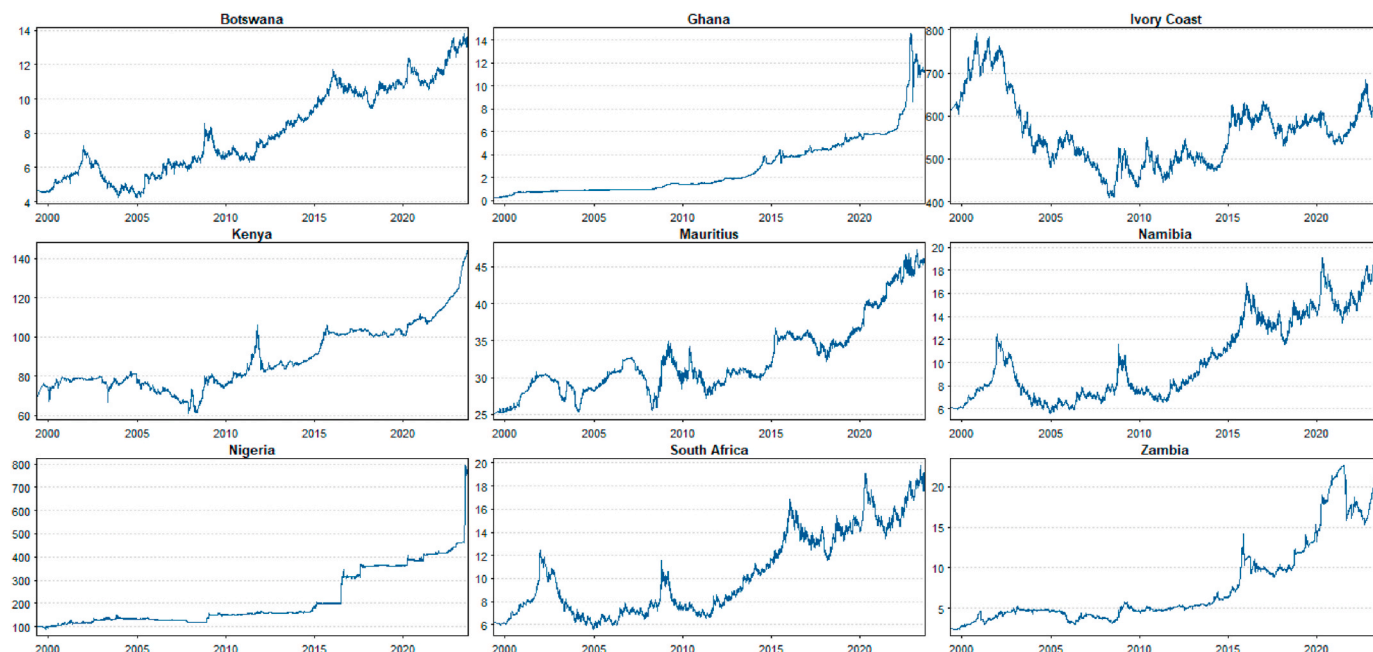


Fig. 1. FX rate series for sub-Saharan African markets.

GJR-GARCH models, are summarized in Tables 1 and 2.

The results presented in Table 2 reveal that each term of  $\Phi$  and  $\theta$  in the ARMA models is statistically significant, thereby validating the mean equation. All  $\alpha_1$  and  $\beta_1$  estimates from the GJR-GARCH models are statistically significant across all conventional levels. With the exception of the Zambian Kwacha, all  $\gamma_1$  estimates are highly significant. This finding suggests that the African forex markets are susceptible to negative news, which can trigger a leverage effect. Examining the conditionally heteroskedastic volatility series depicted in Fig. 2, it is evident that the Nigerian Naira, the Ghanaian Cedi, and the Zambian Kwacha exhibit the highest volatility. Countries such as Namibia and South Africa (Kenya, Botswana, and the Ivory Coast) share similar trends in forex market volatility. Significant growth trends in volatility are observed in these series in March 2020, highlighting the impact of the COVID-19 pandemic. Additionally, the Russia-Ukraine military conflict underscores the influence of geopolitical risk on these markets. These findings provide valuable insights into African forex market dynamics.

#### 4. Results

This section calculates the return and volatility connectedness among sub-Saharan African forex markets using the TVP-VAR extended joint connectedness approach. This method allows us to capture the dynamic interdependencies among these markets over time. Our analysis pays particular attention to the changes brought about by the ongoing military hostility between Russia and Ukraine. Geopolitical events such as these can significantly impact forex markets, causing shifts in returns and volatility connectedness. By focusing on this event, we aim to provide a deeper understanding of how such geopolitical risks can influence the interconnectedness of African forex markets. Our analysis provides comprehensive results across three distinct periods: the full sample period, the period prior to the Russia-Ukraine conflict, and the Russia-Ukraine geopolitical conflict period. This approach allows us to observe how the interconnectedness of sub-Saharan African forex markets evolved over time and under different geopolitical conditions. It also enables us to understand the impact of significant geopolitical events, such as the Russia-Ukraine conflict, on the dynamics

Table 2  
Parameter estimates from various ARMA-GARCH models.

	Botswana	Ghana	Ivory Coast	Kenya	Mauritius	Namibia	Nigeria	South Africa	Zambia
$\phi_1$	0.222*	0.971***	-0.846***	1.186***	0.122***	1.651***	0.520***	0.889***	-0.576***
$\phi_2$	/	-0.356***	-0.090***	-0.221***	0.763***	-1.399***	-0.050**	/	0.409***
$\phi_3$	/	0.213***	/	0.031***	/	0.337***	/	/	/
$\phi_4$	/	0.140***	/	/	/	/	/	/	/
$\phi_5$	/	/	/	/	/	/	/	/	/
$\theta_1$	-0.346**	-1.319***	0.744***	-1.224***	-0.549***	-1.654***	-0.764	-0.894***	0.532***
$\theta_2$	/	0.712***	/	0.236***	-0.683***	1.401***	/	/	-0.446***
$\theta_3$	/	-0.358***	/	/	0.331***	-0.344***	/	/	/
$\theta_4$	/	/	/	/	/	/	/	/	/
$\theta_5$	/	/	/	/	/	/	/	/	/
$\mu$	0.011	0.026***	-0.001	0.041***	0.007	0.029**	-0.004***	0.029**	0.055***
$\varsigma_0$	0.005***	0.003***	0.002***	0.001***	0.002***	0.018***	0.002***	0.018***	0.029***
$\alpha_1$	0.069***	0.130***	0.046***	0.116***	0.091***	0.078***	0.227***	0.078***	0.216***
$\beta_1$	0.943***	0.894***	0.962***	0.867***	0.916***	0.092***	0.816***	0.927***	0.786***
$\gamma_1$	-0.033***	-0.049***	-0.211***	-0.033***	-0.016*	-0.039***	-0.087***	-0.038***	-0.007

Notes: The respective  $\Phi$  ( $\theta$ ) terms are the autoregression (moving average) parameters; variance equations' constant terms are represented by  $\varsigma$ ;  $\alpha$ ,  $\beta$ , and  $\gamma$  are the parameters for ARCH, GARCH, and the leverage, respectively. 10%, 5%, and 1% significance levels are denoted by \*, \*\*, and \*\*\*, respectively.

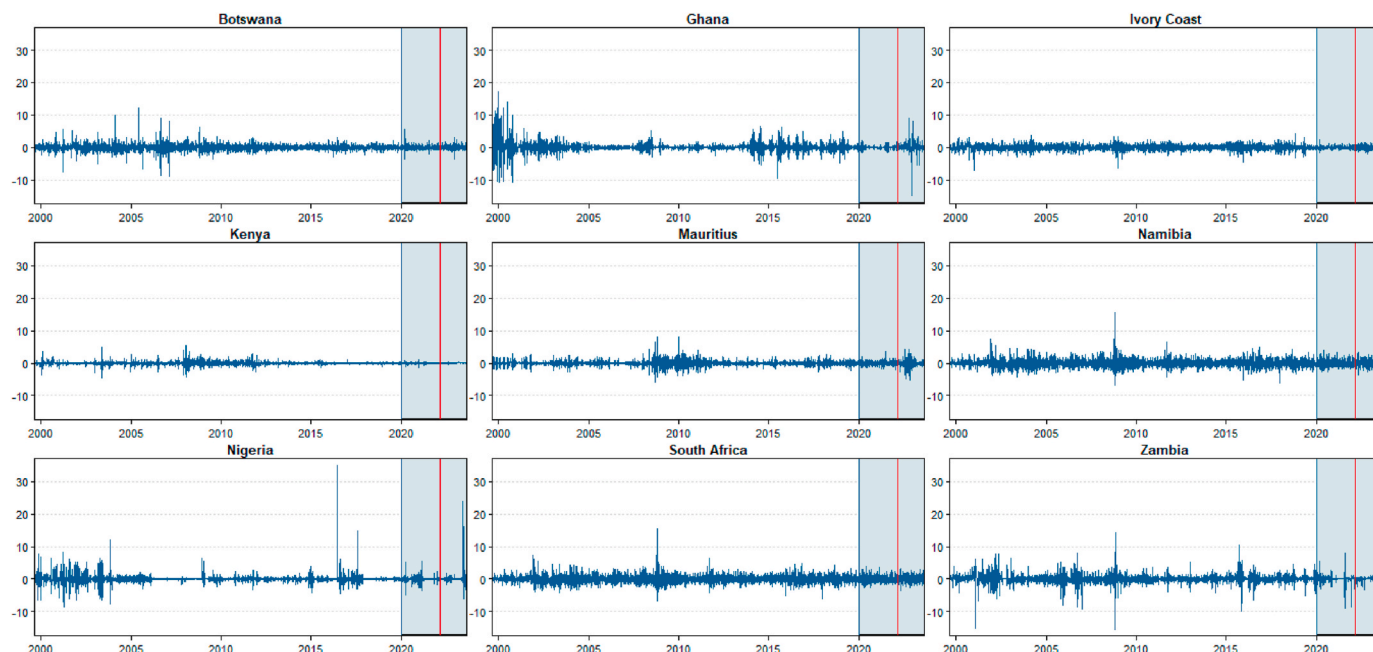


Fig. 2. FX rate return series for sub-Saharan African markets. Notes: The red line in the graph represents the onset of the Russia-Ukraine era, while the entire light greyish-blue-shaded region covers both the COVID-19 pandemic and the geopolitical conflict eras.

of these markets. The detailed findings of this analysis are presented in subsequent subsections.

#### 4.1. Averaged extended joint connectivity

Table 3 presents the average extended joint return connectedness (JTICI) matrix for the nine sub-Saharan African economies. The results are organized into three panels (A, B, and C), representing the full sample period, the pre-Russia-Ukraine conflict period, and the period of the Russia-Ukraine conflict, respectively. A qualitative assessment of the network connections between these markets is offered by the plots in Figure A1 in the Annex.

In the full-sample analysis, the highest self-connectedness was observed in Ghana at 91.80%, indicating that a significant portion of the total variation in Ghana’s forex returns (Cedi) can be explained by its shocks. The highest ‘FROM’ value is for the Namibian Dollar and South African Rand at 99.90%, suggesting that these countries significantly influence other markets. The highest ‘TO’ value is also for these same currencies for Namibia and South Africa at 96.10%, indicating that shocks from other markets most influence these countries’ forex markets. Before the Russia-Ukraine conflict, Ghanaian Cedi maintained its highest self-connectedness at 91.65%. However, the ‘FROM’ value for the Namibian Dollar and South African Rand slightly decreases to 99.93%, while the ‘TO’ value also decreases to 96.37%. During the Russia-Ukraine conflict, the self-connectedness of the Ghanaian Cedi increased slightly to 93.93%. The ‘FROM’ value for the Namibian Dollar and South African Rand increases to 99.46%, and the ‘TO’ value also increases to 92.02%. Thus, the influence of the forex markets in Namibia and South Africa strengthened following the onset of the conflict. The net connectedness, the difference between ‘TO’ and ‘FROM,’ provides insights into the net positions of the various sub-Saharan African forex markets. In the full sample, Namibia and South Africa have the highest net connectedness at  $-3.81$  and  $-3.80$ , respectively. This trend continued in the pre-Russia-Ukraine conflict period, with Namibia and

South Africa having the highest net connectedness at  $-3.56\%$  and  $-3.56\%$ , respectively. During the Russia-Ukraine conflict, the net connectedness for the Namibian Dollar and South African Rand increases to  $-7.44\%$  and  $-7.31\%$ , respectively.

These results suggest that the Russia-Ukraine conflict significantly impacted the return connectedness of the sub-Saharan African forex markets. This conflict increased the influence of other markets on Namibia and South Africa’s forex returns, as well as their influence on other markets. This indicates an increase in the interconnectedness of these markets during periods of geopolitical tension.

Next, we assessed the volatility connectedness matrix. Table 4 presents the average extended joint volatility connectedness matrix for the nine sub-Saharan African economies. Similar to return connectedness, the results for volatility connectedness are organized into three panels (A, B, and C), representing the full sample, the pre-Russia-Ukraine conflict period, and the period of the Russia-Ukraine conflict, respectively.

In the full -sample analysis, the highest self-connectedness is observed for Ghana at 76.60%, indicating that a significant portion of the total variation in Ghana’s forex volatility can be explained by its shocks. The highest ‘FROM’ value is for the Namibian Dollar and South African Rand at 98.00%, suggesting that these countries’ forex rate volatility has the most significant influence on other markets’ volatility. The highest ‘TO’ value is also for Namibia and South Africa at 105.04%, indicating that these countries are most influenced by volatility shocks from other markets. Before the Russia-Ukraine conflict, Ghana’s forex market maintained its highest self-connectedness at 75.91%. However, the ‘FROM’ value for Namibia and South Africa slightly decreases to 98.06%, while the ‘TO’ value also decreases to 105.67%. During the Russia-Ukraine conflict, the self-connectedness of Cedi (Ghana) increased slightly to 86.69%. The ‘FROM’ value for the Namibian Dollar and South African Rand decreases to 97.15%, and the ‘TO’ value decreases to 95.88%. In terms of net connectedness, in the full sample, Namibia and South Africa have the highest net connectedness at 7.04

**Table 3**  
Averaged extended joint return connectedness matrix.

Panel A: Full sample.										
	Botswana	Ghana	Ivory Coast	Kenya	Mauritius	Namibia	Nigeria	South Africa	Zambia	FROM
Botswana	55.96	0.38	4.82	0.67	0.71	18.10	0.38	18.10	0.89	44.04
Ghana	0.97	91.80	0.89	1.12	1.40	0.82	1.22	0.82	0.95	8.20
Ivory coast	4.63	0.55	78.76	0.75	0.92	6.53	0.68	6.53	0.66	21.24
Kenya	1.11	0.89	1.39	91.78	0.56	1.37	0.60	1.37	0.93	8.22
Mauritius	1.56	1.93	2.47	0.59	89.60	1.07	0.98	1.07	0.73	10.40
Namibia	21.16	0.60	8.66	0.90	0.64	0.10	0.50	66.27	1.17	99.90
Nigeria	0.61	1.12	0.91	0.66	0.91	0.51	94.19	0.51	0.58	5.81
South Africa	21.16	0.60	8.66	0.90	0.64	66.27	0.50	0.10	1.17	99.90
Zambia	1.36	0.63	0.99	0.92	0.56	1.43	0.49	1.43	92.19	7.81
TO	52.56	6.70	28.80	6.50	6.34	96.09	5.36	96.10	7.08	<b>jTCI</b>
NET	8.52	-1.50	7.56	-1.71	-4.06	-3.81	-0.45	-3.80	-0.73	<b>33.95</b>
Panel B: Pre-Russia-Ukraine conflict.										
	Botswana	Ghana	Ivory coast	Kenya	Mauritius	Namibia	Nigeria	South Africa	Zambia	FROM
Botswana	56.77	0.39	4.44	0.69	0.72	17.85	0.37	17.85	0.91	43.23
Ghana	1.01	91.65	0.88	1.17	1.36	0.83	1.28	0.83	0.98	8.35
Ivory coast	4.36	0.57	79.62	0.78	0.97	6.18	0.67	6.18	0.68	20.38
Kenya	1.07	0.90	1.35	92.04	0.55	1.32	0.53	1.32	0.91	7.96
Mauritius	1.60	1.80	2.61	0.58	89.42	1.09	1.03	1.09	0.78	10.58
Namibia	20.76	0.62	8.16	0.94	0.64	0.07	0.50	67.11	1.20	99.93
Nigeria	0.62	1.16	0.91	0.64	0.93	0.51	94.13	0.51	0.59	5.87
South Africa	20.76	0.62	8.16	0.94	0.64	67.11	0.50	0.07	1.20	99.93
Zambia	1.39	0.65	1.03	0.92	0.59	1.47	0.50	1.47	91.98	8.02
TO	51.57	6.71	27.54	6.65	6.41	96.37	5.38	96.37	7.25	<b>jTCI</b>
NET	8.34	-1.64	7.16	-1.31	-4.17	-3.56	-0.49	-3.56	-0.76	<b>33.81</b>
Panel C: During the Russia-Ukraine conflict.										
	Botswana	Ghana	Ivory coast	Kenya	Mauritius	Namibia	Nigeria	South Africa	Zambia	FROM
Botswana	44.31	0.24	10.28	0.35	0.48	21.67	0.40	21.69	0.59	55.69
Ghana	0.37	93.93	1.10	0.50	2.02	0.56	0.40	0.58	0.55	6.07
Ivory coast	8.54	0.20	66.25	0.22	0.25	11.67	0.89	11.68	0.30	33.75
Kenya	1.62	0.80	1.89	88.01	0.70	2.11	1.59	2.13	1.15	11.99
Mauritius	0.95	3.78	0.49	0.71	92.30	0.67	0.29	0.69	0.13	7.70
Namibia	26.93	0.34	15.96	0.38	0.54	0.54	0.58	54.03	0.70	99.46
Nigeria	0.54	0.55	0.98	0.96	0.56	0.40	95.10	0.42	0.49	4.90
South Africa	26.93	0.34	15.96	0.38	0.54	54.03	0.58	0.54	0.70	99.46
Zambia	0.98	0.27	0.44	0.89	0.12	0.91	0.32	0.93	95.14	4.86
TO	66.85	6.51	47.09	4.38	5.22	92.02	5.05	92.15	4.61	<b>jTCI</b>
NET	11.16	0.43	13.34	-7.61	-2.49	-7.44	0.15	-7.31	-0.24	<b>35.99</b>

Notes: The table presents the averaged extended joint return connectedness matrix between the daily forex rates of nine African economies—Botswana, Ghana, Ivory Coast, Kenya, Mauritius, Namibia, Nigeria, South Africa, and Zambia—measured against the U.S. dollar from August 27, 1999, to August 22, 2023. The Results are grounded in the TVP-VAR metric specified under BIC and forecast horizons of 1 and 20, respectively.

**Table 4**  
Averaged extended joint volatility connectedness matrix.

Panel A: Full sample.										
	Botswana	Ghana	Ivory Coast	Kenya	Mauritius	Namibia	Nigeria	South Africa	Zambia	FROM
Botswana	50.57	1.25	4.74	1.87	2.39	17.64	2.21	17.63	1.70	49.43
Ghana	2.71	76.60	2.19	2.14	3.60	3.31	3.10	3.30	3.05	23.40
Ivory coast	4.97	2.55	70.91	3.07	3.56	4.81	2.54	4.87	2.71	29.09
Kenya	2.49	2.41	2.81	75.77	3.70	3.72	2.48	3.71	2.90	24.23
Mauritius	2.29	3.05	2.26	4.05	77.10	2.71	3.37	2.75	2.42	22.90
Namibia	13.79	2.15	4.74	2.73	3.76	2.00	2.27	66.47	2.09	98.00
Nigeria	3.62	2.87	1.29	2.47	2.01	2.53	80.62	2.53	2.07	19.38
South Africa	13.85	2.15	4.77	2.75	3.78	66.38	2.30	1.92	2.10	98.08
Zambia	2.46	1.81	2.16	1.78	2.28	3.95	2.38	3.97	79.21	20.79
TO	46.17	18.23	24.95	20.87	25.08	105.04	20.67	105.24	19.04	<b>JTCI</b>
NET	-3.26	-5.17	-4.14	-3.36	2.19	7.04	1.29	7.16	-1.75	<b>42.81</b>

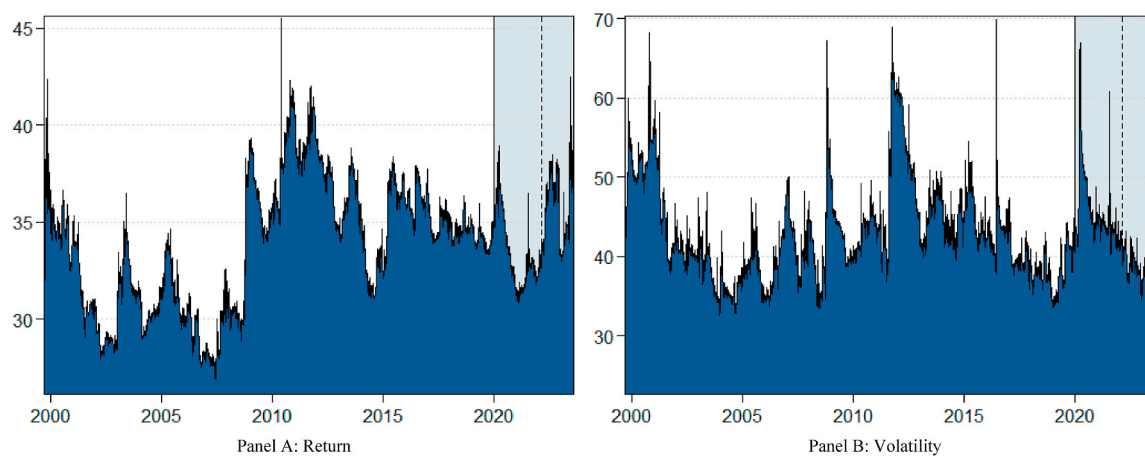
  

Panel B: Pre-Russia-Ukraine conflict.										
	Botswana	Ghana	Ivory coast	Kenya	Mauritius	Namibia	Nigeria	South Africa	Zambia	FROM
Botswana	49.94	1.21	4.78	1.71	2.29	18.02	2.27	18.03	1.75	50.06
Ghana	2.83	75.91	2.17	2.20	3.59	3.46	3.22	3.46	3.15	24.09
Ivory coast	4.82	2.43	71.56	3.18	3.43	4.64	2.53	4.70	2.71	28.44
Kenya	2.34	2.26	2.88	76.08	3.72	3.86	2.32	3.86	2.69	23.92
Mauritius	2.26	3.12	2.35	4.29	76.62	2.66	3.53	2.70	2.47	23.38
Namibia	13.82	2.11	4.54	2.82	3.76	1.94	2.34	66.49	2.17	98.06
Nigeria	3.77	2.90	1.34	2.49	2.08	2.52	80.39	2.53	1.98	19.61
South Africa	13.88	2.12	4.57	2.84	3.78	66.34	2.37	1.91	2.18	98.09
Zambia	2.46	1.80	2.26	1.86	2.35	4.17	2.44	4.20	78.44	21.56
TO	46.19	17.95	24.89	21.39	25.00	105.67	21.03	105.98	19.10	<b>JTCI</b>
NET	-3.88	-6.14	-3.54	-2.52	1.62	7.61	1.42	7.89	-2.46	<b>43.02</b>

Panel C: During the Russia-Ukraine conflict.										
	Botswana	Ghana	Ivory coast	Kenya	Mauritius	Namibia	Nigeria	South Africa	Zambia	FROM
Botswana	59.77	1.82	4.16	4.25	3.82	12.05	1.35	11.85	0.95	40.23
Ghana	0.97	86.69	2.42	1.20	3.73	1.10	1.35	1.03	1.51	13.31
Ivory coast	7.14	4.37	61.40	1.55	5.56	7.36	2.67	7.30	2.64	38.60
Kenya	4.62	4.57	1.89	71.23	3.52	1.68	4.86	1.58	6.03	28.77
Mauritius	2.77	1.96	0.92	0.65	84.06	3.38	1.11	3.42	1.74	15.94
Namibia	13.32	2.63	7.68	1.36	3.70	2.85	1.33	66.16	0.98	97.15
Nigeria	1.43	2.45	0.47	2.33	1.07	2.60	83.86	2.50	3.30	16.14
South Africa	13.36	2.60	7.72	1.36	3.68	66.98	1.34	2.01	0.96	97.99
Zambia	2.39	1.84	0.59	0.58	1.22	0.73	1.55	0.68	90.42	9.58
TO	46.00	22.23	25.85	13.27	26.30	95.88	15.56	94.52	18.10	<b>JTCI</b>
NET	5.76	8.92	-12.75	-15.50	10.36	-1.27	-0.58	-3.47	8.53	<b>39.74</b>

Notes: The table presents the averaged extended joint volatility connectedness matrix between the daily forex rates of nine African economies—Botswana, Ghana, Ivory Coast, Kenya, Mauritius, Namibia, Nigeria, South Africa, and Zambia—measured against the U.S. dollar from August 27, 1999, to August 22, 2023. The Results are grounded in the TVP-VAR metric specified under BIC and forecast horizons of 1 and 20, respectively.



**Fig. 3.** Dynamic total joint FX rate return and volatility connectedness for sub-Saharan African markets. Notes: The black dotted vertical line in the graph represents the onset of the Russia-Ukraine era, while the entire light-greyish-blue-shaded region covers both the COVID-19 pandemic and the geopolitical conflict eras.

and 7.16, respectively. This trend continued in the pre-Russia-Ukraine conflict period, with Namibia and South Africa having the highest net connectedness at 7.61% and 7.89%, respectively. During the Russia-Ukraine conflict, the net connectedness for Namibia and South Africa decreases to  $-1.27\%$  and  $-3.47\%$ , respectively. This position underscores South Africa’s status as a leading emerging market within the African region. South Africa is the only African (sub-Saharan) economy among the top five emerging markets worldwide. Given its substantial trading volume, South Africa is anticipated to maintain significant influence within African forex markets. Our results demonstrate that the influence of the South African Rand on the rest of the African forex markets is particularly evident in terms of volatility. This emphasizes the importance of our analysis of both return and volatility connectivity dynamics rather than focusing solely on returns.

The average extended joint connectedness results suggest that the Russia-Ukraine conflict significantly impacted the volatility connectedness of the sub-Saharan African forex markets. This conflict decreased the influence of other markets on Namibia as well as South Africa’s forex volatility and influence on other markets. This indicates a decrease in the interconnectedness of these markets during periods of geopolitical tension.

From a comparative analysis of the return and volatility connectedness matrices over the full sample, the pre-Russia-Ukraine conflict period, and the Russia-Ukraine conflict period, we summarize the following important revelations. The connectedness matrix for both return and volatility shows that the sub-Saharan African forex markets are significantly interconnected. The Namibian Dollar and South African Rand have the highest influence on other markets and are also the most influenced by shocks from other markets. Prior to the Russia-Ukraine conflict, interconnectedness remained high; however, there was a slight decrease in the influence of Namibia and South Africa on other markets, and vice versa. On average, the return (volatility) interconnectedness of the markets was amplified (lessened) by the Russia-Ukraine conflict. During this period, the influence of other markets on Namibia’s and South Africa’s forex returns, as well as their influence on other markets, increases for returns but decreases for volatility. This indicates that geopolitical events can have diverse effects on different aspects of market interconnectedness.

An important insight from the average connectedness results reveals

that a substantial portion of the SSA forex markets are profoundly impacted by self-induced shocks. However, the South African Rand and Namibian Dollar are exceptions. What are the implications of this? This underscores the necessity for sub-Saharan African policymakers to focus on domestically generated market innovations when managing their forex policies rather than consistently attributing issues to external shocks. This observation aligns with the previously documented conclusions in the African context when considering the connectedness between and among African financial markets either in exclusion (see Ahmed, 2016; Atenga & Mougoué, 2021) or along with other international financial assets or markets (see, e.g., Agyei & Bossman, 2023; Bossman & Agyei, 2022; Bossman, Umar, et al., 2023). A deeper examination of the country-specific factors responsible for driving connectedness with others would be promising. Let us examine how these dynamics unfold in a dynamic setting accounting for time variability.

#### 4.2. Dynamic extended joint connectivity

In this subsection, we dynamically assess the interconnectedness of the SSA forex markets over the period 1999–2023. We graphically present our findings to illustrate the trends and patterns in the interconnectedness of various African forex rates since the beginning of the 21st century. We evaluated the dynamic total extended joint connectedness ( $jTCI$ ) by allowing it to fluctuate over time. This approach enabled us to track the evolution of the  $jTCI$  through the events covered by our sample. Fig. 3 presents our results for return spillovers (Panel A) and volatility (Panel B).

During the analysis period, we observe that the  $jTCI$  for return spillovers among the sub-Saharan African economies ranges between 26% and 46%. It peaked in May 2010, with minor peaks from late 2008 to early 2009 (around 40%) and March 2020 (32%), and a significant increase to above 42% towards the end and the start of Q1/Q2 2022, which also saw the height of the Russia-Ukraine military conflict. The light-greyish-blue-shaded region, representing the period from the COVID-19 pandemic and the Russian military’s invasion of Ukraine on February 24, 2022, to the end of our sample period in August 2023, illustrates the most recent dynamics. This observation aligns with the literature highlighting the high responsiveness of exchange rate markets

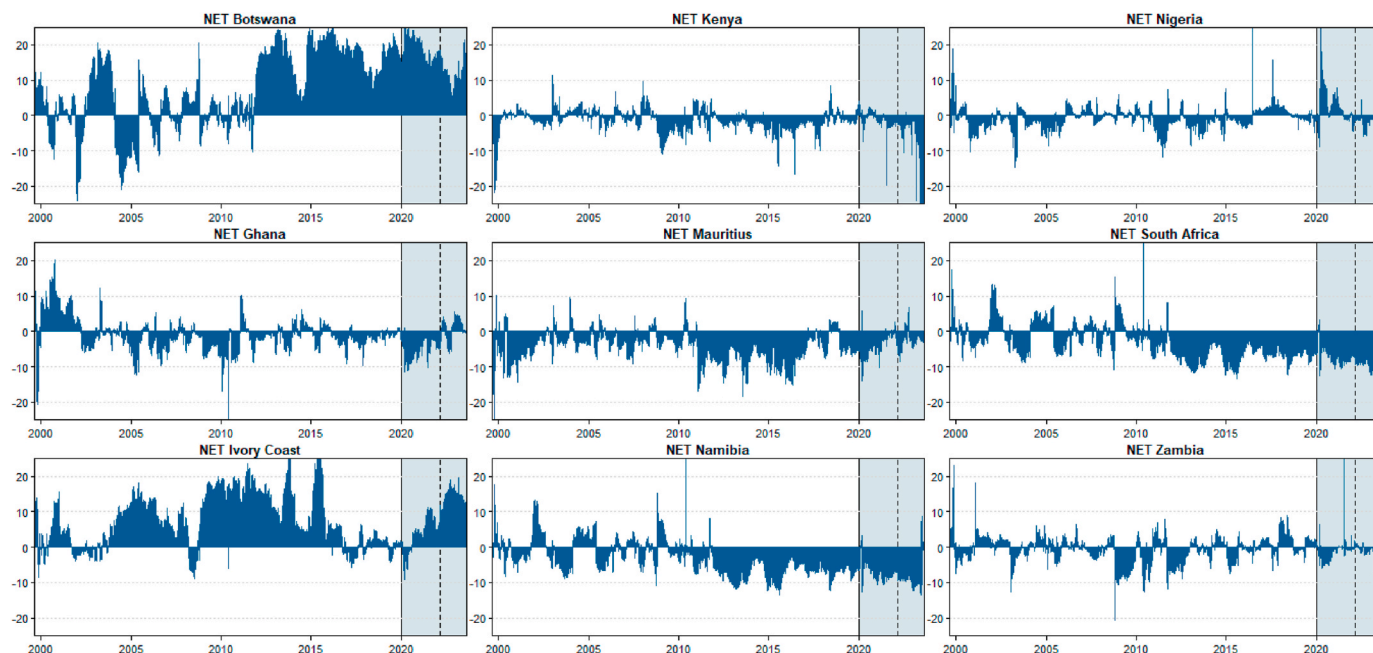


Fig. 4. Dynamic net joint FX rate return connectedness for sub-Saharan African markets. Notes: The black dotted vertical line in the graph represents the onset of the Russia-Ukraine era, while the entire light-greyish-blue-shaded region covers both the COVID-19 pandemic and the geopolitical conflict eras.

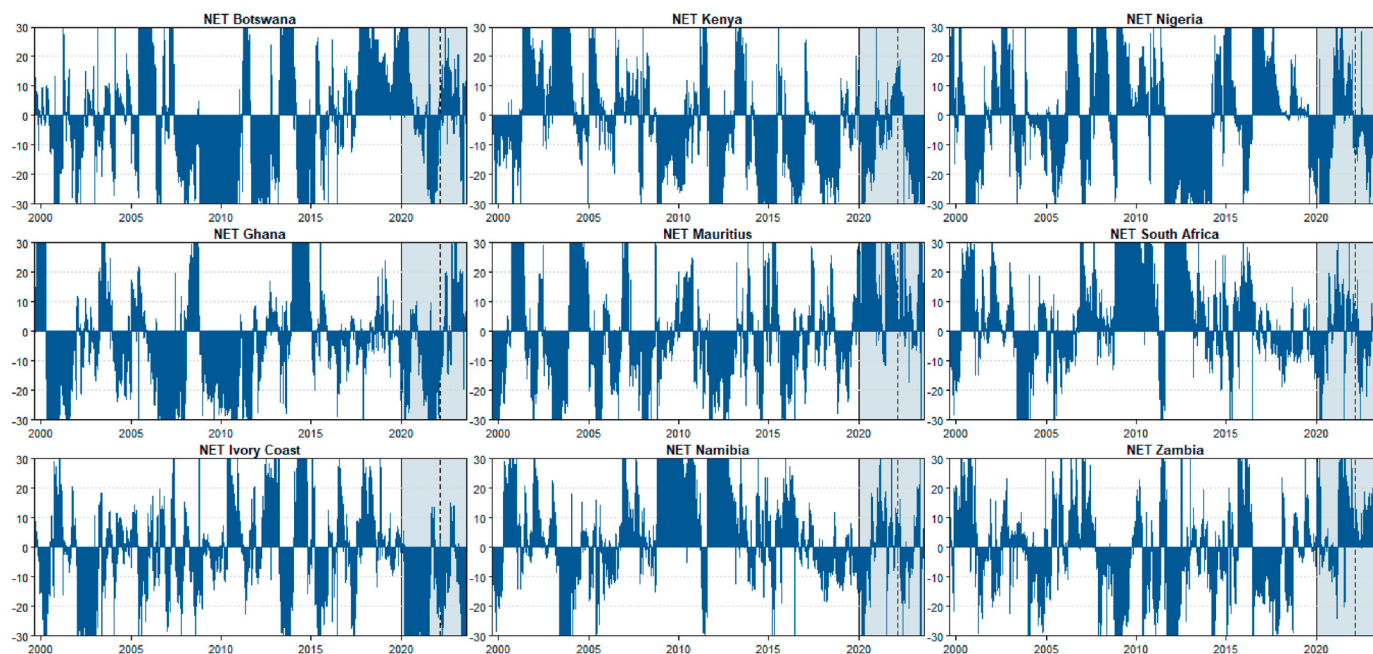


Fig. 5. Dynamic net joint FX rate volatility connectedness for sub-Saharan African markets. Notes: The black dotted vertical line in the graph represents the onset of the Russia-Ukraine era, while the entire light-greyish-blue-shaded region covers both the COVID-19 pandemic and the geopolitical conflict eras.

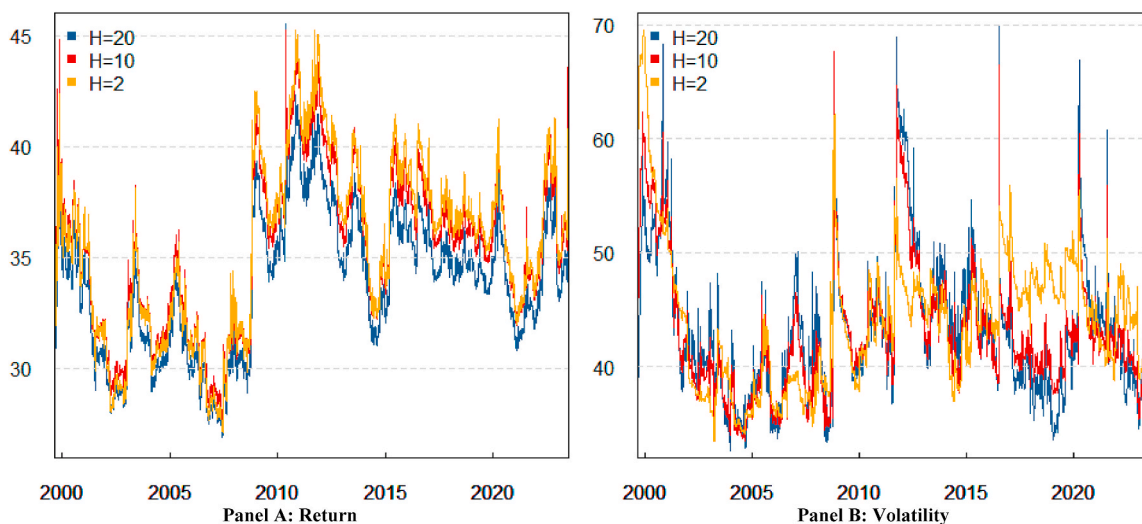


Fig. 6. Dynamic total joint FX rate return (Panel A) and volatility (Panel B) connectedness across different forecast horizons (H = 2, H = 10, and H = 20).

to news and policy interventions (Catalán-Herrera, 2016; Kočenda & Moravcová, 2018; Viola et al., 2019). Regarding volatility spillovers (see Panel B of Fig. 3), two findings stand out: first, the magnitude of the time-varying  $jTCI$  is consistently higher than its return counterpart (ranging between 32% and 71%); second, volatility  $jTCI$  exhibits more fluctuations compared to returns.

Generally, the identified periods of peak return and volatility  $jTCI$  coincide with significant events in the global economy, aside from the ongoing Russia-Ukraine geopolitical conflict. These peaks, which suggest a potential financial contagion effect, occurred during the 2007–2008 Global Financial Crisis, the COVID-19 pandemic, and the beginning of the Russia-Ukraine military hostilities in 2022. During these crises, several emerging countries experienced currency devaluation (Naeem et al., 2023). The COVID-19 surge in March 2020 corresponded to the World Health Organization’s declaration that the rapidly spreading coronavirus was a pandemic. This announcement profoundly

impacted the global economy, as many business and economic activities were halted, leading to drastic market reactions and subsequent policy actions to mitigate these effects (Antipova, 2021; Giles et al., 2020). Despite these measures, the pandemic severely affected financial markets, as documented in previous studies (Gubareva, 2021; Organization for Economic Co-operation and Development, 2020; Zhang et al., 2020).

To further our understanding, we examine the individual characteristics of various sub-Saharan African exchange rate markets. This is accomplished by modeling the net directional connectedness. Figs. 4 and 5 depict the results of the net directional extended joint connectedness, which represent return and volatility spillovers, respectively.

Although most markets alternate between the roles of net recipients and transmitters, certain consistencies are noteworthy. In the context of return spillovers, the Mauritian Rupee, South African Rand, Namibian Dollar, and Kenyan Shilling emerged as the primary net recipients among sub-Saharan African forex rates. Conversely, the Botswanan Pula

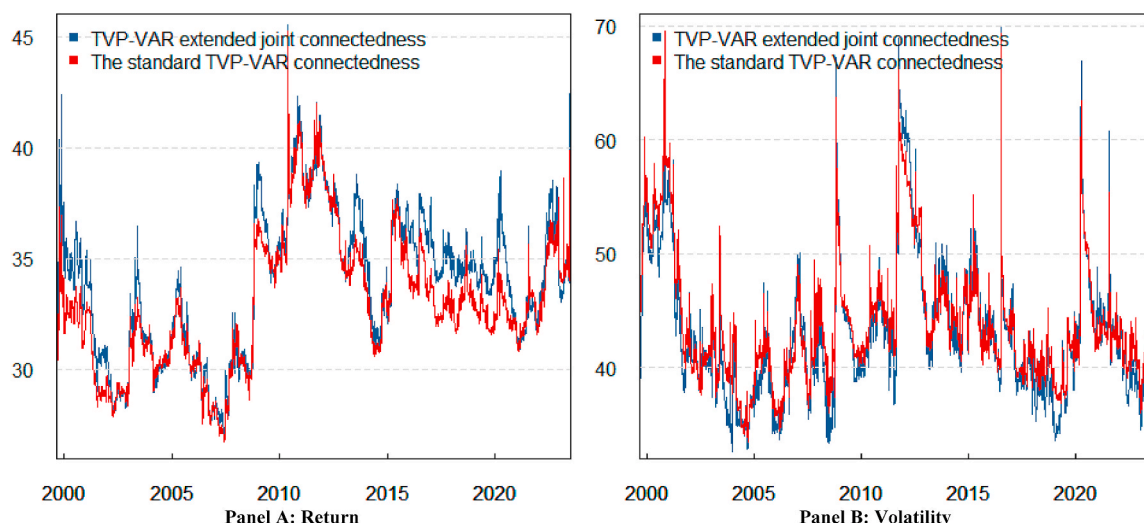


Fig. 7. Dynamic total joint FX rate return (Panel A) and volatility (Panel B) connectedness for the usual TVP-VAR vs. TVP-VAR extended joint metrics.

and CFA franc of the Ivory Coast stand out as significant transmitters. The remaining forex rates, namely the Cedi (Ghana), Kwacha (Zambia), and Naira (Nigeria), typically oscillate between roles, particularly during ongoing geopolitical tensions.

Regarding volatility dynamics, all forex markets aggressively switch between these roles, reflecting the turbulent nature of forex markets in general. Therefore, our findings highlight the importance of analyzing volatility spillovers alongside return spillovers. These compelling results have crucial implications for the management and coordination of policies across emerging sub-Saharan African markets. For more detailed insights, we present the dynamic pairwise joint connectedness between the sub-Saharan African forex markets in Figures A2 and A3.

### 4.3. Robustness

To validate the robustness of our findings, we conduct additional analyses on the time-varying connectedness among the forex rates of sub-Saharan African countries from two perspectives: first, we perform a

sensitivity analysis of the results to forecast horizons, and second, we compare the extended joint connectedness results with those from the traditional TVP-VAR approach. If the results across forecast horizons set at  $H = 2$  and  $H = 10$ , align with those at  $H = 20$ , as previously presented, then the robustness is confirmed. Given that extended joint connectedness is an advanced version of the robust TVP-VAR method, we anticipate comparable results from both approaches to confirm their robustness.

In Fig. 6, we conduct a sensitivity analysis using two additional forecast horizons ( $H = 2$  and  $H = 10$ ) and compare their results with those generated at the base forecast horizon of  $H = 20$ . Although smaller forecast horizons yield trajectories that tend to be slightly lower than the trends of the larger forecast horizons, the patterns remain consistent across the chosen sizes. Furthermore, comparisons between the extended joint connectedness results and those from the original TVP-VAR connectedness model (Fig. 7) reveal consistent trends in jTCIs for the return and volatility spillover measures. All results, irrespective of the forecast step length or estimation model, confirm the increase in

Table 5  
Drivers of return and volatility connectedness of sub-Saharan African forex rates.

Variables	Full post-COVID sample		Pre-Russia-Ukraine		During Russia-Ukraine	
	jTCI return	jTCI volatility	jTCI return	jTCI volatility	jTCI return	jTCI volatility
OVX	2.333*** (0.288)	5.263*** (0.568)	1.998*** (0.231)	4.898*** (0.552)	0.170 (0.922)	3.466*** (1.253)
VIX	1.245*** (0.313)	-5.127*** (0.615)	1.004*** (0.275)	-1.228* (0.658)	0.117 (0.624)	-6.828*** (0.847)
USEPU	0.002*** (0.001)	0.015*** (0.001)	0.005*** (0.001)	0.014*** (0.001)	-0.007*** (0.002)	-0.007*** (0.002)
GPR	-1.138** (0.544)	0.689 (1.071)	0.141 (0.436)	-0.761 (1.044)	-4.194*** (1.298)	-0.870 (1.763)
GPRA	0.397*** (0.152)	-1.026*** (0.300)	0.007 (0.122)	0.136 (0.292)	0.756* (0.423)	0.394 (0.575)
GPRT	0.168 (0.391)	-1.026 (0.769)	-0.591* (0.319)	0.118 (0.764)	2.259** (0.883)	1.887 (1.200)
MCI	-0.106*** (0.004)	0.107*** (0.009)	-0.079*** (0.004)	0.031*** (0.010)	-0.020 (0.027)	-0.073** (0.036)
Constant	30.044*** (0.871)	36.528*** (1.715)	28.930*** (0.822)	28.004*** (1.968)	42.267*** (2.361)	44.535*** (3.207)
Observations	883	883	516	516	367	367
Adj. R <sup>2</sup>	0.497	0.578	0.640	0.653	0.105	0.245

Notes: The table presents the ordinary least squares regression estimates of the drivers of the extended joint volatility connectedness between the daily forex rates of nine African economies—Botswana, Ghana, Ivory Coast, Kenya, Mauritius, Namibia, Nigeria, South Africa, and Zambia—measured against the U.S. dollar from August 27, 1999, to August 22, 2023. OVX is the implied volatility of crude oil, USEPU is the policy uncertainty of the US economy, GPR is the overall geopolitical risk index, GPRA and GPRT are the acts and threats components of the GPR, and MCI is the media coverage index of the coronavirus disease. The OVX, VIX, GPR, GPRA, and GPRT were assessed using natural logarithmic forms.

connectedness levels ( $jTCI$ ) during various event periods, such as the last quarter of 2008 and early 2009, May 2010, March 2020, February–June 2022, and August 2023.

Overall, we find that varying forecast horizons do not compromise or impact our results, thereby ensuring robustness. Hence, our conclusions are not restricted by the choice of estimation parameters in the connectedness model, or the choice of the connectedness model used.

#### 4.4. Drivers of extended joint TCIs

Identifying the key drivers of the Total Connectedness Index (TCI) in recent periods is crucial for investors, portfolio managers, and policy-makers when making currency trading and regulation decisions. In this section, we model the determinants of high spillovers among the forex rates of sub-Saharan African countries.

The two-stage methodology employed in our study was designed to provide a comprehensive and nuanced understanding of the interconnectedness of and idiosyncratic risks found in sub-Saharan African forex markets. The initial spillover analysis focuses on the interconnectedness within sub-Saharan African forex markets, identifying the intrinsic relationships and idiosyncratic risks specific to the region. This first stage ensures that global factors do not confound the analysis, thus providing a clearer picture of internal market mechanisms.

In the second stage, we examine the impact of global variables such as geopolitical risk (GPR), economic policy uncertainty (EPU), and market volatilities (VIX, OVX). This separation allowed us to specifically assess how these external factors influenced the interconnectedness identified in the first stage. By doing so, we can determine how much global shocks affect regional forex markets without conflating these effects with the intrinsic regional dynamics.

This approach ensures methodological consistency with the existing literature, enhances analytical precision by avoiding potential multicollinearity issues, and provides actionable insights for both policymakers and investors. Policymakers can understand regional dynamics independently of global influences, enabling them to design targeted interventions. Investors benefit from a clearer understanding of how global shocks interact with regional market conditions, which aids in better risk management and investment decisions.

Following Zhang et al. (2023), we examine the impacts of key sentiment drivers on the  $jTCIs$ . Specifically, we assess the role of geopolitical risk (GPR, including acts – GPRA and threats – GPRT; Caldara & Iacoviello, 2022), economic policy uncertainty (EPU), volatility of the US stock market and economy (VIX), crude oil market volatility (OVX), and the COVID-19 media coverage index (MCI). Given the recent rise in African forex markets in the wake of the pandemic and data comparability, we use a sample period from January 2020 to August 2023. We employed Ordinary Least Squares (OLS) and Quantile Regression (QR) methods to model the TCI determinants. We discuss the OLS results in this section (Table 5) and present the QR results in the Annex (Table A1).

While the exchange rates analyzed were measured against the U.S. dollar, we did not include the U.S. Dollar Index (DXY) in our model. Since our primary focus was to highlight idiosyncratic risks and interconnectedness within the SSA forex markets, including DXY could overshadow country-specific factors by introducing a global variable

that might have diluted the focus on domestic influence. Additionally, our approach follows the methodology of Zhang et al. (2023), ensuring consistency with existing literature and comparability with other studies. Moreover, our study emphasizes the subsample period from January 2020 to August 2023 (see Figs. 2–5 and their discussions). This time interval reflects the unique economic conditions driven by the pandemic, and including DXY may introduce additional complexity. Our use of robust statistical techniques, such as OLS and QR, allow us to capture the influence of key sentiment drivers without the need for DXY. The selected sentiment drivers are specifically relevant to the sub-Saharan African context, making them more pertinent to our analysis.

The OLS model shows that OVX, VIX, USEPU, GPR, GPRA, GPRT, and MCI explain 49.7% (57.8%) of the return (volatility)  $jTCI$  among the sub-Saharan African forex markets in the full post-pandemic era. GPR and MCI significantly and negatively influenced the return  $jTCI$ , whereas OVX, VIX, USEPU, and GPRA positively influenced the return TCI. These factors also influence volatility, but the effects tend to be opposite for the VIX, GPRA, and MCI. These results align with those across the left tail of the data distribution (see Table A1 in the Appendix). Similar results are observed for the period before the Russia-Ukraine military conflict. However, during the Russia-Ukraine conflict era, OVX primarily drove the volatility  $jTCI$ , but its effect on the return  $jTCI$  was not statistically significant. Here, geopolitical risk threats (GPRT) emerged as strong drivers of return  $jTCI$ . The mixed effects suggest that GPR, USEPU, MCI, VIX, and OVX asymmetrically drive return and volatility connectedness among the SSA forex markets. Recognizing these factors is vital for market regulation and currency trading.

## 5. Discussion

This section discusses the practical significance of these findings. We discuss how these results can influence investment decisions, guide portfolio management, shape policy formulation, and market regulations, and pave the way for future research.

This study examines the interconnectedness and idiosyncratic risks in sub-Saharan forex markets from 1999 to 2023. In terms of investment decisions, the key drivers of the Total Connectedness Index (TCI) that we identified, including geopolitical risk, economic policy uncertainty, volatility in the US stock market, the crude oil market, and COVID-19 media coverage, have significant implications for investors. These drivers can help investors anticipate potential shifts in forex markets. By understanding these dynamics, investors can make informed decisions and adjust their investment strategies accordingly. For portfolio managers, these insights can be instrumental in effectively diversifying their portfolios. The interconnectedness of the sub-Saharan African forex markets and the factors driving this connectedness can help portfolio managers better manage risk and optimize returns. By considering these factors, portfolio managers can build more resilient and profitable portfolios. Understanding the factors that drive the connectedness of forex markets can help policymakers anticipate potential market disruptions and implement policies that mitigate their impacts. Moreover, the results suggest that the drivers of return and volatility connectedness between sub-Saharan African forex markets are asymmetric. This finding underscores the need for robust market regulation mechanisms

that respond to these asymmetric drivers. The documented findings serve as an early warning indicator for similar crises in the future, stressing that the role of innovations within individual sub-Saharan African forex markets should not be underrated.

Our findings have significant implications for various stakeholders in forex markets. By understanding the key drivers of forex market connectedness, stakeholders can make informed decisions, manage risk more effectively, and contribute to the stability and growth of forex markets. The findings also provide a foundation for future research on the dynamics of forex markets, particularly in sub-Saharan Africa. Future studies could explore other potential market-specific drivers of forex connectedness and examine their implications for investors, portfolio managers, and policymakers. Moreover, we reveal significant idiosyncratic risk in numerous sub-Saharan African forex markets. This discovery emphasizes the need for policymakers in sub-Saharan Africa to concentrate on domestically generated market innovations when formulating their forex policies rather than consistently attributing issues to external shocks. Consequently, our study highlights the need for further research to identify the specific factors in various sub-Saharan African economies that lead to the substantial propagation of self-innovation (shocks).

## 6. Conclusion

This study explores the interconnectedness and idiosyncratic risks in sub-Saharan African forex markets from the 1999–2023 period. Our dataset includes the daily foreign exchange (forex) rates of nine African economies: Botswana, Ghana, the Ivory Coast, Kenya, Mauritius, Namibia, Nigeria, South Africa, and Zambia. Using the TVP-VAR extended joint connectedness technique of [Balcilar et al. \(2021\)](#), we gauge the average extended joint connectivity and dynamic extended joint connectivity. Regarding the former, an important insight from the results reveals that their self-induced shocks profoundly impact a substantial portion of sub-Saharan African forex markets, while the South African Rand and Namibian Dollar stand as exceptions. Regarding dynamic extended joint connectivity, we observe that the joint total connectedness index (JTICI) for return spillovers among the sub-Saharan African economies ranges between 26% and 46%. It exhibits a significant increase of more than 42% at the beginning of the Russia–Ukraine military conflict. Regarding volatility spillovers, we find that the magnitude of the time-varying  $j$ TICI ranges between 32% and 71%, which is consistently higher than its return counterpart, and that volatility  $j$ TICI exhibits more fluctuations than returns.

In addition, we report the results of net directional extended joint connectedness in both the return and volatility domains. In the context of return spillovers, the Mauritian Rupee, South African Rand, Namibian Dollar, and Kenyan Shilling emerge as the primary net recipients among sub-Saharan African forex rates. Conversely, the Botswanan Pula and CFA franc of the Ivory Coast stand out as significant transmitters. The remaining forex rates, namely Cedi (Ghana), Kwacha (Zambia), and

## Annex.

Naira (Nigeria), typically oscillate between the roles, particularly during ongoing geopolitical tensions. Regarding volatility dynamics, all forex markets aggressively switch between these roles, reflecting the turbulent nature of forex markets in general. Therefore, our findings highlight the importance of analyzing volatility spillovers alongside return spillovers. These compelling results have crucial implications for managing and coordinating policies across emerging sub-Saharan African markets.

Moreover, we explore the drivers of extended-joint TCIs. We observe mixed effects, which suggest that GPR, USEPU, MCI, VIX, and OVX asymmetrically drive return and volatility connectedness among the SSA forex markets. Recognizing these factors is vital for market regulation and currency trading.

Our results help build a base for further studies on forex market behavior, particularly in sub-Saharan Africa. Future research could address other external factors that may influence forex market connectedness and explore their implications for investors, portfolio managers, and policymakers. Importantly, our study uncovers substantial idiosyncratic risks in the sub-Saharan African forex markets. This finding implies that policymakers in sub-Saharan Africa should urgently concentrate on domestically generated market innovations when formulating their forex policies rather than consistently attributing issues to external shocks. Our study also has several implications for the diverse forex market participants. By comprehending the key drivers of forex market connectedness, these market players can make informed decisions, manage risk more effectively, and contribute to forex market stability and growth.

Moving forward, future contributions to this research field should focus on modeling the drivers of exchange rate volatility in emerging markets, in general, and sub-Saharan African markets, in particular. In such a model, it is recommended that country-level indicators and risk factors be modeled to probe the contributors to self-driven innovations in sub-Saharan African economies.

## CRediT authorship contribution statement

**Mariya Gubareva:** Conceptualization, Investigation, Methodology, Formal analysis, Data curation, Resources, Writing – original draft, Writing – review & editing, Validation, Project administration, Visualization. **Vincent Adela:** Conceptualization, Investigation, Methodology, Formal analysis, Validation, Writing – original draft, Writing – review & editing, Visualization. **Xuan Vinh Vo:** Conceptualization, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Validation, Visualization.

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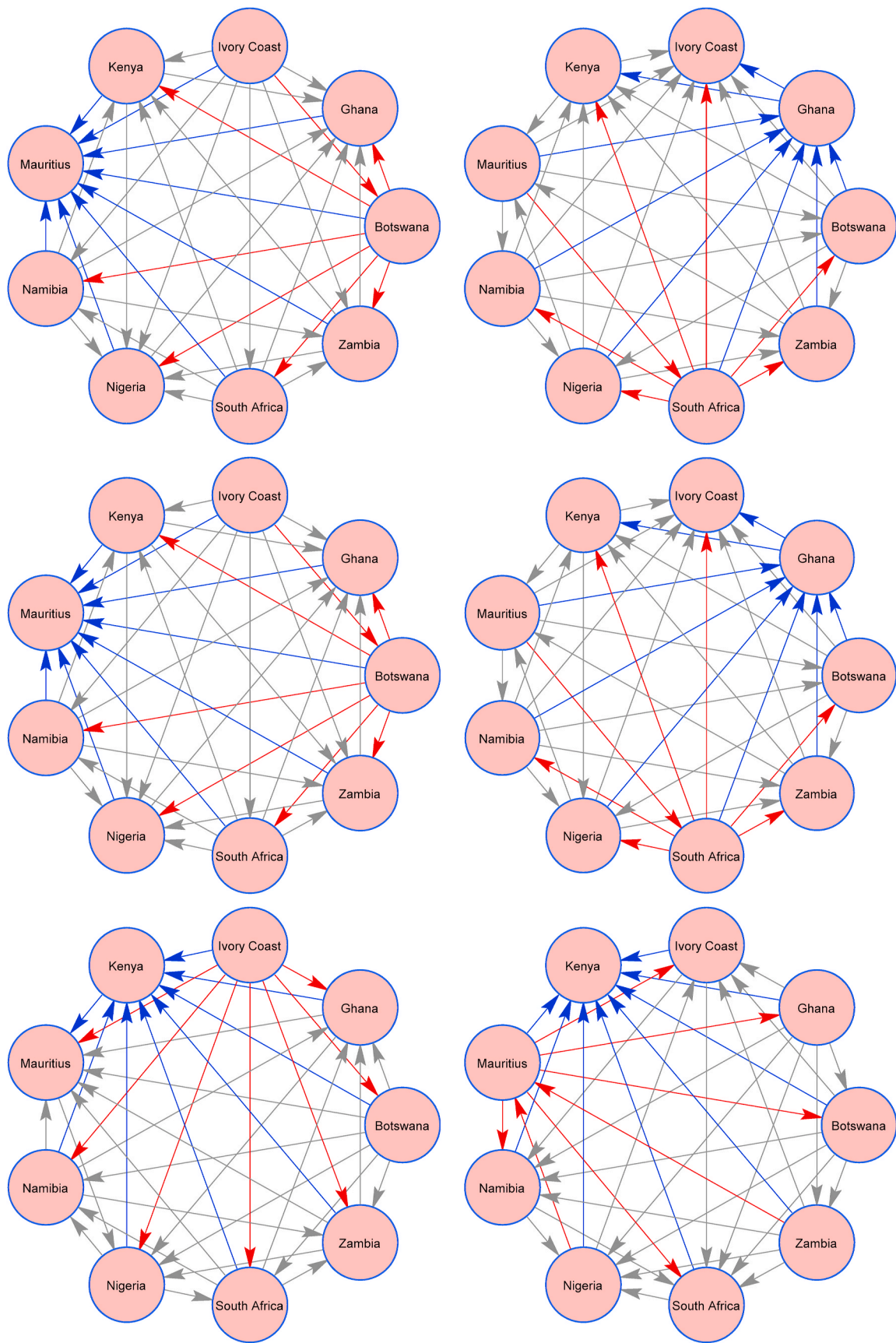


Fig. A1. Extended joint FX rate return and volatility connectedness network.

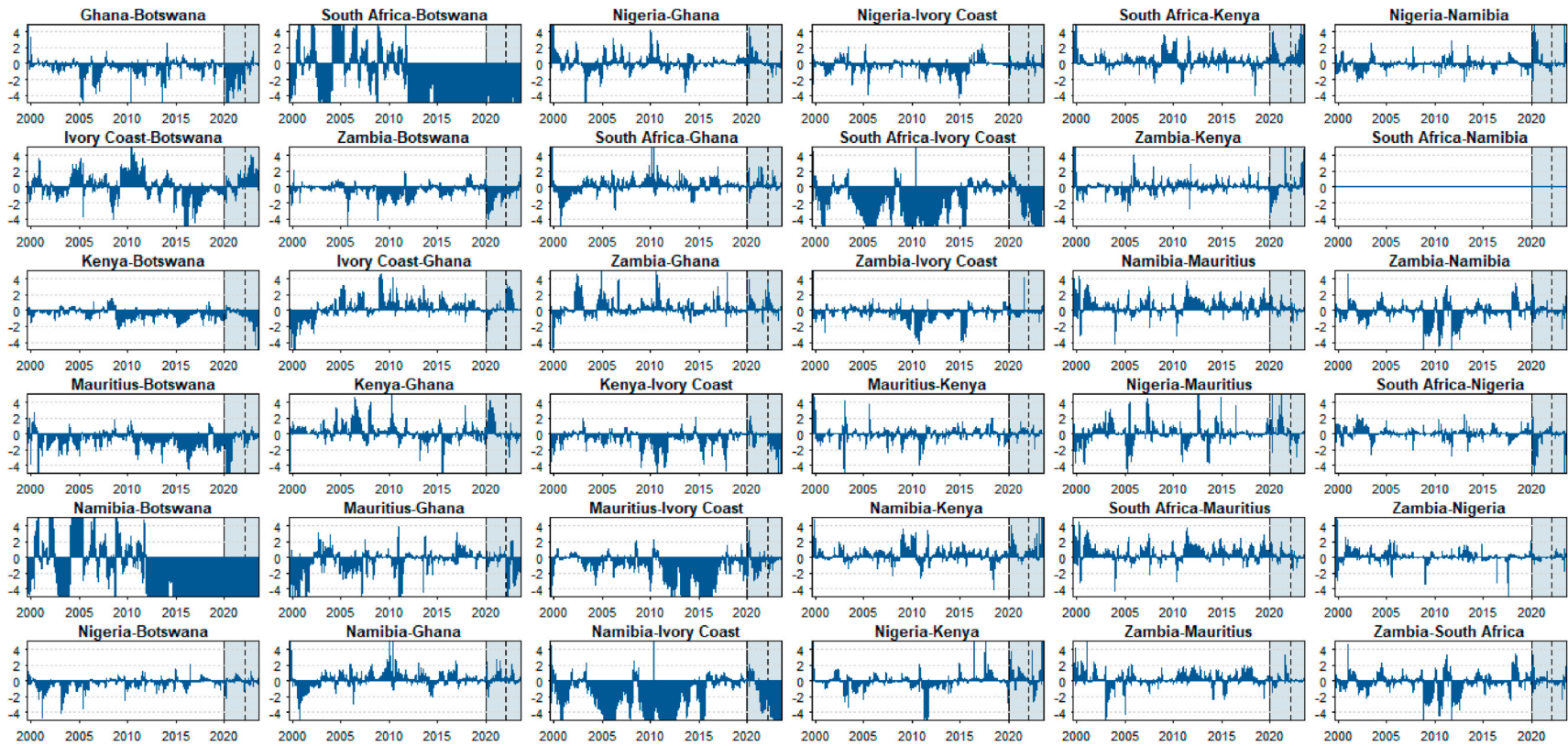
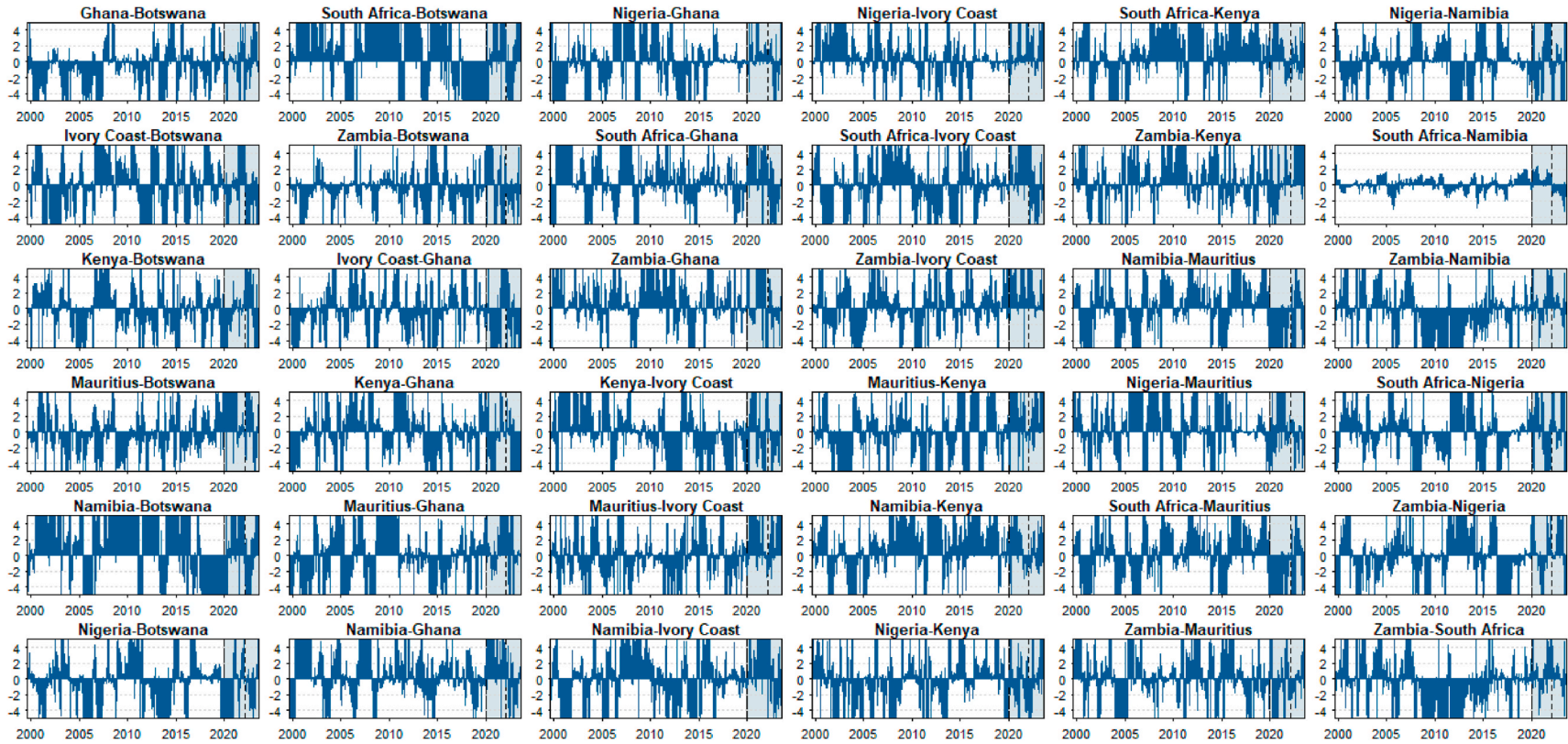


Fig. A2. Dynamic pairwise joint FX rate return connectedness of sub-Saharan African markets. Notes: The black dotted vertical line in the graph represents the onset of the Russia-Ukraine period, while the entire light-greyish-blue-shaded region covers both the COVID-19 pandemic and the geopolitical conflict periods.



**Fig. A3.** Dynamic net joint FX rate volatility connectedness of sub-Saharan African markets. Notes: The black dotted vertical line in the graph represents the onset of the Russia-Ukraine conflict, while the entire light-greyish-blue-shaded region covers both the COVID-19 pandemic and the geopolitical conflict periods.

Table A1

Quantile regression estimates: Drivers of return and volatility connectedness of sub-Saharan African forex rates.

Variables	$\theta = 0.05$		$\theta = 0.25$		$\theta = 0.75$		$\theta = 0.95$	
	$\hat{J}TCI$ return	$\hat{J}TCI$ volatility	$\hat{J}TCI$ return	$\hat{J}TCI$ volatility	$\hat{J}TCI$ return	$\hat{J}TCI$ volatility	$\hat{J}TCI$ return	$\hat{J}TCI$ volatility
OVX	1.379*** (0.222)	2.097** (0.957)	2.700*** (0.296)	2.052*** (0.625)	2.034*** (0.419)	3.796*** (0.904)	2.770*** (0.327)	7.103*** (1.413)
VIX	0.572** (0.241)	-2.736*** (1.038)	0.689** (0.321)	-3.218*** (0.678)	1.288*** (0.454)	-4.536*** (0.980)	-0.145 (0.354)	-5.667*** (1.532)
USEPU	0.002*** (0.001)	0.004* (0.002)	0.001** (0.001)	0.009*** (0.001)	0.006*** (0.001)	0.020*** (0.002)	0.004*** (0.001)	0.020*** (0.003)
GPR	-0.438 (0.419)	0.748 (1.806)	0.648 (0.558)	1.308 (1.180)	-1.596** (0.790)	0.713 (1.706)	-0.844 (0.616)	0.613 (2.665)
GPRA	0.276** (0.117)	-0.612 (0.506)	-0.175 (0.156)	-0.882*** (0.330)	0.362 (0.221)	-0.978** (0.478)	0.229 (0.173)	-0.534 (0.747)
GPRT	0.099 (0.301)	-0.155 (1.297)	-0.941** (0.401)	-1.318 (0.847)	0.568 (0.567)	-1.307 (1.225)	0.421 (0.442)	-1.059 (1.914)
MCI	-0.065*** (0.003)	0.204*** (0.014)	-0.076*** (0.004)	0.141*** (0.009)	-0.151*** (0.006)	0.082*** (0.014)	-0.145*** (0.005)	0.053** (0.021)
Constant	29.017*** (0.670)	27.233*** (2.892)	27.092*** (0.893)	37.879*** (1.889)	34.342*** (1.265)	43.386*** (2.731)	35.207*** (0.986)	36.021*** (4.267)
Observations	883	883	883	883	883	883	883	883
Pseudo R <sup>2</sup>	0.305	0.229	0.306	0.400	0.357	0.392	0.341	0.510

Notes: The table presents the quantile regression estimates of the drivers of the extended joint volatility connectedness between the daily forex rates of nine African economies—Botswana, Ghana, Ivory Coast, Kenya, Mauritius, Namibia, Nigeria, South Africa, and Zambia—measured against the U.S. dollar from August 27, 1999, to August 22, 2023. OVX is the implied volatility of crude oil, USEPU is the policy uncertainty of the US economy, GPR is the overall geopolitical risk index, GPRA and GPRT are the acts and threats components of the GPR, and MCI is the media coverage index of the coronavirus disease. The OVX, VIX, GPR, GPRA, and GPRT were assessed using natural logarithmic forms.

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