UNIVERSITY OF CAPE COAST

GLOBAL ASSET CLASSES AND EQUITY MARKETS' RETURNS IN AFRICA

AHMED BOSSMAN

2022

UNIVERSITY OF CAPE COAST

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BY

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Thesis submitted to the Department of Finance of the School of Business, College of Humanities and Legal Studies, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Commerce degree in Finance

JULY 2022

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature …… Date ……

Name: Ahmed Bossman

Supervisor's Declaration

I hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Supervisor's Signature …… Date ……

Name: Dr Samuel Kwaku Agyei

ABSTRACT

Although newly-created alliances between African economies and top-emerging markets may stimulate economic growth, the tendency to deepen integration across African markets could render African markets less resilient to global shocks as they are known. Notwithstanding, the financial market meltdown occasioned by the COVID-19 outbreak has resulted in intense commodity market volatility for which market participants in Africa have been cautioned about its persistence. Motivated by investors' relentless search for safety assets and the ripple impact of the recent trade liberalisation in Africa, this thesis examined the interdependence, spillover connectedness, and information transfer between returns on global commodity classes and African equity markets. Hinged on available and comparable data, the research employed daily datasets – equity (Egypt, Ghana, Ivory Coast, Kenya, Malawi, Morocco, Namibia, Nigeria, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe) and commodity (cocoa, coffee, copper, corn, crude oil, gold, natural gas, palladium, palm oil, rice, sugar, and soybeans) market indices – spanning from 22nd February 2010 to 4th February 2022. The findings from the study underscored high interdependence between commodity and African equities in the short term with idiosyncratic and contagious return spillovers. The effective transfer entropy results suggested high uncertainties with commodity-African equity investments although the markets are efficient in the medium-and-long-term horizons. Regulators should deploy vibrant measures that could limit the creation or transmission of shocks across markets. Portfolio managers should deploy effective risk management strategies that capitalise on the changing roles of some assets as diversifiers, hedgers, and safe-havens across time horizons.

KEYWORDS

African equities

Asset classes

Diversification

Dynamic connectedness

Effective transfer entropy

Spillovers

ACKNOWLEDGEMENTS

This Master's thesis was completed under the discerning supervision, compassion, and prompt guidance of my supervisor, Dr Samuel Kwaku Agyei [CA] (Senior Lecturer, Department of Finance, University of Cape Coast). Being my mentor and supervisor, words may insufficiently describe how grateful I am for your unwavering support throughout my academic path after National Service and the inexorable effort you contributed towards the completion of this thesis. I would forever appreciate your fatherly support and most importantly for introducing me to peer-reviewed research publications. I wish for you the eternal blessings of God Almighty and pray that you are granted good health and strength.

With a sincere heart, I am thankful to Professor Anokye Mohammed Adam (Professor of Finance, Department of Finance, University of Cape Coast) and Dr Peterson Owusu Junior (Lecturer, Department of Finance, University of Cape Coast) for their encouragement throughout the master's programme. Your initiative that led to the further development of my research abilities has been fruitful. May your efforts be replenished by God Almighty.

I extend a heartfelt appreciation to my parents – Mr Saeed Bossman and Hajia Rakia Pinto, two of my sisters – Rahmat Bossman and Khadijah Bossman, and my brother and his wife, Ing. Frank Kwofie Pinto and Mariam Mahmud Pinto, for their invaluable prayers and support. I especially acknowledge the support and encouragement of Dr Munirat Odanyi throughout the master's programme. To all those who have made contributions towards my academic path until now, whose names have not been mentioned here, I say thank you and may God Almighty replenish you with goodness.

DEDICATION

To my family

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LIST OF ACRONYMS

AEMs	African Equities Markets
AfCFTA	African Continental Free Trade Area
AMH	Adaptive Markets Hypothesis
AHME	Alternative Hypothesis to Market Efficiency
CAT	Comparative Advantage Theory
CMH	Competitive Markets Hypothesis
COVID-19	Coronavirus Disease 2019
EMH	Efficient Market Hypothesis
GAC	Global Asset Classes
GFC	Global Financial Crisis
HMH	Heterogeneous Markets Hypothesis
MPT	Modern Portfolio Theory
SIFT	Situated Information Flow Theory
TCI	Total Connectedness Index
TVP-VAR	Time-Varying Parameter Autoregressions
UNECA	United Nations Economic Commission for Africa
WAMZ	West African Monetary Zone

CHAPTER ONE

INTRODUCTION

In recent decades, the attraction of significant private capital flows to the real sector of economies has been integrated into the development strategy of African economies, leading to the formation of several alliances among countries in the region or its sub-regions. These alliances have resulted in arrangements on, among others, the West African Eco currency within the West African Monetary Zone (WAMZ) slated for launch in 2027, the African Free Trade Zone, and on top of all, the African Continental Free Trade Area (AfCFTA), which commenced in January 2021. To a large extent, on the one hand, these alliances are directed toward enhancing economic growth and development and boosting investor confidence in the region. On the other hand, however, these alliances would probably intensify integration among African markets, and investors may be indisposed to African investments. This, in turn, could lessen the resilience of African markets to global shocks. A resilient real sector is essential to boosting investor confidence and facilitating the growth of the macroeconomy.

Background to the Study

For sustained economic growth, economic and/or market blocs, as well as regional and/or geographical blocs need to pay attention to the advantages they possess. The Chinese and Malaysian economies, for instance, have upper hands in terms of the cost of the basic labour force; the Japanese and the US economies have technological advantages. In the case of Africa, most countries have advantages over essential commodities (United Nations Economic Commission for Africa [UNECA], 2021) which are traded on the global stage,

and serve as a major contributor of income to the African continent. The forerunning argument bears principles that are reminiscent of the comparative advantage theory (CAT), which relays that multinational corporations (MNCs) could penetrate African markets to tap immovable advantages (Madura, 2018).

Given that other regional and/or market blocs are more integrated with the global financial market than African markets, the comparative advantage possessed by African economies could be inferred. Although high reliance on commodities results in poor indications of human development across developing markets (Karingi, 2021), effective and efficient management of such advantages in Africa would promote international trade, which would generate high capital flows through direct foreign investments for the region as a whole. The CAT does not stress overreliance on advantages; rather, it fosters trade among economic blocs such that economies should specialise in what they hold advantages for, after which exchange could be facilitated through cross-border trade (Madura, 2018). From another breadth of the CAT, MNCs may move to settle in foreign countries to tap into their advantages (resources or technologies). Through this channel, MNCs achieve low production costs, which result in increased profitability and firm value for investors, as well as increased capital flow between economies which, to a larger extent, could contribute towards poverty reduction.

While sub-Saharan Africa (SSA) witnessed a rise in private capital flows in the early 21st Century, the sub-region experienced declines following the emergence of the 2008/09 global financial crisis (GFC), which was attributable to amplified levels of risk aversion among investors, stringent international credit conditions, and the bond markets' development (Boako, Alagidede, Sjo,

& Uddin, 2020; Boako & Alagidede, 2016). Intercontinental investors' indisposition to consider African investments as desirable surrogates could also account for the post-GFC downturn (Boako et al., 2020). Uncertainties surrounding the generation of higher projected recompenses in Africa have been a key issue in the continent's failure to attract handsome flows from portfolio investment.

Although investors are somehow indisposed to African investments owing to the above reasons, they are not debarred from a continuous search for alternate assets that could help them achieve overriding portfolio objectives, as addressed by the modern portfolio theory (MPT) (Markowitz, 1952). This search by investors has led to the financialisation of several asset classes, which represent a group of assets with similar underlying economic properties and have distinguishing qualities that isolate them from other assets belonging to different classes (Greer, 1997). According to Markowitz (1952), investors are faced with conflicting portfolio objectives – maximisation (minimisation) of yields (risks) and this ought to be incorporated in portfolio allocation decisions. In the spirit of the MPT, the marginal risks from an asset or asset class introduced to a portfolio must be outweighed by the accompanying returns.

Through the combinations of separate assets and/or asset classes, this overriding objective may be achieved by investors and explains why their search for safe assets in Africa continues despite the risky nature of African investments. Also, given that theoretically, African equities markets (AEMs) could shield against global economic shocks (Asafo-Adjei et al., 2020; Boako et al., 2020; Boako & Alagidede, 2016), international investors keep on their search for assets and/or asset classes that could offer the diversification, safe-

haven, and hedging opportunities across their investment horizons. Aside from faith-based investments, commodities and equities from emerging markets serve as a preference for international portfolios. Therefore, when paid attention, resilient AEMs could additionally be a source of attracting substantial amounts of capital flows into the African region. This might have been ignored by regulators of African economies.

With the intense commodity financialisation that is gradually making commodities bear similar characteristics to traditional assets like stocks and bonds (Idilbi-Bayaa & Qadan, 2021), there could be some comparative advantages for African markets to attract increased capital flows given that their stock market returns are less integrated with tradable commodity markets, particularly those that are financialised. Notable asset classes that have been financialised vis-à-vis commodities resulting from investors' search include precious metals, softs, grains, meats, and energies (National Association of Securities Dealers Automated Quotations [NASDAQ], 2021).

Commodities form 'superclasses' from which various asset classes emerge (Greer, 1997) and the uniqueness of these asset classes lies in the difficulty in replicating their returns by simple linear blends of equities and other assets like bonds and real estate. Notably, the increasing financialisation of commodities stems from the merit that they are inversely related to stocks and bonds, but have positive connections with inflation, as Mongars and Marchal-Dombrat (2006) proved earlier in their study using data from the US financial markets. This resulted in their conclusion that returns on commodity-based investments are susceptible to similar anomalies in the yields on other asset classes.

Mongars and Marchal-Dombrat (2006) further contend that investor responses to abnormal commodity price volatilities are contingent on their investment timescale and the extent of diversities in their portfolios. Anomalies in commodity prices may largely result from financial market turmoil which means that given the series of financial crises experienced globally in the 21st Century, asset classes are most likely susceptible to unexpected volatilities (Umar, Gubareva, & Teplova, 2021c; Umar, Jareño, & Escribano, 2021e). During the GFC for instance, the sum of commodity index-based assets acquired by institutional investors soared from a $15 billion estimate in 2003 to not less than $200 billion in 2008 (Tang & Xiong, 2012). This suggests that not only are individual investors essential players in commodities markets, but institutional investors also play a key role in such markets.

Suffice to say, therefore, that the African economy would grow if the region realises more capital inflows by attracting international investors, both individual and institutional, into its markets (Bossman, 2021). Thus, portfolio creation could be a vital strategy that African economies could adapt. This strategy could complement their fundamental strategy for attracting capital flows to boost the growth rate of the constituent economies and the continent as a whole. By so doing, not only would the extended and rapid economic growth contribute to bridging the gap between developed and developing economies, but it would also contribute toward poverty reduction in the region through a boost in overall economic activity.

Aside from the relations with China, Africa's recent growth prospect is heightened through the build-up of new alliances with top-developing economies like India, Russia, and the UAE. These new ties are projected to be

critical, subject to the trade tensions between the US and China, and the policy uncertainty in the UK by virtue of the Brexit dialogues (Fokuo & Ochieng, 2020). Moreover, recent developments in the region in the likes of the AfCFTA and other factors – such as the enlarged visa openness and monetary policy coordination via the innovative Eco currency of the WAMZ – could result in the integration of markets within the region and this is unsafe for investors vis-à-vis portfolio diversification.

With these new developments, AEMs are expected to be more integrated than before, owing to the financial market integration theory (Shadlen, 2005). Furthermore, given these contemporary arrangements among African states, financial markets liberalisation and extended volumes of cross-border transactions are envisaged, which collectively results in an increased flow of financial assets between and within market blocs and subsequently expanding investment opportunities. The preceding argument stresses the international portfolio investment theory (Bartram & Dufey, 2001), which suggests that due to integrated markets, financial assets from emerging markets would be more accessible to investors across the globe. Not only would these alliances contribute to the growth of the international market, but they would also foster the economic growth of the African continent.

Fokuo and Ochieng (2020) describe the recent alliances of Africa and other nations as 'an inception of 21st Century alliances for Africa,' as against a century of 'scramble' for other regional blocs or individual states. Although on the one side, this may result in some comparative advantages for Africa, which is significant to economic growth in the region, the consequences on investment portfolios cannot be sidelined. Moreover, the ramifications of the turbulent

trading periods initiated by several episodes of financial crises in recent decades cannot be downplayed, as they have discerning impacts on several markets across the globe. A trajectory of some selected commodity (Figure 1) and equity (Figure 2) indices suggest a volatile period for both broad markets.

The indices largely depict an upward trend for commodities whilst equity indices plummet during notable crisis periods such as the 2014 Russian market turmoil, the Brexit era and the Chinese market crash in 2016, and the systemic crisis occasioned by the COVID-19 pandemic in 2020. These developments in African equities and global commodities cast doubts on the existing credence of the resilience of African equity and global commodity markets. Furthermore, just as AEMs stand the chance of high integration, commodities markets in Africa are projected to be detrimentally affected by the novel coronavirus disease 2019 (COVID-19), as cautioned by Karingi (2021). Collectively, these factors are liable to impact the relative resilience of AEMs and the African economy as a whole.

AEMs must bear diversification, hedging, and safe-haven properties to attract all classes of international investors to patronise investments in the continent, but international investors stand the chance of being indisposed to such investments because high levels of market integration expel diversification benefits between equities markets (Baur & Lucey, 2010). When markets are integrated, shocks to one market are highly transmittable to other markets and this results in positive correlations between markets or assets, rendering diversification inexpedient.

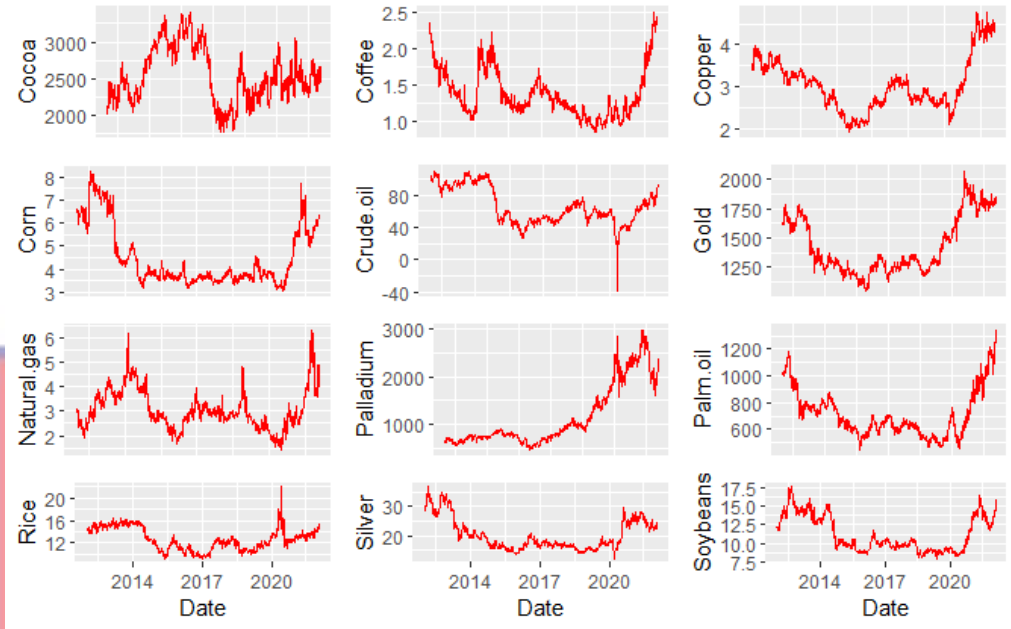


Figure 1: Trajectory of Selected Global Commodity Indices
Source: Estimations based on data from EquityRT (2022).

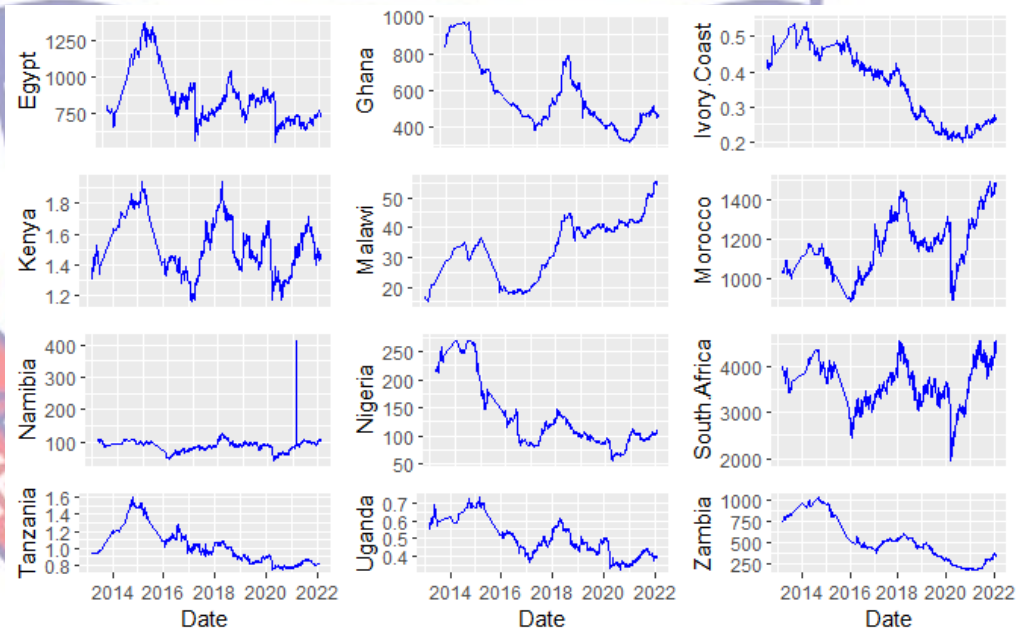


Figure 2: Trajectory of Selected African Equity Indices
Source: Estimations based on data from EquityRT (2022).

Therefore, in a period full of systemic crises, empirical assessments of the connectedness of AEMs and global asset classes (GACs) – which are mostly dominated by commodities – are not trivial. This brought to light the propulsion of this study, to examine the dynamic interrelations between the returns on global asset classes and African equities markets.

Statement of the Problem

Recent episodes of financial crises have caused several repercussions to international markets, motivating investors to create novel diversification opportunities (Bossman, Agyei, et al., 2022; Owusu Junior et al., 2021). Distressed economic conditions impact stock market performance via the flow of information to investors, which then influences investor behaviour. It is through this channel that information flow also affects asset prices (Fama, Fisher, Jensen, & Roll, 1969). Fama (1970, 1998), through the efficient market hypothesis (EMH), contended that markets are expected to be efficient with any given information such that, asset prices (and returns) wholly reflect prevailing information in the market and so no trader could benefit from a transaction based on the available information. Meanwhile, Mongars and Marchal-Dombrat (2006) divulged that investors respond to commodity price and yield anomalies based on their investment time scale and the degree of diversification.

The preceding argument corroborates the homogeneous markets hypothesis (HMH) (Müller et al., 1993) and the adaptive market hypothesis (AMH) (Lo, 2004), and further suggests that empirical works on the subject matter need to integrate multiscale analysis to ensure that the true relationships are revealed for the assets to aid efficient portfolio creation and management (Boako et al., 2020). Under the HMH, market participants analyse current and past news after which they exhibit diverse investment responses contingent on their risk-return preferences (Bossman, Agyei, et al., 2022; Müller et al., 1993; Owusu Junior et al., 2021). The AMH also suggests that owing to events and structural variations, markets are created with diverse efficiencies in differing horizons (Bossman, Agyei, et al., 2022; Lo, 2004).

In a more simplistic hypothesis, the rational and irrational investor attitudes are argued to be dependent on states of nature and individual investors. This argument is contrary to the EMH but captures both the HMH and AMH, resulting in the "alternative hypothesis to market efficiency" (AHME) (Cornell, 2018). Common to all these hypotheses is the intuition that market participants are heterogeneous; yet, they embark on a series of searches for safe assets that could shield their investments during turbulent trading periods like the one occasioned by the COVID-19 pandemic. According to Owusu Junior et al. (2021), owing to rational yet irrational investor attitudes, this search escalates in crisis periods, causing increased spillovers and information flows, and this is what is termed the competitive market hypothesis (CMH).

Suffice to say, empirical investigations centred on financial-based assets must not only employ sufficiently high-frequency data such as daily or weekly, but also fitting methods that account for complexities in investor behaviour and yet produce non-biased and detailed results for reliable asset allocation and investment decisions. The role of international portfolio management in the growth of financial markets cannot be overemphasised, but within the African domain, knowledge about the interrelations between African equities and global commodities is scanty. Existing works fail to assess the extent to which African markets could capitalise on portfolio management to boost capital flows into the continent and they also fail to situate their study in the context of the AMH, HMH, AHME, and the CMH (Boako & Alagidede, 2021, 2016; Boako et al., 2020; Kablan, Ftiti, & Guesmi, 2017).

Three main weaknesses are common to the existing studies. First, they fail to employ the available high-frequency data. High-frequency data such as

daily and weekly stand the chance of revealing detailed and significant market dynamics relative to mid-and low-frequency data such as monthly, quarterly, and annual datasets (Asafo-Adjei, Adam, & Darkwa, 2021). Studies that employ medium-to-low frequency (e.g., weekly, monthly, etc.) data stand the chance of missing important information structures in the market as would have been otherwise revealed by high frequency (daily or intraday) data. Sufficiently high-frequency data is essential to generating findings that corroborate the AMH, HMH, AHME, and CMH, as recent studies advocate in the context of asset pricing and returns.

Second, the methods employed in these studies fail to completely account for investor complexities. It is worth noting that heterogeneous cross-market dynamics – as revealed by earlier works on the connection between commodity and traditional financial markets – are traceable to the asymmetric, nonlinear, nonstationary, and noisy properties of financial economics time-series (Adam, Gyamfi, Kyei, Moyo, & Gill, 2021; Kristoufek, 2013; Kumar & Raj, 2022). These features of financial time series partly explain why the degree, shape, and direction of variables' linkages have been long understood by economists to be timescale-dependent. Unlike in the past when methods to demarcate economic datasets into all orthogonal timescale constituents were lacking, techniques are presently available. Thus, the instruments to cater for noise, which is usually transitory to economic data series, are accessible in present times (Bossman, 2021; Bossman, Agyei, et al., 2022), but have been ignored in the existing studies.

Third, spillover connectedness and information flow between GACs and AEMs have not been incorporated in the extant studies; neither during the

previous financial crises nor during the COVID-19 pandemic era. Knowledge about the connection between the returns on global commodities and African equity markets during pandemics and systemic crises is non-existent in the literature. Strategic asset and policy management hinges on knowledge about cross-market linkages (Diebold, Liu, & Yilmaz, 2017; Zaremba, Umar, & Mikutowski, 2021a). Moreover, in the spirit of the EMH, no study uses transfer entropy to examine the efficiency levels of equity and commodity markets, particularly in the African domain. These aspects of the empirical analysis are of great significance not only for time-based international investors but also for strategic market regulation to attract capital flows through international portfolio management which could, to a large extent, help in poverty reduction and bridge the gap between developed and developing economies.

Existing studies leave the aforementioned gaps to be filled and, as such, this study employed a multiscale analysis of the time-varying interdependence, connectedness, and information flow between returns on African equities and global asset classes.

Purpose of the Study

This study investigated the multiscale dynamic interdependencies, spillovers, and situated information flow between returns on African equities and global asset classes.

Objectives of the Study

Specifically, the study sought to:

1. examine the dynamic interdependencies between returns on African equities and global commodities.

2. investigate the spillover connectedness between returns on African equities and global commodities in a unified system.
3. analyse the flow of information between returns on African equities and global commodities.

Research Hypotheses

Based on the level of knowledge in the extant literature, the following hypotheses were tested in the study:

1. H_{01}: there is no significant dynamic interdependence between returns on African equities and global commodities.
2. H_{02}: there is no significant spillover effect between returns on African equities and global commodities.
3. H_{03}: there is no significant information flow between returns on African equities and global commodities.

Significance of the Study

This study provides significant contributions to the body of knowledge in several ways. First, with the emergence of several episodes of financial crises, investors are presented with emerging surrogates to construct diversified investment portfolios. The study's empirical investigations yield wide-ranging evidence concerning the safe-haven, hedging, and diversification prospects of several commodities and equities. In-depth knowledge – which provides details of any diversification prospects – vis-à-vis the nature and extent of the connectedness between AEMs and the international economy is indispensable for African and international investors to discover and profit from such potential intercontinental portfolio investment flows and diversification possibilities.

Second, by empirically determining whether AEMs could offer reliable channels for cross-border portfolio investors, the results from this study should provide rigorous answers to analyse questioning themes such as the potential of AEMs for attracting substantial portfolio investment flows amid harsh global commodities market conditions; whether African equities are viable in providing hedging, safe-haven, and/or diversification benefits in times of global commodities price uncertainties and volatilities. A frontier regional bloc like Africa had limited or no answers to these concerns. Hence, the timelines of this study cannot be overemphasised, as wide-ranging analytical results are provided by this research. Indicatively, the study's focus on the African continent is not a misplaced priority given that the findings of this study suggest some potential comparative advantages to which African regulators could pay attention.

Third, financial and economic data series such as those related to stocks and commodities are nonlinear, asymmetric, and non-stationary due to fat tails (Owusu Junior, Tiwari, Tweneboah, & Asafo-Adjei, 2022). This suggests that noise in the market may present complex conditions to investors when ascertaining the driving factors of a data series' trend and whether volatilities in trends are attributable to fundamental dynamics or they are merely temporal fluctuations in the short term. Given these limitations, data decomposition is surely a useful approach when financial data series are employed in empirical investigations. Consequently, this study decomposed the data series on both equities and commodities to show equities and commodities markets participants' various investing time horizons, which are commensurate with the HMH, AMH, AHME, and CMH. Thus, this is the first study to incorporate investor complexities in analysing the connections between AEMs and GACs.

Fourth, the study employed novel methods to help produce unbiased results over the short-, intermediate-, and long-term periods. The improved ensemble empirical mode decomposition with adaptive noise (ICEEMDAN) was employed together with the effective transfer entropy approach to quantify information transfer between AEMs and GACs. The application of these novel methodologies did not only help to determine how African equities and global commodities observed each other across different states of nature and economic or trading horizons, but also facilitated the examination of the efficiency levels of the studied markets which are essential for time-based investors.

Furthermore, the study utilised a strand of the wavelet approaches, the "vector wavelet coherence" (VWC), which produced multiple, quadruple, and *n*-dimensional VWC for multivariate time series. Previous studies were limited by the econometric approach to adopt for multiple time series when assessing their degree or power of interdependence. The multiple and quadruple wavelet coherence techniques fall short of the number of variables to be examined. Without any such limitation, the VWC was beneficial in this regard. Moreover, connectedness is better measured using spillover dynamics between assets such that how the risks of the assets are related could be determined, which aids in proactive portfolio planning and asset allocation. Hence, the new spillover index approach designed by Antonakakis, Chatziantoniou and Gabauer (2020) was employed to estimate the dynamic spillover connectedness of AEMs and GACs. This study is the first to utilise these methods in the context of GACs and AEMs.

Finally, through several novel approaches, the outcome of this study provides essential guides for portfolio construction and management. Investors, both individual and institutional, could be reliably informed of cross-market

connectedness, which also gives essential information for governments and policymakers regarding the regulation of local, regional, or international trade to facilitate reliable management of assets and funds. More importantly, the estimation procedures covered different time horizons, which makes the study's findings particularly relevant for time-based investors, policymakers, and practitioners since they are offered evidence across both time and frequency domains (short-, mid-, and long-term). Through strategic assessments of comparative advantages, regulators in Africa could rely on the findings of this research to supplement their fundamental strategy for attracting capital flows and boosting growth in the continent. The direct and indirect means of reducing poverty through this strategy cannot be shelved.

Delimitation

This study assessed the multiscale interlinkages between the returns on African equities and global asset classes. In terms of the African equities, the study employed the daily stock market indices for African equities exchange markets with available and sufficient data for achieving the study objectives. With the global asset classes, this study was delimited by four major commodity classes viz. precious metals, softs, grains, and energies. These groups follow the classifications of (NASDAQ, 2021). For precious metals, the specific assets included gold, silver, palladium, and copper; cocoa and coffee for softs; corn and soybeans for grains; crude oil and natural gas for energies; palm oil was also analysed but under an isolated classification. The study period – predicated by data availability – fell from 22nd February 2010 to 4th February 2022.

Limitations

Despite the essential and unique contributions to the body of knowledge, this study suffered some limitations as follows. Not every African market was studied due to the unavailability and inaccessibility of stock market data for some countries. This means that essential diversification, safe-haven, and hedging benefits possessed by those countries were unrevealed by the study. Also, missing values were borne by the data series for some countries with available data, leading to a cut in the length of the dataset and this might have constrained the outputs generated and subsequently impacted the conclusions in this study. Notwithstanding the aforementioned limitations, needless to say, careful estimation procedures were followed to mitigate the effect of these limitations on the outcome of the study.

Organisation of the Study

Four more chapters were added to the introductory chapter of this study. The second chapter presented a systematic synthesis and critique of theories and the findings from related works. A detailed description of the methods employed in the conduct of the study was presented in the third chapter, with the fourth chapter detailing the results and their discussion. The fifth chapter summarised the study by highlighting the main findings, important conclusions, and appropriate recommendations, not leaving out directions for future studies.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This study covered a multiscale analysis of the dynamic interrelations between global asset classes (GACs) and African equities markets (AEMs). To substantiate and advance the need for this study, there was the need to examine, synthesise, compare, and contrast existing works in the field. This ensured that unique and substantial contributions were made to the body of knowledge. This Chapter presented comparative reviews on theories and hypotheses, concepts, and the findings from existing studies.

Theoretical Review

Three theories – the modern portfolio theory (MPT), the interdependence theory, and the information flow theory – were fundamental to this study. These were all essential to the study because they directly related to financial markets and more specifically, the studied variables (equities and commodities). Of the three theories, the central theory that cuts across the three distinct research objectives was the MPT. The interdependence theory, specifically, helped to explain and hypothesise the interdependence structure of global commodities and African equity markets' returns. By aiding in quantifying information transfer, the information flow theory extended support to the third research objective and hypothesis. The second research objective and hypothesis were centrally based on the MPT since spillover connectedness of asset returns is central to asset allocation and international portfolio management. Highlights of the theories and how they connect to the study were explained as follows.

Modern portfolio theory (MPT)

The MPT posits that investors are disposed towards the maximisation (minimisation) of expected return (variance) produced by their portfolios (Markowitz, 1952). Under the tenets of the MPT, investors are more concerned with the net marginal contribution of new assets to their portfolios, suggesting that the input of a financial asset to investment portfolios is valued more than the risks associated with the asset (Asafo-Adjei, Owusu Junior, & Adam, 2021; Bossman, 2021; Bossman, Agyei, et al., 2022). Thus, the financial asset's covariance with the portfolio's other assets becomes a concern in this regard (Rubinstein, 2002). In the confines of this study, investors are expected to react to dynamics in the commodities markets especially when there seem to be lucrative trading patterns and once essential market players participate in the trade of commodities, commodity prices may stabilise (Boako et al., 2020). This is not far from stock markets also.

Therefore, the application of the MPT in this study helped to stress and assess the contribution of financial assets – specifically, commodities and equities – to investment portfolios. The study analysed the likelihood for investments in both commodities and stocks to yield safe-haven, hedging, and diversification advantages across different timescales.

Interdependency theory

A direct linkage between two or more assets describes interdependence. For the sake of simplicity, the study assumed two assets or markets: commodities and equities. For interdependence to prevail, a change in market dynamics for one asset or market is directly translated to the other. The channel and degree of change between the markets, in this regard, are largely

comparable due to the common characteristics shared by the markets (Rosecrance et al., 2015). The authors document two forms of market interdependence – horizontal and vertical. Horizontal interdependence defines the size of transactions between two markets in terms of the movement of goods, funds, etc. whereas vertical interdependence represents the relative response of economies to movements in prices of factor inputs. As horizontal interdependence relates to the flow of funds between markets, it was most suitable for this study.

It is worthy of notice that the interdependency theory, to a large extent, captures both the financial market integration and international portfolio theories stressed by Shadlen (2005) and Bartram and Dufey (2001) respectively. That is, the interdependency theory is substantiated by financial market integration and international portfolio theories. First, through the integration of financial markets, economies are linked and alliances between economies increase (Doyle, 1997), which several governments aim to maintain. Second, through the international portfolio theory, the flow of funds between financial markets is easily facilitated due to similar trading values and norms (Polachek, 1980). The aforementioned are all in line with horizontal interdependence.

Rosecrance et al. (2015) posit that horizontal interdependence implies connectedness. Therefore, this study employed the theory of interdependence, precisely, horizontal interdependence to assess the connectedness between returns on commodity classes and African equities. This aided in explaining how investors move funds from one asset or market (say equities) to the other (say commodities) for diversification, safe-haven, and hedging benefits.

Information flow theory (IFT)

With credits to Dretske's (1981) philosophy and Pearl's (2009) statistics, Benthall (2019) engineered the situated IFT (SIFT), suggesting that information flows represent causal flows situated in the premise of other causal connections (Bossman, Agyei, et al., 2022). Thanks to the mathematical applications of probability and statistics, quantification of the flow of information between variables is possible. If we could count on any relationship between two random variables such that one variable could study the state of the other by means of observation, then such a relationship is grounded on mutual information the variables share (Benthall, 2019). In the context of commodities and equities, the trading volumes, price volatilities, and investor sentiments are examples of mutual information shared by the African equity and global commodity markets (Bossman, 2021; Bossman, Agyei, et al., 2022).

The above principles substantiate the SIFT and, hence, in this study, the theory helped to analyse how various commodities and African equities observed each other across different timescales. The application of the SIFT in the context of this study facilitated the assessment of the efficiency levels of the studied markets and whether or not investments in one market (say commodity) pose high or low uncertainty for investments in the other (say African equities).

Conceptual Review

After explaining the relevance of essential theories and their application in this study, essential concepts were reviewed to define what they mean and how they were applied in context. The fundamental essential concepts, per this study, include asset classes and asset allocation. These concepts were reviewed in this section.

Asset class

Greer (1997) defined an asset class as a group of assets that share similar underlying economic characteristics and have distinct qualities that isolate them from other assets that do not belong to that class. An asset class, according to Mongars and Marchal-Dombrat (2006) is any security: that provides yields in excess of the yields on risk-free securities; whose yields may either have low or no correlation with those of other asset classes; whose yields may not be reproduced through 'ordinary' linear combinations of other securities. It is worthy of notice that assets with differing betas or those with historically low correlations may not necessarily constitute asset classes in and/or of themselves relative to those that have high correlations (Greer, 1997). Low betas may only reflect that they are from distinct market sectors of specific domestic equities.

Distinguishing between asset classes

Concerning the constituents of asset classes, it is essential for financial managers to distinguish between assets themselves and derivative instruments whose values are derived from the underlying asset. Therefore, stock options and commodity futures, whose values are respectively derived from underlying physical stocks and commodities, do not constitute asset class in themselves at the broadest level (Greer, 1997). According to Greer, we could point out three general asset classes namely capital assets, consumable or transformable (C/T) assets, and store of value (SOV) assets, which Greer termed as 'superclasses.' Each superclass yields traditional asset classes and groups. This study defined each superclass as follows:

Capital assets

Generally, a capital asset represents a continuous source of something of value. Financial capital assets are those assets whose value would decline (flourish) when investors' rate of discount increases (reduces). For capital assets, their value/worth is generated by discounting the expected cash flows associated with them (i.e., they are valued based on their net present values (NPVs)) (Greer, 1997). It is this economic feature that ensures the unification of the superclass of capital assets. Examples of capital assets include stocks, bonds, real estate, foreign stocks, foreign debt, etc.

Consumable/transformable (C/T) assets

C/T assets are those assets with economic worth but do not yield a continuous stream of value and they could both be consumed or converted into another asset (Greer, 1997). Basic examples of C/T assets include energy products, grains, metals, etc. These assets cannot be valued based on the NPV analysis since they do not possess continuous cash flow streams.

Store of value (SOV) assets

SOV assets are those assets that can neither be consumed nor could they generate income; notwithstanding, they have a value (Greer, 1997). E.g., currency, and fine art (sculpture), among others. It is worth noting that the classification gets distorted at times. Gold, for instance, could be C/T and at the same time an SOV asset. Real estate investment trusts (REITs) could also have exceptions.

Commodities as an asset class

The energy sector's contribution to commodities indices is primarily responsible for the strong annualised commodities returns over time (Mongars

& Marchal-Dombrat, 2006). Unlike the returns on stocks and bonds, returns on commodities typically rise during inflationary periods. In addition, together with commodity futures, funds tracking aggregated commodity indices provide diversification based on the stage of the business cycle. Traditionally, returns on commodities have been higher in the late expansion stages of the business cycle and have consistently been positive in early recession or economic slowdown phases; on the other hand, stock returns have been strongly unfavourable (negative) in early recession periods of the business cycle. Thus, commodities share negative relations with equities and bonds but positive connections with inflation. On this premise, Mongars and Marchal-Dombrat (2006) concluded that commodities are an asset class in and/or of themselves.

Relationship between asset classes

It seems difficult to replicate the returns produced by commodity-based investments with ordinary linear combinations of other securities (Baur & Lucey, 2010). Using weekly and quarterly datasets and applying different combinations, Mongars and Marchal-Dombrat (2006) found no significant linear relationship between commodities and other assets. This explains why a linear combination of returns on assets like stocks (S&P500), bonds (10-year US T-bonds), and housing prices (office of federal housing enterprise oversight (OFHEO) index) could not replicate the returns on commodities (proxied by the Goldman Sachs commodity index (GSCI)) when examined by Mongars and Marchal-Dombrat. To check for the robustness of this finding, the GSCI was replaced with other composite commodity indices but did not modify the existing conclusion (that it may be difficult replicating the returns on

commodity-related investments). This, thus, substantiated their conclusion that commodities are an asset class on their own.

Commodities are classified into sub-groups, which include precious metals (e.g., gold, silver, palladium, and copper), softs (e.g., cocoa and coffee), grains (e.g., corn and soybeans), energies (e.g., crude oil and natural gas), and meats (e.g., live cattle, feeder cattle, lean hogs) (NASDAQ, 2021). In this study, commodities that fall under metals, softs, grains, and energies are used since they are those that African countries make significant production or export.

Asset allocation

The decisions on the fraction of a portfolio that would be exposed to volatilities in the values of specific asset classes, as well as the decisions on whether the exposure should be positive or negative are classified under asset allocation (Greer, 1997). Allocating assets strategically is an essential decision for portfolio managers for two reasons. First, a proactive approach to investment decisions would facilitate the selection of asset classes that have the potential to gain or yield additional or excess worth over the investment horizon. Second, even when a passive approach to investment decisions is employed by portfolio managers, a strategic asset allocation would be effective in resulting in a controlled diversification, which is expected to curtail the volatilities of the portfolio.

Empirical Review

Interdependence between global asset classes and equities

In ascertaining whether or not commodities constitute an asset class in their selves, Mongars and Marchal-Dombrat (2006) combined commodities – proxied by the GSCI – with stocks, bonds, and real estate (housing), proxying

them by the S&P500, 10-year US T-bonds, and the OFHEO index, respectively, with weekly dataset covering the period between 1959 and 2003. It was revealed that in the long-term, commodity-based investments produced better yields than risk-free-based investments, making them an asset class on their own. Mongars and Marchal-Dombrat divulge that commodities tend to have either no or low linkage with other assets and/or asset classes, meanwhile, their linkage with inflation proves positive. Mongars and Marchal-Dombrat also document that mere linear combinations of other assets and/or asset classes may not succeed in replicating the returns offered by commodities. The authors employed a quarterly dataset to test the same relationships and the robustness of their results was corroborated.

In exploring the relative prospects of African stocks to offer investors hedging and diversification benefits against international commodities, Boako and Alagidede (2016) employed daily data from January 01, 2003, to December 29, 2014. The authors employed the dynamic conditional correlation-based generalised autoregressive conditional heteroscedasticity (DCC-GARCH) estimator. Their findings divulged that some African equities and international commodities are non-linearly related, such that the reactions of commodities investors toward investment opportunities in African equities differ across market conditions. Boako and Alagidede document that the inclusion of African equities could increase (reduce) expected returns (variance) on an investor's portfolio. Their findings corroborated Mongars and Marchal-Dombrat's conclusions. However, the study failed to reveal the market dynamics of the studied variables given that they share mutual information, as Benthall's (2019)

SIFT suggests. Besides, the studied commodities were limited to gold, platinum, oil, cocoa, and silver.

Kablan et al. (2017) employed an evolving co-spectral analysis to examine the time-variant dynamic linkage between financial distress and commodities with a monthly dataset covering the period 1980-2014 for commodity exporters in Africa. Their results divulged that when shocks to commodities prices persist, the real economy is highly negatively impacted relative to when shocks to commodities markets are temporary. Significant commodity-specific results were also reported by Kablan et al., where they revealed strong coherency among agricultural inputs and beverages (oil and metals) during bearish (bullish) trading periods. The work of Kablan et al. (2017) failed to account for the Brexit period, which was a significant event in the history of financial markets (David, 2016). The study also failed to show the applicability of the EMH and other hypotheses across timescales; only exporting countries were considered, but intuitively, countries to whom the production of commodities is a substantial economic activity – but do not export – would also be indirectly impacted by price shocks.

Under the wavelet paradigm, two follow-up studies to the work of Boako and Alagidede (2016) were undertaken by Boako et al. (2020) and Boako and Alagidede (2021), both of which examined the time- and frequency-domain linkages between commodities and stock markets using a daily dataset from February 1996 to February 2018. The findings of both Boako et al. (2020) and Boako and Alagidede (2021) suggested a cointegration possibility between commodities and African equities after they sparsely co-move through the multiscale. Their findings (Boako & Alagidede, 2021; Boako et al., 2020), in

corroborating the earlier results of Boako and Alagidede (2016), suggested that a portfolio that contains a mix of commodities and African stocks perform better across different timescales. These studies failed to account for information flow between commodities and African stocks to reveal how the assets observe each other given that there is a mutual information between them (Benthall, 2019).

Demirer et al. (2015) contribute to the contentions surrounding the financialisation of commodities when they extended the test of the herd behaviour to the market for commodity futures under a regime-switching framework. They examine the herd behaviour in commodity classes such as grins, energy, livestock, and metals using daily data from 17 January 1995 to 30 November 2012. Among the sectors studied, the herd behaviour was found significant in grains only during extreme volatility periods. Between equities and commodities, no significant impact of equities markets on the herd behaviour of commodities futures markets was revealed, suggesting that the financialisation hypothesis was unsupported in their study. Thus, Demirer et al.'s (2015) findings failed to corroborate those of other studies (Boako & Alagidede, 2021, 2016; Boako et al., 2020; Kablan et al., 2017; Mongars & Marchal-Dombrat, 2006) whose findings divulged significant evidence for the financialisation of commodities.

Situated in the United States, Bekiros et al. (2016) examined the nexus between commodities and US equities by analysing the risk-return profitability of the assets across timescales in a wavelet approach. The dataset employed was monthly frequency covering the period January 1990 to October 2013. Their findings divulged that across various time horizons, the coherence between equities and commodities varies, although causality between the two assets was

established. These findings were similar to what Boako and Alagidede (2021, 2016), Boako et al. (2020), and Kablan et al. (2017) reported but contrary to the main conclusion of Demirer et al. (2015). The study does not cover recent episodes of financial crises such as the ones occasioned by Brexit, the US-China trade tension, and the COVID-19 pandemic.

By focusing on how commodity prices evolve, Rossi (2012) reports that per out-of-sample analysis, the stock returns of a commodity-exporting economy significantly predict future commodity prices or indices. Rossi employed a quarterly dataset between 1980 and 2008 (up to the first quarter) covering stocks from Australia, Canada, New Zealand, South Africa, and Chile. The findings of Rossi were robust to the use of control variables and firm-level stock data. Rossi's findings suggested that exchange rates better predict commodity prices relative to stock markets, particularly at high frequencies (i.e., the short term). Rossi's research failed to cover the 2008/09 GFC, which could have revealed a better picture to global investors concerning the prospects for hedging, safe-haven, and diversification of their portfolios amid financial crises. Thus, the conclusions drawn may not apply in recent times where several episodes of systemic crises have been witnessed by the global economy.

Olson (2014) investigated the linkage between the energy and equities markets using the multivariate BEKK framework. Olson employed a weekly dataset covering the period from January 1, 1985, to April 24, 2013. Volatility impulse response functions were computed using the energy index of Goldman Sachs and the S&P500 as well as the dynamic correlations across diverse timescales. Olson's results indicated that low returns on S&P500 drive a significant increment in the energy index's volatility although the volatilities in

S&P500 had a weak impact on the volatility of the energy index. Olson concluded that, generally, the energy index serves as a poor hedge for stocks proxied by the S&P500. This study suffers from the aforementioned limitations such as failing to cover recent financial crises, which bear distinct characteristics from earlier ones (Quinsee, 2021; Umar, Trabelsi, & Alqahtani, 2021).

Evidence from the above-reviewed works indicates some significant interdependencies between global asset classes and equities. To empirically examine this position in the context of Africa and various commodity classes, the study hypothesised as follows:

H_{01}: there is no significant dynamic interdependence between returns on African equities and global commodities.

H_{A1}: there are significant dynamic interdependencies between returns on African equities and global commodities.

Spillovers between global asset classes and equities

The existing literature on spillovers in the context of African equities is largely scarce relative to other markets. This strand of works emphasises the dynamic connectedness between commodity classes and equities. When the TVP-VAR estimator was employed for the volatility and return series of precious metals amid the COVID-19 pandemic-induced global panic indices, the findings of Umar, Aziz, et al. (2021) evidenced silver's resistance to global shocks whiles the risk reduction roles of palladium and platinum were reported time-varying. With datasets on oil price shocks and agricultural commodities, Umar, Gubareva, et al. (2021) examined their volatility and return connectedness across the period between January 2002 and July 2020. Their

findings – from the dynamic spillover index approach – divulged peaked connectedness in notable crisis periods such as the Global Financial Crisis, the European Sovereign debt, and the financial market meltdown in the era of the COVID-19 pandemic.

The findings of Umar, Gubareva, et al. (2021) were similar to those reported by Umar, Jareño, et al. (2021) who investigated the return and volatility linkages between crude oil and agricultural commodity markets under the TVP-VAR connectedness measure. Ahmed and Huo (2021) examined the transmission of volatility across global markets for oil, commodity futures, and stocks by focusing on the Chinese case. The tri-variate VAR-BEKK-GARCH technique was employed. The authors reported a one-way causal influence from stock and oil markets to principal commodity markets in China. The authors concluded that there exists a high dependence of Chinese stocks on the oil market.

Bouri, Lei, Jalkh, Xu and Zhang (2021) the dynamics of spillovers between strategic commodities and equities from the US. The TVP-VAR model was employed by the authors on datasets covering the period 11th April 2006, to 29th April 2019. The authors revealed that spillovers are responsive to time and stressed market events. In their assessment of the spillover dynamics between the studied markets, the authors emphasized the sampled data's jumps, kurtosis, and skewness. For the realised volatility and kurtosis, stocks were found as the main transmitter of spillovers but for realised skewness and jumps, the primary net transmitter was found to be oil.

To ascertain the optimization that could be made from the spillovers between agricultural commodities and global equities, Hernandez, Kang and

Yoon (2021) analysed the degree of asset allocation and risk/returns reduction characteristics of agricultural commodities and global stocks. Through the spillover connectedness approach, the authors revealed that global equities transmit the most spillovers to cocoa and cotton. They further found sugar (cocoa) as the highest (lowest) contributor to portfolio risk. the authors recommended lumber and cocoa for safe investments and diversification advantages.

Findings from the above-reviewed works, which are largely from the international perspective, indicate that spillovers between markets or assets could be used to ascertain the risk reduction roles of such assets. Hence, to ascertain the degree of spillovers between global asset classes and African stocks, this study hypothesised that:

H_{02}: there is no significant spillover effect between returns on African equities and global commodities.

H_{A2}: there are significant spillover effects between returns on African equities and global commodities.

Information transfer between global asset classes and equities

Two main strands of works on commodity-stock nexus discourse on the dynamic interrelations between commodity classes only (Tiwari, Umar, & Alqahtani, 2021; Umar, Aziz, & Tawil, 2021a; Umar, Gubareva, Naeem, et al., 2021b; Umar, Jareño, & Escribano, 2021d; Umar, Zaremba, & Olson, 2020) and/or between commodities and traditional assets (like equities and exchange-traded funds (ETFs)) (Esparcia, Jareño, & Umar, 2022; Naeem, Umar, Ahmed, & Ferrouhi, 2020; Umar, Trabelsi, & Zaremba, 2021f). Undoubtedly, these works have been motivated fundamentally by high volatility in commodity

markets and the issue of commodity financialisation, which still lingers in the empirical literature (Zaremba, Umar, & Mikutowski, 2021b).

Specifically, in the first strand of works that examine the dynamic interdependencies between commodities classes, Tiwari et al. (2021) examined long memory's persistence in petroleum and crude products from which the authors underscored weak (strong) efficiency in energy spot (Diesel Fuel) markets, with Propane lacking efficiency. Using the Generalised Hurst exponent method, the import of their study was the emphasis on the appropriateness of a dynamic model rather than static estimators. By employing datasets spanning over seven centuries, Umar et al. (2020) identified high coherence between agricultural, energy, and industrial commodity groups. The authors stressed the leading role of energy across the time domain.

From the second strand of works, which evaluated the dynamic interrelations between commodity classes and other asset classes, Naeem et al. (2020) examined the linkages between commodities and ETFs in a GARCH-based framework. Specifically, the authors explored the heterogeneous dependence between ETFs and crude oil. The findings emphasised the conclusions held by the first strand of works on commodity classes in the recent literature. Umar, Trabelsi, et al. (2021) investigated the link between crude oil shocks (risk, demand, and supply shocks) and equity markets of BRICS and GCC. The authors reported that the connectedness between oil shocks and equities is averagely moderate, but measured high in the COVID-19 pandemic era. They emphasised the high influence of oil exporters' equities in their volatility connectedness with oil shocks. Esparcia et al. (2022) revisited the safe haven attribute of gold in a time-frequency paradigm covering the COVID-19

era. The basis for the study was to examine the role of gold in an equity-dominated portfolio using hybrid wavelet- and GARCH-based approaches. They added to the second strand of works by examining the cross-linkage between commodities and other asset classes (i.e., equities) from BRICS and G7 markets.

It is worth noting that the two main strands of works on commodities and other asset classes are influenced partly by the recent strand of works which encompasses the literature focused on investigating the financialisation hypothesis and the plausible consequences to commodity-dominated or multi-asset portfolios (Cheng, Xiong, & Hall, 2013; Demirer et al., 2015; Tang & Xiong, 2012; Zaremba et al., 2021b). Notwithstanding, the existing evidence is devoid of the links between African markets and global commodities. In terms of asset allocation, African stocks and global commodities are surrogates for foreign investors. Portfolio benefits for international portfolio management would very certainly be wiped out if African stocks were to become integrated during the financialisation of global commodities.

In the African context, Boako and Alagidede (2021, 2017) examined the connectedness of commodity and equity markets with a focus on their comovements whereas Kablan et al. (2017) focused on the link between commodity exporters' credit and commodities. From their analysis, these works draw no knowledge concerning the efficiency levels of commodity and equity markets. Thus, from the existing literature, the issue of market efficiency (through information transfer) between commodity and equity markets is yet to be attended to. To provide evidence from the African context, this study

examined the information flow dynamics between African equities and global commodity classes and hypothesised as follows:

H_{03}: there is no significant information flow between returns on African equities and global commodities.

H_{A3}: there is significant information flow between returns on African equities and global commodities.

Research Gaps Filled by this Thesis

Indeed, with the interesting revelations made from the empirical review, some limitations need to be overcome through the conduct of new empirical studies on the underlying subject. None of these commodity-equity studies, per the extant literature thus far, account for information flow, nor do they examine spillovers to reveal the nature of interdependence and/or contagion between the markets. Interdependence between equities and commodities, as identified by some works, needs to be explained further whether it results from fundamental linkages or market shocks, as explained by Forbes and Rigobon (2001, 2002). Such interdependence may be well-classified as contagion in line with the extant literature on financial contagion if there is a significant change in the linkage structure between markets (assets) after one of them experiences shocks (Forbes & Rigobon, 2001, 2002; Owusu Junior, Alagidede, & Tweneboah, 2020).

Besides, there have been new episodes of financial crises that are yet to be covered by the empirical literature to test and confirm or disprove the applicability of fundamental market dynamics between the two assets per the conclusions of earlier studies. The COVID-19 pandemic has introduced persistent exogenous shocks to financial markets (Bossman, 2021; Bossman, Agyei, et al., 2022; Quinsee, 2021), and per Kablan et al.'s (2017) conclusion

that the real sector suffers more effects when shocks are persistent, there is the need to re-visit the equities-commodities phenomenon using appropriate techniques and sufficiently high-frequency data. Suffice to say, therefore, that new studies are required to fully account for investor complexities and information flow within financial markets.

Furthermore, it is important to note that knowledge about the cross-market connectedness, as applied to African equities and global commodities is non-existent in times of pandemics. As this systemic crisis persists, knowledge about the linkages between these markets is vital for market regulation, asset allocation, and international portfolio management. Such knowledge could further influence the strategy employed by the African economies to attract capital flows into the continent. Suffice to say, therefore, that this thesis focused on investigating a timely issue.

Methodologically, the appropriateness of quantifying information flow using the transfer entropy approach has been underscored in the recent literature (Adam, Gyamfi, et al., 2021; Agyei, Owusu Junior, Bossman, & Arhin, 2022; Asafo-Adjei, Owusu Junior, et al., 2021; Bossman, 2021; Bossman, Agyei, et al., 2022; Owusu Junior et al., 2021). Furthermore, knowledge of cross-market connectedness has been proven to be a key input for effective asset allocation, risk management, and policy formulation (Aharon, Umar, & Vo, 2021; Antonakakis, Chatziantoniou, & Filis, 2017; Antonakakis et al., 2020; Antonakakis, Chatziantoniou, & Gabauer, 2021; Diebold et al., 2017; Owusu Junior, 2020; Owusu Junior, Alagidede, et al., 2020; Umar, Jareño, & Escribano, 2021e; Umar, Riaz, & Zaremba, 2021b, 2021a; Umar, Yousaf, & Aharon, 2021). Therefore, studies need to integrate spillover linkages between

equities from African markets and global commodities to aid the effectiveness of international policies that affect cross-markets including Africa.

As a result, this thesis employed the newly robust connectedness approach (i.e., time-varying parameter vector autoregressions (TVP-VAR) connectedness measure) proposed by Antonakakis et al. (2020), which overcomes the limitations of earlier approaches from Diebold and Yilmaz (2009, 2012, 2014) and Baruník and Křehlík (2018). Furthermore, in terms of assessing integration, the study further resorted to the novel technique, the vector wavelet coherence (VWC) of Oygur and Unal (2020), which gives room for assessing the interdependence structure between multiple time series in a unified system without limiting the number of variables. Existing works that restricted the number of assets or markets to study as a result of the absence of methods are limited on this front as well. This research overcomes the limitations of existing works by employing several novel techniques.

Heterogeneous cross-market dynamics are traceable to the asymmetric, nonlinear, nonstationary, and noisy properties of financial economics time-series (Bossman, 2021; Kristoufek, 2013; Kumar & Raj, 2022; Owusu Junior et al., 2021) and they partly explain why the degree, shape, and direction of variables' linkages have been long understood by economists to be timescale-dependent (Ramsey & Lampart, 1998). Unlike in the past when methods to demarcate economic datasets into all orthogonal timescale constituents were lacking, techniques are presently available. Thus, the instruments to cater for noise, which is usually transitory to economic data series, are accessible in present times (Bossman, 2021; Bossman, Agyei, et al., 2022; Owusu Junior et

al., 2021). Existing studies had failed to appropriately deal with tailed and noisy data which could impact their findings and conclusions.

Therefore, based on the outlined issues of commodity market volatility and financialisation, and the plausible integration of AEMs, this thesis tested the efficiency of global commodity and African equity markets' returns in novel Econophysics approaches of decomposition-based transfer entropy. Specifically, this thesis employed the improved form of the complete ensemble empirical mode decomposition with adaptive noise (ICEEMDAN)-based Rényi effective transfer entropy to examine information transfer between African equities and global commodities across different investment horizons. Through these approaches, several shortfalls associated with the existing studies were overcome by this thesis.

Chapter Summary

This study encompasses a multiscale analysis of the dynamic links between commodity classes and African equities. After examining, synthesising, comparing, and contrasting existing works in the field, the study found gaps that warrant new research to employ novel techniques and also cover contemporary episodes of financial crises to corroborate or disprove what the extant literature has suggested is fundamental to the relationship(s) between African stocks and international commodities. This Chapter presented comparative reviews on theories and hypotheses, as well as concepts, and the findings from existing studies, which was concluded with the research and knowledge gaps to be filled by this study. The approaches that were employed in this study to overcome the weaknesses identified are outlined and discussed in the next Chapter.

CHAPTER THREE

RESEARCH METHODS

Introduction

In the previous Chapter, theories, hypotheses, as well as concepts, were reviewed together with the findings from the extant literature, which revealed gaps that needed to be given attention. The methods and/or approaches employed in this study to contribute to filling the identified gaps were presented in this Chapter. The Chapter covered a presentation on the study philosophy, the design, and the approach of the study. The units of analysis and mode of data collection were also defined in this Chapter. Moreover, statistical processing, estimation techniques, and the means of analysing gathered data together with ethical considerations were also highlighted in this Chapter.

Research Paradigm

The study adopted the positivist philosophy of research due to the aim it held. Positivism was employed to offer explicit and accurate information to the relevant users of this study. This philosophy is ideal because the conclusions and generalisations that were made from the hypotheses upheld by the study were at least backed by rigorous empirical computations which are devoid of subjectivity in any form. Under this philosophy, findings are more apparent and quantifiable (Wilson, 2014). Given that the magnitude of spillover connectedness and information flow were examined in this study, there was no ideal philosophy other than the positivist philosophy.

Research Approach

This study adopted the quantitative research approach. In this study, the application of the quantitative approach to research aided the adoption of

arithmetic and statistical procedures to test hypotheses (Creswell, 2014; Creswell, Hu, & Chang, 2017). The quantitative approach was deemed appropriate because the study investigated how one variable influences or predicts another variable. This study examined the interdependence structure, spillovers, and information flow between commodities and African equities; therefore, the influence of one variable on the other was assessed. Thus, a quantitative research approach was deemed more essential to this study.

Research Design

The study employed the explanatory design in analysing the interrelations between global commodity classes and African equities. The explanatory research, per this study, provided the extent to which one variable influenced the other (Zikmund, Babin, Carr, & Griffin, 2013). The explanatory design was relevant to this study because the study placed emphasis on the analysis of a situation or a specific problem to explain the patterns of relationships between the returns on global commodity classes and African equities.

Units of Analysis

In arriving at the units of analysis for this study, a gradual approach was followed. First, the study focused on African equities and their interrelationships with global commodities; hence, all African equities were deemed prospective units of analysis. Second, the study investigated which commodities are predominantly produced and/or exported by African countries. The premise was that, if commodities are principally produced or exported by a country, then at least a materially significant portion of the GDP or capital flow of such a country is contributed by such commodity(ies) (Kablan et al., 2017).

Finally, the identified countries and the commodities they commensurate with were selected to be examined. Thus, African countries that deal in (by substantially producing or exporting) commodities and also have available data on equities markets served as the units of analysis in this research.

Source and Mode of Data Collection

Data were gathered from the datahub of EquityRT, a licensed data repository for financial and economic variables. As identified, to qualify as a unit of analysis, An African country needed to be among the top producers and/or exporters of selected commodities, as well as have a stock market that has available data over the studied period. After the list of countries was ascertained, data were gathered using the ticker or name of the stock market for selected African countries. Data – in daily frequency – were downloaded for the selected countries and commodities. Details and sources of the data employed in this research are tabulated in Table 1. A summary of the selected commodities and their corresponding African stock markets was also presented in Table 2.

Table 1: Data and Data Source(s)

Variable (ticker/unit/index)	Source
African equities (all indices were in US$) 1. Egypt (Egypt EGX30) 2. Ghana (GSE Composite) 3. Ivory Coast (Ivory Coast BRVM 10) 4. Kenya (Nairobi All Share) 5. Malawi (Malawi All Share) 6. Morocco (Casablanca All Share) 7. Namibia (Namibia FTSE JSE Overall) 8. Nigeria (NGX All Share) 9. South Africa (FTSE/JSE Top 40) 10. Tanzania (Tanzania All Share) 11. Uganda (Uganda ALSI) 12. Zambia (Zambia All Share) 13. Zimbabwe (Zimbabwe All Share)	EquityRT
Global commodities 1. Metals i. Gold (US$/t.oz) ii. Silver (US$/t.oz) iii. Palladium (US$/t.oz) iv. Copper (US$/Lbs) 2. Energies i. Oil (US$/Bbl) ii. Natural gas (US$/MMBtu) 3. Grains i. Corn (US$/BU) ii. Soybeans (US$/BU) iii. Rice (US$/cwt) 4. Softs i. Cocoa (US$/T) ii. Coffee (US$/Lbs) 5. Unclassified i. Palm oil (US$/)	EquityRT

Source: Preliminary Survey (2022)

Table 2: Selected Commodities and Equities Markets

Commodity	Equities markets
Gold	Ghana, Ivory Coast, South Africa, Tanzania
Silver	Namibia, Zambia
Palladium	South Africa, Zimbabwe
Copper	Zambia, South Africa, Namibia
Crude oil	Nigeria, Egypt, Tunisia, Morocco
Natural gas	Nigeria, Egypt, Tanzania
Corn	South Africa, Nigeria, Egypt, Kenya, Malawi, Uganda
Soybeans	Nigeria, Zambia, Malawi, Uganda, Ghana
Rice	Nigeria, Egypt, Tanzania
Cocoa	Ivory Coast, Ghana, Togo
Coffee	Tanzania, Kenya, Uganda, Ivory Coast
Palm oil	Ivory Coast, Ghana, Kenya, South Africa

Source: Preliminary Survey (2022)

Estimation Techniques and Model Specification

This research focused on the dynamic interrelations between global asset classes and African stock markets' returns across multiscale. The main estimators included the vector wavelet coherence (VWC) (Oygur & Unal, 2020), time-varying parameter vector autoregressions (TVP-VAR)-based spillover connectedness (Antonakakis et al., 2020), and the Rényi transfer entropy. The improved ensemble empirical mode decomposition with adaptive noise (ICEEMDAN) was utilised to decompose the data series for estimating the transfer entropies. The estimation techniques and models were described as follows:

Vector wavelet coherence (VWC)

The VWC estimator was employed to facilitate the achievement of the first research objective aimed to examine interdependencies between GACs and AEMs. Given the varied dimensions of the study's samples, based on commodity groups, the application of the VWC aided in examining interdependencies for multiple (three variables), quadruple (four variables), and *n*-dimensional (for more than four variables) samples. The technique is described as follows.

For a given return series y and other return series $x_1, x_2, x_3, \dots, x_n$, the square of the *n*-dimensional VWC between them is expressed as $VR^2_{y(x_1,x_2,x_3,\dots,x_n)}$, which can be re-expressed as $VR^2_{y(q)}$ and formulated as

$$VR^2_{y(q)} = VR^2_{1(2,3,4,\dots,n)} = 1 - \frac{M^d}{S_{11}M^d_{11}}, \quad (1)$$

where M is the $n \times n$ matrix of the smoothened cross-wavelet spectra S_{ij} which represents the smoothened form of W_{ij} such that

$$S_{ij} = S(W_{ij}), \quad (2)$$

where S is an intended smoothing operator.

$$M = \begin{bmatrix} S_{11} & S_{12} & S_{13} & \dots & S_{1n} \\ S_{21} & S_{22} & S_{23} & \dots & S_{2n} \\ S_{31} & S_{32} & S_{33} & \dots & S_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ S_{n1} & S_{n2} & S_{n3} & \dots & S_{nn} \end{bmatrix}. \quad (3)$$

It must be noted that matrix M is a Hermitian matrix such that $M = M^H$ where H denotes conjugate transpose. $S_{ij} = S^*_{ij}$, $\forall\ i \neq j$ and $S_{ii} = S(|W_i|^2)$ denotes a positive real number $\forall\ i$.

The co-factor of the element in position (i, j) of M is denoted by M^d_{ij}

$$M_{ij}^{d} = (-1)^{(i+j)} \det M_{i}^{j}, \tag{4}$$

where M_{i}^{j} is the sub-matrix generated from M after its i^{th} row and j^{th} column; $M^{d} = \det M$.

Equivalent to matrix M, the matrix C, which encompasses all the smoothened composite wavelet coherencies ρ_{ij}, is considered.

$$C = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \dots & \rho_{1n} \\ \rho_{21} & 1 & \rho_{23} & \dots & \rho_{2n} \\ \rho_{31} & \rho_{32} & 1 & \dots & \rho_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ \rho_{n1} & \rho_{n2} & \rho_{n3} & \dots & 1 \end{bmatrix}. \tag{5}$$

It is worth noting that, $\rho_{jj} = \frac{s(w_{jj})}{\sqrt{\left(s\left(|w_j|^2\right)s\left(|w_j|^2\right)\right)}} = \frac{s\left(|w_j|^2\right)}{s\left(|w_j|^2\right)} = 1$. The matrix C is a Hermitian matrix just as matrix M, such that $\rho_{ij} = \rho_{ij}^{*}$.

Finally, the vector coherence with "n" dimensions is defined as:

$$VR_{1(q)}^{2} = 1 - \frac{C^{d}}{C_{11}^{d}}. \tag{6}$$

TVP-VAR connectedness

This estimation technique was purposely for the second research objective, which investigated the dynamic return spillover connectedness of GACs and AEMs. Antonakakis et al. (2020) proposed a TVP-VAR model that extends the connectedness approach of Diebold and Yilmaz (2014) by allowing the variance-covariance matrix to vary via a Kalman filter estimation with forgetting factors in the view of Koop and Korobilis (2014).

The $\text{TVP} - \text{VAR}(p)$ model is introduced as follows:

$$y_t = B_t z_{t-1} + \varepsilon_t \qquad \varepsilon_t \mid \Omega_{t-1} \sim N(0, \Sigma_t) \tag{7}$$

$$vec(B_t) = vec(B_{t-1}) + \xi_t \qquad \xi_t \mid \Omega_{t-1} \sim N(0, \Xi_t) \tag{8}$$

with

$$z_{t-1} = \begin{pmatrix} y_{t-1} \\ y_{t-2} \\ \vdots \\ y_{t-p} \end{pmatrix} \qquad B_t' = \begin{pmatrix} B_{1t} \\ B_{2t} \\ \vdots \\ B_{pt} \end{pmatrix}$$

where Ω_{t-1} expressed all available information until $t-1$, y_t and z_t correspond to $m \times 1$ and $mp \times 1$ vectors, respectively. B_t and B_{it} are $m \times mp$ and $mp \times 1$ dimensional matrices, respectively. ε_t is an $m \times 1$ vector, and ξ_t is $m^2p \times 1$ dimensional vector, with Σ_t, and Ξ_t being $m \times m$ and $m^2p \times m^2p$ dimensional matrices, respectively. $vec(B_t)$ is the vectorisation of B_t and is an $m^2p \times 1$ dimensional vector.

A transformation of the TVP-VAR is made to its vector moving average (VMA) form based on the "Wold" representation theorem. In doing so, the generalised impulse response functions (GIRF) and generalised forecast error variance decompositions (GFEVD) are estimated. Resultantly, the retrieval of the VMA representation y_t takes its depicted form as $\sum_{j=0}^{\infty} A_{jt}\mu_{t-j}$, where A_{jt} is $m \times m$ dimensional matrix.

The $GIRF\left(\Psi_{ij,t}(H)\right)$ represents the responses of all variables j, following a shock in i computed with an $H-step$ ahead forecast. $GIRF\left(\Psi_{ij,t}(H)\right)$ has the following form:

$$GIRF\left(H, \sigma_{j,t}, \Omega_{t-1}\right) = E\left(y_t + H | e_j = \sigma_{j,t}, \Omega_{t-1}\right) - E\left(y_{t+j} \middle| \Omega_{t-1}\right), \qquad (9)$$

$$\Psi_{j,t}(H) = \frac{A_{H,t}\Sigma_t e_j}{\sqrt{\Sigma_{jj,t}}} \cdot \frac{\sigma_{j,t}}{\sqrt{\Sigma_{jj,t}}} \qquad \sigma_{j,t} = \sqrt{\Sigma_{jj,t}}, \qquad (10)$$

$$\Psi_{j,t}(H) = {\Sigma_{jj,t}}^{-1/2} A_{H,t}\Sigma_t e_j, \qquad (11)$$

where e_j is an $m \times 1$ selection vector which takes 1 with the selection of jth element, and 0 otherwise. Thence, the $GFEVD\left(\widetilde{\Phi}_{ij,t}(H)\right)$ is computed based on $\widetilde{\Phi}_{ij,t}(H)$, which has the following representation:

$$\widetilde{\Phi}_{ij,t}(H) = \frac{\sum_{t=1}^{H-1} \Psi_t^2}{\sum_{j=1}^{m} \sum_{t=1}^{H-1} \Psi_t^2}, \tag{12}$$

with $\sum_{j=1}^{m} \widetilde{\Phi}_{ij,t}(H) = 1$, and $\sum_{i,j=1}^{m} \widetilde{\Phi}_{ij,t}(H) = m$.

Hinged on the above data, the total connectedness index (TCI) takes the expression:

$$C_t(H) = \frac{\sum_{i,j=1, i \neq j}^{m} \widetilde{\Phi}_{ij,t}(H)}{\sum_{i,j=1}^{m} \widetilde{\Phi}_{ij,t}(H)} * 100 = \frac{\sum_{i,j=1, i \neq j}^{m} \widetilde{\Phi}_{ij,t}(H)}{m} * 100. \tag{13}$$

Total directional connectedness (TDC) to others, i.e., i transmits its shock to all other variables j is introduced as:

$$C_{i \to j,t}(H) = \frac{\sum_{j=1, i \neq j}^{m} \widetilde{\Phi}_{ji,t}(H)}{\sum_{j=1}^{m} \widetilde{\Phi}_{ji,t}(H)} * 100. \tag{14}$$

TDC from others, i.e., i receives from all other variables j takes the specification:

$$C_{i \leftarrow j,t}(H) = \frac{\sum_{j=1, i \neq j}^{m} \widetilde{\Phi}_{ij,t}(H)}{\sum_{j=1}^{m} \widetilde{\Phi}_{ij,t}(H)} * 100. \tag{15}$$

Net total directional connectedness is defined as:

$$C_{i,t}(H) = C_{i \to j,t}(H) - C_{i \leftarrow j,t}(H). \tag{16}$$

The ICEEMDAN algorithm

The methodology was purported to provide inputs for the main estimation technique for achieving the third objective. This technique delineates the main data into their short-, medium-, and long-term components known as inter-modal functions (IMFs) (Bossman, Agyei, et al., 2022). The degree, shape,

and direction of variables' linkages have been long understood by economists to be timescale-dependent (Ramsey & Lampart, 1998). Unlike in the past when methods to demarcate economic datasets into all orthogonal timescale constituents were lacking, techniques are presently available. Thus, the instruments to cater for noise, which usually dominates short term economic data series are accessible in present times (Bossman, 2021; Bossman, Agyei, et al., 2022; Ramsey & Lampart, 1998; Yang, Sun, & Wang, 2020).

The latest strand of the EMD family, the ICEEMDAN, from Huang et al. (1998), is a fitting example. Its strengths include efficiency, the noise-to-signal ratio (i.e., SNR) reduction of modal decompositions in dynamic signals, and precision with reconstruction (Luukko, Helske, & Räsänen, 2016). Colominas et al.'s (2014) ICEEMDAN has the best of these properties (Bossman, 2021; Bossman, Agyei, et al., 2022). Note that although CEEMDAN may be good in terms of removing noisy data, signal reconstruction, and revealing SNR (Peng, Wen, & Gong, 2021), it is limited because of the persistence of residual noise and the propensity of spurious mode, as identified by Li et al. (2020). To provide an extremely novel approach to this research, the ICEEMDAN was, thus, employed.

In the spirit of the extant literature (Bossman, 2021; Bossman, Agyei, et al., 2022; Colominas et al., 2014; Li et al., 2020), the ICEEMDAN algorithm is summarised in three stages:

Stage I: generate a new series by appending a white-noise $\tau_1[\omega^{(i)}]$ to a signal α

$$\alpha^{(i)} = \alpha + \rho_0(\omega^{(i)}), i = 1, 2, \dots, N, \quad (17)$$

where $\omega^{(i)}$ is the i-th white noise term added, ρ_0 denotes the SNR, and the number of added white noise is represented by N.

Stage II: estimate the local average of $\alpha^{(i)}$ by applying the EMD to glean the opening residual

$$r_1 = \left(\frac{1}{N}\right)\sum_{i=1}^{N} M\left(\alpha^{(i)}\right), \tag{18}$$

from which the first IMF $c_1 = \alpha - r_1$ could be deduced.

Stage III: in a recursive process, generate the k-th IMF $c_k = r_{k-1} - r_k$, for $k \geq 2$, where

$$r_k = \left(\frac{1}{N}\right)\sum_{i=1}^{N} M\left(r_{k-1} + \rho_{k-1}\tau_k\left(\omega^{(i)}\right)\right). \tag{19}$$

Rényi transfer entropy

This use of this estimation technique aided in the achievement of the third research objective, which examined the information flow between the returns on global asset classes and African equities. Transfer entropy is a consequence of Hartley's (1928) general information theory. As an uncertainty measure, modern studies on TE employ Shannon's (1948) arithmetical communication theory, which is gleaned from theoretic information.

The average symbolic information for a probability distribution having distinguishable symbols of a particular experiment P_j is expressed as

$$H = \sum_{j=1}^{n} P_j log_2\left(\frac{1}{P_j}\right) \text{ bits}, \tag{20}$$

where n is the quantity of distinct symbols associated with probability p_j (Hartley, 1928). The average number of bits necessary for optimal encoding autonomous draws may be estimated with Shannon's (1948) paradigm (i.e., Shannon entropy (SE)) for a discretised random variable J with $p(j)$ probabilities.

$$H_J = -\sum_{j=1}^{n} p(j) log_2 p(j) \quad (21)$$

Given two Markov time series procedures, a quantification of information flow between them is made with Kullback and Leibler's (1951) distance model (KLDM). Let I, with marginal probability $p(i)$, and J with marginal probability p(j) represent two discrete random time series. their joint probability is then defined as $p(i,j)$. At order k (process I) and I (process J), dynamic stationarity for the Markov process is also assumed. As stated by the Markov property, the probability at which I is observed in state i and time $t+1$ conditioned on k preceding data points is $p(i_{t+1}|i_t, \dots, i_{t-k+1}) = p(i_{t+1}|i_t, \dots, i_{t-k})$. The mean bits needed for encoding the data point at $t+1$ prior to knowing k observations is given as

$$h_j(k) = -\sum_i p(i_{t+1}, i_t^{(k)}) log_2 p\left(i_{t+1}\middle|i_t^{(k)}\right) \quad (22)$$

where $i_t^{(k)} = (i_t, \dots, i_{t-k+1})$ (correspondingly for process J). Information flow to I from J is examined in a bivariate case by quantifying the variance from the Markov property $p\left(i_{t+1}\middle|i_t^{(k)}\right) = p\left(i_{t+1}\middle|i_t^{(k)}, j_t^{(l)}\right)$, as hinged on the KLDM. SE is then expressed as follows:

$$T_{J\to I}(k,l) = \sum P(i_{t+1}, i_t^{(k)}, j_t^{(l)}) log \frac{P\left(i_{t+1}\middle|i_t^{(k)}, j_t^{(l)}\right)}{P\left(i_{t+1}\middle|i_t^{(k)}\right)}, \quad (23)$$

where $T_{J\to I}$ aggregates the information flow towards I from J. Analogously, the flow of information to J from I, which is $T_{I\to J}$, can be obtained. The net estimate of information flow is computed as the excess of $T_{J\to I}$ over $T_{I\to J}$, which serves as the central information flow path.

The expediency of SE in the area of finance cannot be overemphasised, but it does not attribute equal weights to all probable expectations in a probability distribution. Note that fat-tails are pervasive in asset pricing, but SE does not overcome this assumption. Therefore, this research resorts to Rényi's (1961) transfer entropy, which uses a weighting value q, to overcome the shortfall of SE. RTE is computed as

$$H_j^q = \frac{1}{1-q} log_2 \sum_j P^q(j) \tag{24}$$

with $q > 0$. For $q \rightarrow 1$, RE and SE converge. For $0 < q < 1$, more weight is assigned to low probability events, while for $q > 1$, outputs j with higher initial probabilities are favoured by the weights. Resultantly, based on q, RTE facilitates the assignment of different weights to unequal regions of the distribution (Adam, 2020; Behrendt et al., 2019; Bossman et al., 2022). This feature of RTE makes it superior to SE and, hence, its desirability in finance.

The companion distribution $\emptyset_q(j) = \frac{p^q(j)}{\sum_j p^q(j)}$ for $q > 0$ is applied to normalise the weighted distributions (Beck & Schögl, 1995), from which RE is estimated as

$$RT_{J \rightarrow I}(k,l) = \frac{1}{1-q} p(i_{t+1}, i_t^{(k)}, j_t^{(I)}) log_2 \frac{\sum_i \emptyset_q \left(i_t^{(k)}\right) P^q \left(i_{t+1} \middle| i_t^{(k)}\right)}{\sum_{i,j} \emptyset_q \left(i_t^{(k)}, j_t^{(I)}\right) P^q \left(i_{t+1} \middle| i_t^{(k)}, j_t^{(I)}\right)} \tag{25}$$

Note that negative estimates could be provided by the RTE. Acknowledging J's record, in this case, connotes significantly more uncertainty than acknowledging only I's record would imply. Negative (positive) estimates depict higher (lower) risks in this context.

TE estimations are subject to biases in small samples (Marschinski & Kantz, 2002). The effective transfer entropy (i.e., ETE) can resolve this and is derived as

$$ETE_{J\to I}(k,l) = T_{J\to I}(k,l) - T_{Jshuffled\to I}(k,l), \quad (26)$$

where the TE using faltered forms of the data series J is represented as $T_{Jshuffled\to I}(k,l)$. The procedure removes the data series' serial reliance of J whilst the statistical linkages amid J and I are preserved through repetitive random draws from the given return series J and rearranging them to produce a fresh return series. $T_{Jshuffled\to I}(k,l)$ is therefore caused to approach zero as the sample size increases; non-zero values of $T_{Jshuffled\to I}(k,l)$ are caused as a result of biases with a small sample. Consequently, recurrent shuffles and the average of the shuffled TE estimates across all replications could be employed as an estimator of small sample bias, which from which the derivation of bias-corrected ETE estimates are gotten after being deducted from the RE or SE estimates.

To establish the statistical significance of ETEs, the Markov block bootstrap technique is adopted. This process retains the dependencies within the variables J and I, but eliminates their statistical linkages as opposed to shuffling. Resultantly, in line with the H_0 of "no information flow," a distribution of TE estimates is retrieved by bootstrapping. $1-\hat{q}$T provides the accompanying $p-value$ while $\hat{q}$T offers a specification of the quantile of the simulated distribution produced by the relevant TE estimations (Behrendt et al., 2019; Bossman, 2021).

Computation of log-returns

For all estimations, the market returns for the various commodity and stock market indices were used. The log-returns were computed as

$$r_t = lnP_t - lnP_{t-1}, \quad (27)$$

where r_t denotes the continuously compounded returns, P_t is the price of an asset in period t, and P_{t-1} denotes the price of an asset in the previous period $t-1$.

Ethical Considerations

This study did not engage human participants. As a result, issues of confidentiality, and seeking participants' consent, among others, were not the main challenges to compromising the ethical stance of this research. However, since the study used secondary data for analysis, the researcher ensured that a credible database was consulted for acquiring the needed data on equities and various asset classes. Hence, a licensed database – EquityRT – was used as the source of data. Furthermore, the study ensured that the execution of data processing techniques and the use of software for the needed estimations were carefully done to comply with all applicable ethical standards.

Chapter Summary

The methods and/or approaches that were employed in this study to contribute to filling the identified knowledge and research gaps were presented in this Chapter. The Chapter covered a presentation on the study philosophy, the design, and the approach of the study. The units of analysis, source(s) and mode of data collection were also defined in this Chapter. Moreover, processing, estimation techniques, and the means of analysing gathered data together with ethical considerations were additionally highlighted in this

Chapter. These methods are thoroughly applied in the succeeding Chapter in pursuit of achieving (testing) the stated research objectives (hypotheses).

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This thesis focused on the dynamic multiscale linkages between global asset classes and stock returns in Africa. Having had a comprehensive description of the research methods applied in this study, the results from rigorous estimations were presented and discussed. In this Chapter, a descriptive summary of the various samples is presented. Next, a presentation of the main results for all three research objectives is made followed by a results discussion.

Descriptive Statistics

Following the commodity- and market-based samples, the descriptive statistics of the variables used were also categorised according to the commodity classes and the particular stock markets of African countries that dominate in the commodity's production or exportation. Specifically, the samples were made up of the groups of cocoa (Ghana and Ivory Coast), coffee (Ivory Coast, Kenya, Tanzania, Uganda), copper (Namibia, South Africa, and Zambia), corn (Egypt, Kenya, Malawi, Nigeria, South Africa, and Uganda), crude oil (Egypt, Morocco, Nigeria, and Tunisia), gold (Ghana, Ivory Coast, South Africa, and Tanzania), natural gas (Egypt, Nigeria, and Tanzania), palladium (South Africa and Zimbabwe), palm oil (Ghana, Ivory Coast, Kenya, and South Africa), rice (Egypt, Nigeria, and Tanzania), silver (Namibia and Zambia), and soybeans (Ghana, Malawi, Nigeria, Uganda, and Zambia).

The descriptive statistics of all the market return series were reported in Table 3 with Figure A1 (see Appendix) providing a pictorial view of the raw and return series based on the respective samples.

Table 3: Descriptive Summary

Panel A: Cocoa	Obs.	Min	Max	Mean	*SD*	Skewness	Kurtosis	Normtest.W	ADF	PP
Ghana	1972	-0.1844	0.1750	-0.0003	0.0101	0.0652	104.8500	0.6661[a]	-17.528[a]	-48.7839[a]
Ivory Coast	1972	-0.0823	0.1036	-0.0002	0.0121	0.1671	6.4977	0.9370[a]	-46.8546[a]	-47.0482[a]
Cocoa	1972	-0.0890	0.1149	0.0001	0.0180	-0.0475	1.7259	0.9878[a]	-45.0131[a]	-45.0131[a]
Panel B: Coffee										
Ivory Coast	1680	-0.0723	0.1091	-0.0003	0.0124	0.5190	8.4786	0.9190[a]	-43.6861[a]	-43.6501[a]
Kenya	1680	-0.3384	0.3205	0.0001	0.0173	-1.7359	184.4839	0.4779[a]	-49.6608[a]	-49.8064[a]
Tanzania	1680	-0.3807	0.3911	-0.0001	0.0190	0.2442	218.9706	0.4415[a]	-37.4915[a]	-58.0894[a]
Uganda	1680	-0.1995	0.1055	-0.0002	0.0126	-2.1530	44.1631	0.8072[a]	-38.2268[a]	-38.6505[a]
Coffee	1680	-0.1505	0.2180	0.0003	0.0239	0.5653	6.1437	0.9537[a]	-43.0812[a]	-43.0746[a]
Panel C: Copper										
Namibia	2514	-1.4841	1.5234	0.000	0.0476	0.9116	787.6078	0.2793[a]	-38.9807[a]	-93.3737[a]
South Africa	2514	-0.1214	0.0891	0.0001	0.0179	-0.5405	3.6386	0.9646[a]	-49.6459[a]	-49.8784[a]
Zambia	2514	-0.0851	0.1234	-0.0002	0.0122	0.3057	12.1004	0.8648[a]	-41.7554[a]	-41.7409[a]
Copper	2514	-0.1109	0.0988	0.0001	0.0155	-0.1475	3.8851	0.9636[a]	-51.6736[a]	-51.7484[a]
Panel D: Corn										
Egypt	1500	-0.4048	0.2659	-0.0002	0.0245	-3.7138	81.0439	0.6664[a]	-34.8129[a]	-34.6987[a]
Kenya	1500	-0.3384	0.3205	0.0002	0.0185	-1.6310	148.3292	0.5600[a]	-43.1659[a]	-43.0374[a]
Malawi	1500	-0.3944	0.3033	0.0003	0.0192	-8.9872	278.4907	0.2901[a]	-19.7749[a]	-39.7032[a]
Nigeria	1500	-0.3213	0.1037	-0.0002	0.0187	-5.3234	81.6910	0.6589[a]	-35.6957[a]	-36.3834[a]
South Africa	1500	-0.2240	0.0876	0.0001	0.0225	-1.9575	16.3399	0.8766[a]	-40.4411[a]	-40.4639[a]
Uganda	1500	-0.2022	0.1055	0.0000	0.0158	-1.5903	23.5141	0.8387[a]	-37.3765[a]	-37.7664[a]
Corn	1500	-0.2909	0.0858	-0.0001	0.0241	-2.9605	29.2003	0.7994[a]	-36.4454[a]	-36.3915[a]
Panel E: Crude Oil										
Egypt	2023	-0.4048	0.1170	-0.0002	0.0216	-5.8759	100.6912	0.7104[a]	-39.7403[a]	-39.4535[a]
Morocco	2023	-0.1732	0.0556	0.0000	0.0102	-2.4088	44.2860	0.8518[a]	-40.8932[a]	-40.8884[a]
Nigeria	2023	-0.3426	0.0812	-0.0002	0.0163	-5.8521	110.6448	0.6922[a]	-40.0702[a]	-40.7037[a]
Tunisia	2023	-0.0951	0.1086	-0.0002	0.0096	-0.1891	16.8704	0.8915[a]	-47.959[a]	-47.959[a]
Crude Oil	2023	-0.6856	0.3196	0.0001	0.0358	-3.8484	84.6567	0.7053[a]	-24.5349[a]	-49.6916[a]
Panel F: Gold										
Ghana	1765	-0.1844	0.1750	-0.0003	0.0103	-0.9313	111.4390	0.6378[a]	-17.5152[a]	-48.3704[a]
Ivory Coast	1765	-0.0663	0.1148	-0.0003	0.0126	1.0164	10.6749	0.8996[a]	-43.911[a]	-43.9843[a]
South Africa	1765	-0.1492	0.0840	0.0001	0.0182	-0.9988	7.6810	0.9333[a]	-43.4889[a]	-43.4889[a]
Tanzania	1765	-0.3807	0.3930	-0.0001	0.0186	0.4598	226.0898	0.4428[a]	-38.6487[a]	-60.0466[a]
Gold	1765	-0.0888	0.0525	0.0001	0.0101	-1.1150	9.7180	0.9124[a]	-40.8272[a]	-40.8123[a]

Panel G: Natural Gas	Obs.	Min	Max	Mean	*SD*	Skewness	Kurtosis	Normtest.W	ADF	PP
Egypt	1880	-0.4048	0.2548	-0.0003	0.0222	-3.0051	74.0860	0.7287 [a]	-38.0372 [a]	-37.9597 [a]
Nigeria	1880	-0.3426	0.0893	-0.0002	0.0171	-5.8108	103.1627	0.6708 [a]	-38.6803 [a]	-39.3506 [a]
Tanzania	1880	-0.1907	0.1778	0.0000	0.0137	0.7186	56.4202	0.6514 [a]	-53.2264 [a]	-52.2806 [a]
Natural Gas	1880	-0.2866	0.2637	0.0000	0.0386	0.3514	7.6845	0.9118 [a]	-46.9268 [a]	-47.3475 [a]
Panel H: Palladium										
South Africa	973	-0.1264	0.0840	0.0001	0.0187	-0.8466	5.4978	0.9396 [a]	-31.8417 [a]	-31.8349 [a]
Zimbabwe	973	-0.9230	0.1656	0.0001	0.0499	-11.6507	200.3893	0.3812 [a]	-13.995 [a]	-28.0297 [a]
Palladium	973	-0.2298	0.1814	0.0008	0.0234	-0.7266	15.9859	0.8704 [a]	-27.4854 [a]	-27.3236 [a]
Panel I: Palm Oil										
Ghana	1971	-0.1899	0.1750	-0.0003	0.0102	-0.2971	108.8040	0.6714 [a]	-15.0156 [a]	-49.813 [a]
Ivory Coast	1971	-0.0663	0.1114	-0.0002	0.0122	0.6882	8.7048	0.9200 [a]	-47.3046 [a]	-47.416 [a]
Kenya	1971	-0.3384	0.3205	0.0000	0.0153	-0.9127	234.9609	0.5133 [a]	-55.1105 [a]	-55.6653 [a]
South Africa	1971	-0.1400	0.0840	0.0001	0.0178	-0.6833	5.2416	0.9544 [a]	-46.3204 [a]	-46.3017 [a]
Palm Oil	1971	-0.1219	0.1304	0.0003	0.0179	-0.1353	5.5025	0.9511 [a]	-47.2528 [a]	-47.2528 [a]
Panel J: Rice										
Egypt	1849	-0.4048	0.2548	-0.0003	0.0224	-2.9181	72.2304	0.7279 [a]	-38.0794 [a]	-38.0155 [a]
Nigeria	1849	-0.3426	0.0893	-0.0002	0.0173	-5.6259	99.9010	0.6705 [a]	-38.1888 [a]	-38.8014 [a]
Tanzania	1849	-0.1907	0.1778	0.0000	0.0139	0.8522	56.0470	0.6438 [a]	-52.7263 [a]	-51.8117 [a]
Rice	1849	-4.6766	4.8092	0.0001	0.1575	1.2361	887.3842	0.0565 [a]	-22.3664 [a]	-309.259 [a]
Panel K: Silver										
Namibia	2724	-1.4841	1.5234	0.0000	0.0458	0.9491	852.4708	0.2763 [a]	-40.5522 [a]	-97.5834 [a]
Zambia	2724	-0.1055	0.1234	-0.0002	0.0119	0.3309	14.1308	0.8546 [a]	-44.8787 [a]	-44.994 [a]
Silver	2724	-0.1979	0.1472	0.0001	0.0195	-0.8753	10.8045	0.8996 [a]	-38.5115 [a]	-50.5268 [a]
Panel L: Soybeans										
Ghana	2022	-0.1844	0.1750	-0.0003	0.0104	-1.0241	104.6118	0.6534 [a]	-18.6538 [a]	-51.1332 [a]
Malawi	2022	-0.3946	0.2992	0.0003	0.0164	-10.9823	393.8550	0.2505 [a]	-44.9919 [a]	-45.8344 [a]
Nigeria	2022	-0.3426	0.0947	-0.0002	0.0158	-7.4810	143.8948	0.6165 [a]	-40.091 [a]	-40.8739 [a]
Uganda	2022	-0.1995	0.1055	0.0000	0.0138	-1.5791	29.4339	0.8302 [a]	-45.0267 [a]	-45.3517 [a]
Zambia	2022	-0.3908	0.1505	-0.0004	0.0149	-8.3849	239.6836	0.6076 [a]	-41.7939 [a]	-41.8346 [a]
Soybeans	2022	-0.1668	0.0726	0.0001	0.0149	-1.4990	13.6953	0.9033 [a]	-42.6755 [a]	-42.6686 [a]

Notes: [a] signifies $p < 0.001$.

Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The data points for the various samples ranged between 973 and 2022 among the various samples. It could be observed from Table 3 that over the sample period, all commodities recorded positive mean returns except for corn. This observation, in part, is suggestive of the highly volatile nature of agricultural commodity markets (Frimpong et al., 2021). The stock market returns for the various samples reflect a fluctuating position in terms of stock market returns for the studied African countries. The return series for all samples exhibited mild deviations from their mean, as they fall within the range 0.0101–0.0499. This may be unsurprising given that the returns on emerging market equities may be predictable (Mensi, Hammoudeh, & Kang, 2017) and this is not far from commodity markets, which may explain the reason behind their increasing financialisation in recent periods (Hu, Li, & Liu, 2020).

Furthermore, the return series portrayed either mild or negative skewness, explaining why most of the stock markets recorded mean negative returns. The study period is filled with notable financial market meltdowns and, hence, it is unsurprising that stock markets may – on average – record negative returns. This is also confirmatory of the results from the Jarque-Bera test of normality (Jarque & Bera, 1980), in which all return series reject the hypothesis for normally distributed series. The return series for all the variables showed a leptokurtic character, which mimics the stylized fact about financial assets (Adam, 2020; Bossman et al., 2022; Owusu Junior et al., 2021). The stationarity properties of the return series were confirmed using the tests of Dickey and Fuller (1981) and Phillips and Perron (1988). The results from both tests proved that the return series are stationary at the 1% level of significance.

Observations from the trajectory view of the return series' behaviour across the sample period – as offered pictorially in Figure A1 – cause no change to the findings presented by the descriptive statistics in Table 3. As the raw series for the various indices indicate either peaks and troughs across crisis periods, the return series also display volatility clusters across diverse times and events. Notably, after experiencing peaks or troughs in crisis periods, the return series bounce back or assume their fundamental behaviour (Owusu Junior et al., 2021).

Pairwise Correlations

The unconditional pairwise correlations between the variables are reported in Table 4. As preliminary checks, these were investigated to ascertain the extent and direction of unconditional linkage(s) between the market returns on the studied global asset classes and African equities. Table 4 has 12 panels, from A-J which are respectively represented by the samples for cocoa, coffee, copper, corn, crude oil, gold, natural gas, palladium, palm oil, rice, sugar, and soybeans.

Table 4: Sample Correlations

Panel A	Cocoa	Ghana	Ivory coast
Cocoa	1.0000		
Ghana	-0.0169	1.0000	
Ivory coast	0.0180	0.0061	1.0000

Panel B	Coffee	Ivory coast	Kenya	Tanzania	Uganda
Coffee	1.0000				
Ivory coast	0.0306	1.0000			
Kenya	0.0252	0.0460	1.0000		
Tanzania	0.0552	0.0438	0.1372	1.0000	
Uganda	0.0267	0.0225	0.2498	0.1897	1.0000

Panel C	Copper	Namibia	S. Africa	Zambia
Copper	1.0000			
Namibia	0.1704	1.0000		
S. Africa	0.3932	0.4236	1.0000	
Zambia	0.0017	0.0270	0.0618	1.0000

Panel D	Corn	Egypt	Kenya	Malawi	Nigeria	S. Africa	Uganda
Corn	1.0000						
Egypt	-0.0945	1.0000					
Kenya	-0.0536	0.2245	1.0000				
Malawi	-0.1235	0.3114	0.2495	1.0000			
Nigeria	-0.0554	0.1794	0.2213	0.2146	1.0000		
S. Africa	0.0593	0.2842	0.1716	0.1927	0.1189	1.0000	
Uganda	-0.0691	0.1774	0.3649	0.2366	0.2312	0.1540	1.0000

Panel E	Crude Oil	Egypt	Morocco	Nigeria	Tunisia
Crude Oil	1.0000				
Egypt	0.0986	1.0000			
Morocco	0.1489	0.1747	1.0000		
Nigeria	0.0132	0.0860	-0.0089	1.0000	
Tunisia	0.0407	0.0683	0.2394	-0.0313	1.0000

Panel F	Ghana	Gold	Ivory Coast	S. Africa	Tanzania
Ghana	1.0000				
Gold	0.0670	1.0000			
Ivory Coast	-0.0333	0.0169	1.0000		
S. Africa	0.0429	0.1242	0.0663	1.0000	
Tanzania	0.0716	0.0364	0.0047	0.0770	1.0000

Panel G	Egypt	Natural Gas	Nigeria	Tanzania
Egypt	1.0000			
Natural Gas	0.0889	1.0000		
Nigeria	0.1244	0.0284	1.0000	
Tanzania	0.1805	0.0897	0.1449	1.0000

Panel H	Palladium	S. Africa	Zimbabwe
Palladium	1.0000		
S. Africa	0.4061	1.0000	
Zimbabwe	-0.0381	0.0266	1.0000

Panel I	Ghana	Ivory Coast	Kenya	Palm Oil	S. Africa
Ghana	1.0000				
Ivory Coast	-0.0080	1.0000			
Kenya	0.0345	0.0065	1.0000		
Palm Oil	0.0000	0.0181	0.0278	1.0000	
S. Africa	-0.0288	0.0817	0.0413	0.2304	1.0000

Panel J	Egypt	Nigeria	Rice	Tanzania
Egypt	1.0000			
Nigeria	0.1218	1.0000		
Rice	0.0020	0.0055	1.0000	
Tanzania	0.1879	0.1389	-0.0282	1.0000

Panel K	Namibia	Silver	Zambia
Namibia	1.0000		
Silver	0.1097	1.0000	
Zambia	0.0247	0.0178	1.0000

Panel L	Ghana	Malawi	Nigeria	Soybeans	Uganda	Zambia
Ghana	1.0000					
Malawi	0.1508	1.0000				
Nigeria	0.1313	0.2233	1.0000			
Soybeans	0.0726	-0.0013	0.0157	1.0000		
Uganda	0.1046	0.2160	0.1832	0.0325	1.0000	
Zambia	0.1817	0.4322	0.2390	0.0258	0.2431	1.0000

Notes: panels A-L are for the various samples namely cocoa, coffee, copper, corn, crude oil, gold, natural gas, palladium, palm oil, rice, sugar, and soybeans, respectively.
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

For all samples, this research found mild correlations – with varying directions – between commodity and stock markets' returns. Notably, most of the correlation matrices exhibited similar patterns in terms of the direction of correlation coefficients. From the samples for coffee, copper, crude oil, gold, natural gas, palm oil, and silver, all pairwise correlations were positive between the respective stock market returns and commodity returns. However, the results were mixed for the samples of corn, palladium, and soybeans. For the cocoa sample, the study found that the stock market returns of Ghana (Ivory Coast) were mildly inversely (directly) related to returns on cocoa. These insights about the basic behaviour of the various assets facilitated empirical assessments using advanced and robust approaches.

Main Results

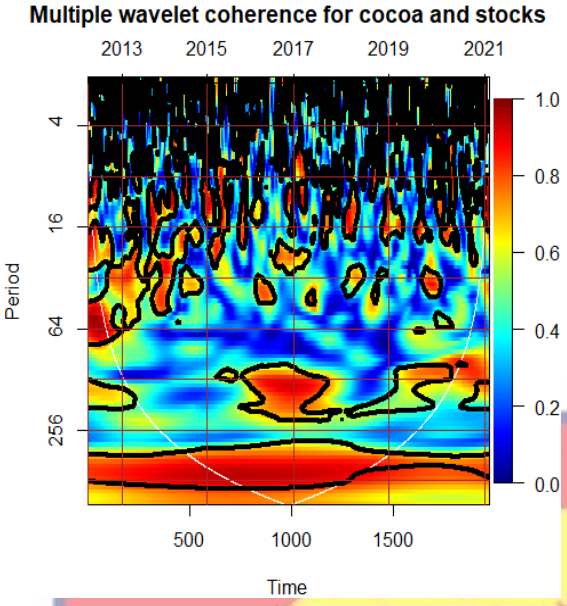
This section presents the main results based on the research objectives. Highlights of the results were provided in this section with their discussion made in the next section. For each research objective, and where results were dissimilar among commodity classes, the discussions are additionally delineated for the various asset classes as were already delineated. The objective-based results were presented as follows.

Dynamic interdependencies between returns on African equities and global commodities

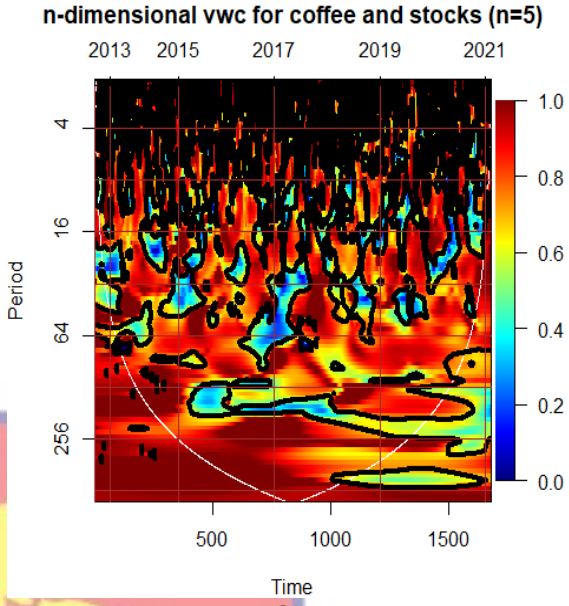
The first objective sought to examine the time- and frequency-varying interdependence structure of the returns on global commodities and African equities. The vector wavelet coherence (VWC) approach was employed to facilitate the achievement of this objective. Other methods such as the wavelet transform (Torrence & Compo, 1998), partial and multiple wavelet coherence

(PWC and MWC, respectively) (Mihanović, Orlić, & Pasarić, 2009), and quadruple wavelet coherence (QWC) (Oygur & Unal, 2017) failed to cover *n*-dimensional time series. The VWC carries the PWC, MWC, and QWC to the generalised form of *n*-dimensions, allowing the assessment of interdependence without constraints on dimensions (Oygur & Unal, 2020). The number of countries that dominate in the production and/or exportation of commodities in Africa may exceed the specifications and boundaries of MWC and QWC.

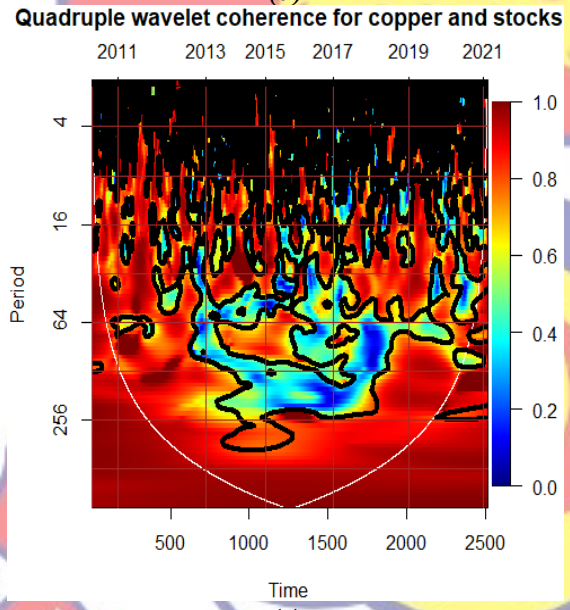
Meanwhile, recent alliances in African markets warrant that assessments of interdependence should encapsulate all markets that make a significant contribution or earn significantly from commodity production and/or sale. Hence, the VWC served as the appropriate approach for this objective. The interdependence structure between the various commodity-based samples is presented in Figure 3, which contains 12 plots based on the 12 commodity samples viz. cocoa, coffee, copper, corn, crude oil, gold, natural gas, palladium, palm oil, rice, sugar, and soybeans, respectively for Figure 3(*a*) – Figure 3(*l*).



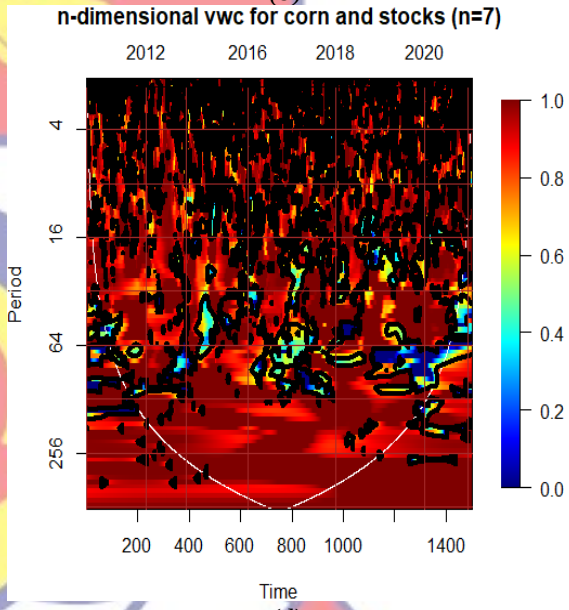
(a)



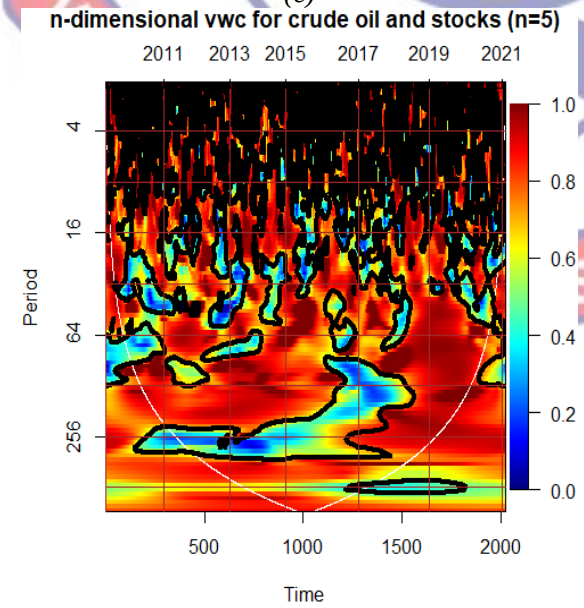
(b)



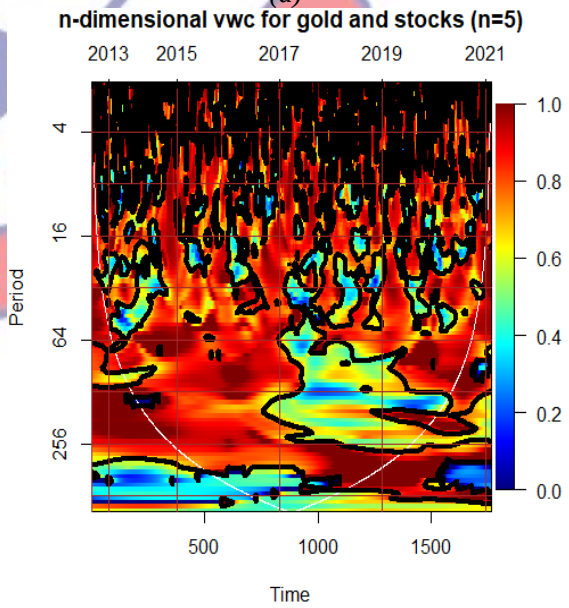
(c)



(d)



(e)



(f)

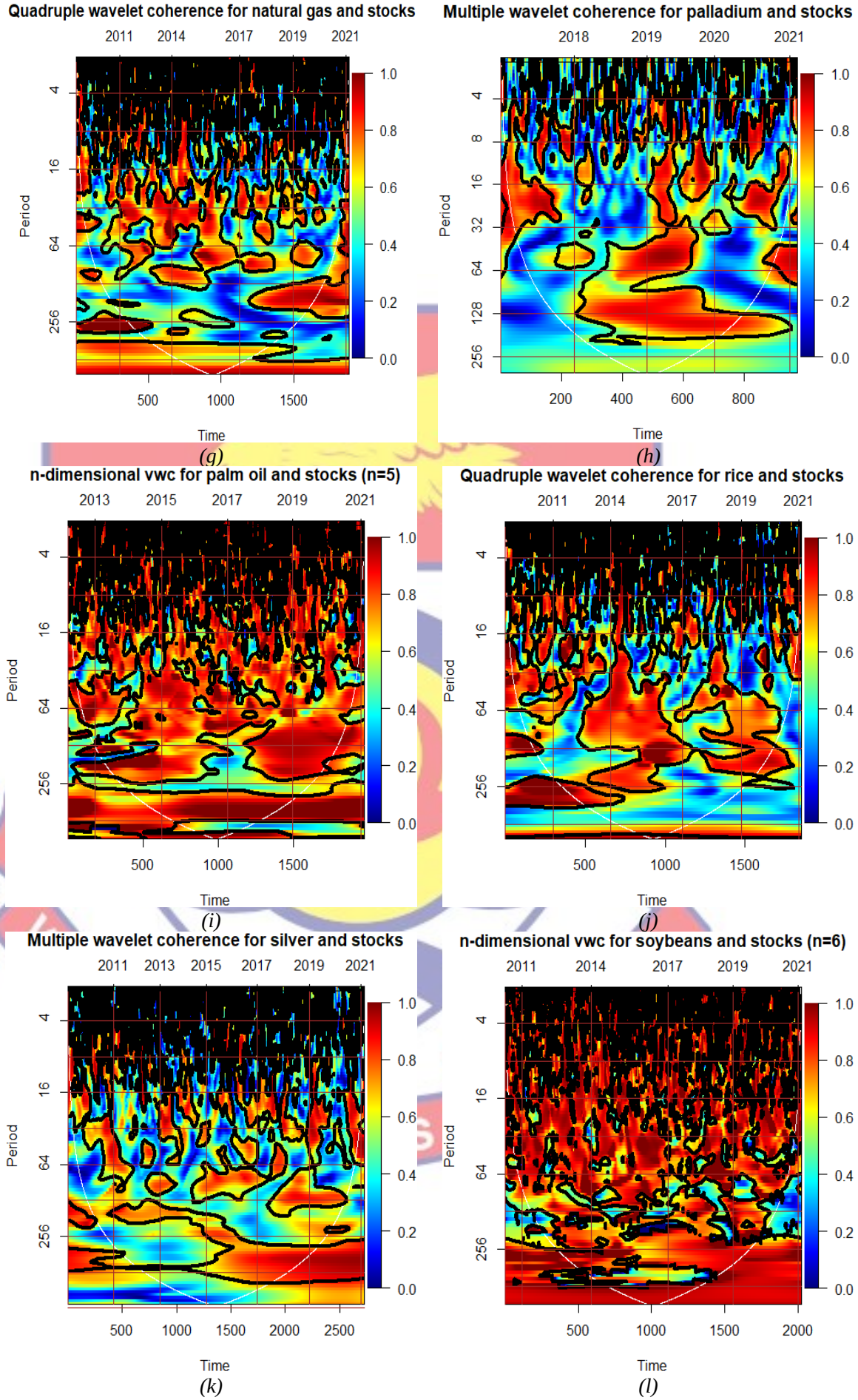


Figure 3: Vector Wavelet Coherence of Commodities and Stock Returns
Source: Estimations based on data from EquityRT (2022) from 22/02/10 to 04/02/22.

The vertical (horizontal) axis of each plot represents daily frequencies or periodic scales (time-steps). With the daily return series, wavelet scales were defined as 2-4 (intraweek), 4-16 (intraweek-to-fortnight), 16-64 (fortnight-to-quarter), and 64-256 (quarter-to-annual) daily trading cycles. The periodic scales or frequencies are representative of economic or investment horizons of short-, medium-, and long-term whereas the time-steps are the regular calendar time. Low frequencies represent high scales with high frequencies denoting low scales. The thick black contour represents the 5% significance threshold versus red noise, which was calculated using Monte Carlo simulations. A lighter shade of white line represents the cone of influence (COI), which denotes the region in which interdependencies are significant. Interrelations outside the COI lack statistical significance. The power colour code or bar runs from blue (low power) to red (high power).

Generally, the results divulged high dependence between stock market returns and commodities at high frequencies, specifically between the 2~4 wavelet scale (which matches the daily to weekly periodicities) which represents the short-term investment or economic trading cycle. However, the strength or power of interdependence between the respective stock markets and cocoa and palladium was exceptionally low for the short- and medium-term wavelet scales (2~64 daily periodicities) corresponding to the weekly and quarterly economic trading periods. It is worth noting that the respective stock market returns and their cocoa and palladium returns stand the chance of being highly interdependent in the long-term (around 128 up to 256 cycles).

Across the intermediate-to-long-term frequencies (64~128 wavelet scale), reductions in power and significance of the interdependence between the

stock and commodity markets' returns are observed for natural gas, rice, and silver. These reductions vary across frequencies and commodity samples. Thus, the reductions are largely conditional on market states across the various commodity and equity markets. Corn and soybeans tend to have the highest interdependence with their matching stock markets. This supports the preliminary observation from the descriptive statistics, which confirmed the highly volatile state of agricultural commodities in general (Frimpong et al., 2021; Umar, Jareño, & Escribano, 2021e).

For coffee, copper, crude oil, and palm oil, the VWC plots indicate interspersed degrees of interdependence among the respective commodity returns and stock market yields. Generally, in the intermediate (short) term, moderate (strong) interdependence – with varying significance – between commodity and stock markets' returns could be spotted from the VWC plots. The observations based on asset classes were delineated as follows.

Precious metals

In general, the VWC for gold (Figure *3f*), silver (Figure *3k*), palladium (Figure *3h*), and copper (Figure 3*4c*) showed qualitatively similar results. With mild coherence power in the mid-to-long term for gold, silver, and palladium, there are possible prospects for diversification between African equities and precious metals either in the medium-term or the long-term, as evidenced by moderate coherence power from the scalograms. Thus, for the class of precious metals and African equities, the overall observation that was made from the results suggested moderate interdependence across the medium- and long-term frequencies with some peculiarities among the various commodities.

Grains

Among the class of grains and the respective African equities, in general, the VWC for corn (Figure *3d*), rice (Figure *3j*), and soybeans (Figure *3l*) showed qualitatively similar results. Except for rice that proved inconsistently exceptional in some instances, the high coherence power in the short-, mid-, and long-term periods for all groups, suggested that no prospects for diversification between African equities and grains could be envisaged either in the short-, medium-, or the long-term, as evidenced by high coherence power from the scalograms. Thus, for the class of grains and African equities, the overall observation that was made from the results suggested high interdependence across the short-, medium-, and long-term scales with a few peculiarities for rice, which was inconsistent across the studied period.

Softs

Generally, among the class of softs and the respective African equities, the VWC for cocoa (Figure *3a*) and coffee (Figure *3b*) showed qualitatively dissimilar coherences but were comparable for some time scales across the medium-term frequencies. The group of African equities and cocoa exhibited low coherence power in the short- and mid-term periods, suggesting viable prospects for diversification between African equities and cocoa in the short- and medium-term horizons. For the group of African equities and coffee, diversification prospects could be envisaged at interspersed frequencies and time scales. Thus, for the class of softs and African equities, the overall observation that was made from the results suggested low interdependence across the short- and medium-term scales with a few peculiarities for coffee, which was inconsistent across the studied period.

Energies

The VWC for the class of energies – crude oil (Figure *3e*) and natural gas (Figure *3g*) – and the respective African equities generally showed qualitatively similar results. The high coherence power in the short- and mid-term frequencies were interspersed with low coherence power and this suggested that viable prospects for diversification between African equities and energies could be envisaged in the long-term, as evidenced by moderate coherence power from the scalograms. Thus, for the class of energies and African equities, the overall observation that was made from the results suggested high interdependence across the short- and medium-term scales.

Unclassified

The unclassified class of commodities related to palm oil (Figure *3i*), which from the scalogram, depicted high coherence power across most scales. with a consistent moderate coherence power between the group of African equities and palm oil in the long term, this research found that the prospect for diversification between these assets could be envisaged in the long term. Thus, for the unclassified commodity group and African equities, the overall observation that was made from the results suggested high interdependence across the short- and medium-term scales but moderate interdependence across the long-term frequencies.

Spillover connectedness between returns on African equities and global commodities in a unified system

The second objective aimed at investigating spillover effects between commodity and stock returns in Africa. For this objective, the newly developed spillover index approach hinged on time-varying parameter autoregressions

(TVP-VAR) of Antonakakis et al. (2020) was employed. Assessments of the spillover dynamics between markets and asset classes are essential for asset selection and fund allocation for a well-suited portfolio based on the risk appetite of investors and market players (Diebold et al., 2017; Zaremba et al., 2021a). The wake of contemporary alliances and liberalisation of market powers in recent periods are suggestive of prospective high market integration. Notwithstanding, given the increasing commodity financialisation, commodities may tend to have similar features to traditional assets like stocks and bonds (Hu et al., 2020; Idilbi-Bayaa & Qadan, 2021; Zaremba et al., 2021a).

As a result, knowing how the returns on commodity classes and stock markets have evolved over the period serves as a vital instrument for risk management and market regulation (Bossman, Owusu Junior, & Tiwari, 2022; Diebold et al., 2017; Zaremba et al., 2021a). The TVP-VAR connectedness measure does well over previous approaches such as the connectedness approach of Diebold and Yilmaz (2014) by allowing the variance-covariance matrix to vary via a Kalman filter estimation with forgetting factors in the view of Koop and Korobilis (2014). Furthermore, the arbitrary selection of window size and possible loss of observation in the course of dynamic connectedness estimations in a rolling window framework from the spillover index of Baruník and Křehlík (2018) is overcome by the TVP-VAR-based connectedness (Antonakakis et al., 2020). Therefore, the TVP-VAR-based connectivity measure served as the best approach to be used in this research in line with the second objective.

The results from the TVP-VAR spillover connectedness approach are presented in three stages. First, the overall static connectedness of markets is

presented in spillover tables for each commodity-based sample. The time-varying and directional spillovers are presented in the second and third stages, respectively.

Static connectedness analysis

Tables 5-16 display the overall system connectedness of the various commodities and their accompanying stock markets in a static paradigm. For each Table, 'FROM others' (last column) represents the system's return spillovers contributed by all other variables to a stated variable. 'TO others' (third to the last row) displays return spillovers from a named variable to the system of all other variables. 'NET' (penultimate row) shows the net directional return spillovers of each variable. TCI (bold, right bottom corner) is the total connectedness index of the system of all variables. The last row displays the net pairwise directional spillovers, which are reported to only give supplementary insights on the pairwise position of each variable. Highlights from the spillover Tables are presented in turns.

Table 5: Total Connectedness Index of Stocks and Cocoa

	Ghana	Ivory Coast	Cocoa	FROM others
Ghana	98.07	0.57	1.37	1.93
Ivory Coast	0.77	98.57	0.67	1.43
Cocoa	1.26	0.61	98.13	1.87
TO others	2.02	1.17	2.03	5.23
Inc. own	100.09	99.74	100.17	TCI
NET	0.09	-0.26	0.17	**1.74**
NPDC	1.00	2.00	0.00	

Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The overall degree of interconnectedness of cocoa and stock returns is expressed by the TCI, which is 1.74%, in the right bottom corner of Table 5. This means that the combined dynamics of the system variables may explain roughly 2% of the variations in the system variables. Turning to the last but

second-row ("TO"), each variable's contribution to the system's connectedness is found. Ghana (2.02%) and cocoa (2.03%) are the largest providers of spillover "TO" the system. The last column "FROM" depicts the spillover received by each variable from the system. Again, Ghana and cocoa are the main recipients of the system spillovers (1.93% and 1.87%, respectively). The net spillover for each variable is shown in the last row ("NET") of Table 5. A positive (negative) value indicates a net transmitter (receiver) of spillovers. Cocoa and Ghanaian stock returns are the net transmitters whereas stocks from Ivory Coast are net spillover receivers.

Table 6: Total Connectedness Index of Stocks and Coffee

	I.Coast	Kenya	Tanzania	Uganda	Coffee	FROM others
I.Coast	95.63	1.29	1.52	1.01	0.55	4.37
Kenya	1.21	90.31	4.37	3.64	0.48	9.69
Tanzania	1.18	11.87	70.93	13.4	2.62	29.07
Uganda	0.63	22.66	14.07	61.3	1.35	38.7
Coffee	0.53	0.85	1.8	2.13	94.69	5.31
TO others	3.54	36.67	21.75	20.18	4.99	87.14
Inc. own	99.18	126.98	92.68	81.48	99.68	TCI
NET	-0.82	26.98	-7.32	-18.52	-0.32	**17.43**
NPDC	4	0	2	2	2	

Notes: I.Coast is Ivory Coast.
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The overall connectedness of coffee and stock returns is expressed by the TCI, which is 17.43%, in the right bottom corner of Table 6. This means that the combined dynamics of the system variables may explain roughly 17% of the variations in the system variables. Kenya (36.67%) and Tanzania (21.75%) are the largest providers of spillover "TO" the system whiles Uganda (38.7%) and Tanzania (29.07%) serve as the main recipients of the system spillovers. Whiles Kenya acts as a net transmitter of shocks, Ivory Coast, Tanzania, Uganda, and coffee are all net shock recipients.

Table 7: Total Connectedness Index of Stocks and Copper

	Namibia	South Africa	Zambia	Copper	FROM others
Namibia	69.78	25.14	0.24	4.84	30.22
South Africa	25.31	63.74	0.59	10.35	36.26
Zambia	0.79	1.37	97.07	0.77	2.93
Copper	6.46	11.55	0.75	81.25	18.75
TO others	32.56	38.05	1.58	15.97	88.16
Inc. own	102.34	101.79	98.66	97.22	TCI
NET	2.34	1.79	-1.34	-2.78	**22.04**
NPDC	0	1	3	2	

Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The TCI of copper and stock returns is 22.04%, in the right bottom corner of Table 7. This means that the combined dynamics of the system variables may explain roughly 22.04% of the variations in the system variables. South Africa (32.56%) and Namibia (32.56%) are the largest providers of spillover "TO" the system whiles South Africa (36.26%) and Namibia (30.22%) serve as the main recipients of the system spillovers. The net transmitters (recipients) of system spillovers are Namibia and South Africa (Zambia and coffee).

Table 8: Total Connectedness Index of Stocks and Corn

	Egypt	Kenya	Malawi	Nigeria	S.Africa	Uganda	Corn	FROM others
Egypt	74.76	4.01	0.19	0.97	17.49	0.69	1.9	25.24
Kenya	3.96	75.59	0.24	2.71	5.76	10.33	1.42	24.41
Malawi	0.25	1.08	96.89	0.29	0.65	0.36	0.48	3.11
Nigeria	0.67	3.31	0.28	88.32	4.05	2.87	0.5	11.68
S.Africa	15.96	5.07	0.54	2.6	70.82	1.32	3.68	29.18
Uganda	1.52	23.9	0.42	4.35	3.05	66.07	0.69	33.93
Corn	2.46	1.55	0.47	0.82	4.32	0.55	89.82	10.18
TO others	24.82	38.92	2.15	11.74	35.32	16.12	8.67	137.73
Inc. own	99.57	114.5	99.03	100.07	106.14	82.2	98.49	TCI
NET	-0.43	14.5	-0.97	0.07	6.14	-17.8	-1.51	**19.68**
NPDC	3	1	5	2	0	6	4	

Notes: S.Africa is South Africa.
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The TCI of corn and stock returns from African markets is 19.68%, as reported in Table 8. This suggests that roughly 20% of the variations in the system are explained by the combined dynamics of the system variables. Kenya (38.92%) and South Africa (35.32%) are the largest providers of spillover "TO"

the system whiles Uganda (33.93%) and South Africa (29.18%) receive the most system spillovers. The net transmitters (recipients) of system spillovers are the market returns from Kenya, Nigeria, and South Africa (Egypt, Malawi, Uganda, and corn).

Table 9: Total Connectedness Index of Stocks and Crude Oil

	Egypt	Morocco	Nigeria	Tunisia	C.Oil	FROM others
Egypt	72.68	15.83	1.08	3.9	6.5	27.32
Morocco	15.21	70.21	0.4	9.76	4.42	29.79
Nigeria	0.71	0.96	97.49	0.22	0.61	2.51
Tunisia	5.07	14.62	0.21	79.78	0.31	20.22
C.Oil	7.77	5.17	0.09	0.49	86.48	13.52
TO others	28.76	36.59	1.8	14.37	11.85	93.36
Inc. own	101.43	106.79	99.29	94.15	98.33	TCI
NET	1.43	6.79	-0.71	-5.85	-1.67	**18.67**
NPDC	2	0	3	2	3	

Notes: C.Oil is Crude Oil.
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The overall connectedness of crude oil and stock returns is expressed by the TCI, which is 18.67%, in the right bottom corner of Table 9. This means that the combined dynamics of the system variables may explain about 19% of the variations in the system variables. Morocco (36.59%) and Egypt (28.76%) are both the largest providers and recipients of system spillovers, making them the net transmitters of spillovers with a 'NET' spillover index of 6.79% and 1.43%, respectively. Meanwhile, Nigeria (-0.71%), Tanzania (-5.85%), and crude oil (-1.67%) are net system shock recipients.

Table 10: Total Connectedness Index of Stocks and Gold

	Ghana	I.Coast	S.Africa	Tanzania	Gold	FROM others
Ghana	97.11	0.75	0.89	0.43	0.81	2.89
I.Coast	1.31	93.2	1.4	1.45	2.65	6.8
S.Africa	0.93	1.25	89.77	1.65	6.39	10.23
Tanzania	0.67	1.23	7.43	89.32	1.36	10.68
Gold	0.56	1.75	4.49	0.95	92.26	7.74
TO others	3.46	4.98	14.2	4.48	11.21	38.35
Inc. own	100.57	98.18	103.98	93.8	103.47	TCI
NET	0.57	-1.82	3.98	-6.2	3.47	**7.67**
NPDC	1	4	2	3	0	

Notes: I.Coast is Ivory Coast; S.Africa is South Africa.
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The TCI of gold and stock returns from African markets is 7.67%, as reported in Table 10. This implies that roughly, less than 8% of the variations in the system are explained by the combined dynamics of the system variables. South Africa (14.2%) and gold (11.21%) are the largest providers of spillovers "TO" the system whiles Tanzania (10.68%) and South Africa (10.23%) receive the most system spillovers. The net transmitters (recipients) of system spillovers are the market returns from Ghana, South Africa, and gold (Ivory Coast and Tanzania).

Table 11: Total Connectedness Index of Stocks and Natural Gas

	Egypt	Nigeria	Tanzania	Natural Gas	FROM others
Egypt	97.31	1.03	0.48	1.17	2.69
Nigeria	0.49	96.14	2.61	0.75	3.86
Tanzania	3.2	5.85	90.19	0.76	9.81
Natural Gas	0.53	0.91	1.2	97.37	2.63
TO others	4.22	7.79	4.29	2.69	18.98
Inc. own	101.54	103.93	94.48	100.06	TCI
NET	1.54	3.93	-5.52	0.06	**4.75**
NPDC	2	0	2	2	

Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The TCI of natural gas and stock returns from African markets is 4.75%, as reported in Table 11. This suggests that roughly 5% of the variations in the system are explained by the combined dynamics of the system variables.

Nigeria (7.79%) transmits the largest spillover "TO" the system while Tanzania (9.81%) receive the most system spillovers. The net transmitters of system spillovers are the market returns from Nigeria (3.93%), Egypt (1.54%), and natural gas (0.06%). Tanzania is the only net recipient of spillovers in the system.

Table 12: Total Connectedness Index of Stocks and Palladium

	South Africa	Zimbabwe	Palladium	FROM others
South Africa	81.22	0.77	18	18.78
Zimbabwe	0.65	99.02	0.32	0.98
Palladium	17.66	0.16	82.18	17.82
TO others	18.31	0.94	18.33	37.57
Inc. own	99.53	99.96	100.51	TCI
NET	-0.47	-0.04	0.51	**12.52**
NPDC	2	1	0	

Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The overall connectedness of palladium and stock returns is expressed by the TCI, which is 12.52%, in the right bottom corner of Table 12. This means that the combined dynamics of the system variables may explain about 13% of the variations in the system variables. South Africa (18.31%) and Palladium (18.33%) are the largest providers and recipients (18.78% and 17.82, respectively) of system spillovers. Stock returns from South Africa (-0.47%) and Zimbabwe (-0.04%) are net recipients of spillovers from palladium's net transmitter position with a net index of (0.51%).

Table 13: Total Connectedness Index of Stocks and Palm Oil

	Ghana	I.Coast	Kenya	S.Africa	P.Oil	FROM others
Ghana	94.28	0.48	3.53	0.54	1.18	5.72
I.Coast	0.95	95.65	1.07	1.99	0.34	4.35
Kenya	3.04	1.77	88.49	5.32	1.39	11.51
S.Africa	0.59	1.62	4.33	86.94	6.53	13.06
P.Oil	0.97	0.38	1.35	6.91	90.39	9.61
TO others	5.56	4.24	10.28	14.76	9.43	44.26
Inc. own	99.83	99.89	98.76	101.69	99.82	TCI
NET	-0.17	-0.11	-1.24	1.69	-0.18	**8.85**
NPDC	2	2	3	1	2	

Notes: I.Coast is Ivory Coast; S.Africa is South Africa; P.Oil is Palm Oil.
Source: Estimations based on data from EquityRT (2022) from 22/02/10 to 04/02/22.

The TCI of palm oil and stock returns from African markets is 8.85%, as reported in Table 13. This suggests that roughly 9% of the variations in the system are explained by the combined dynamics of the system variables. South Africa (14.76%) and Kenya (10.28%) transmit and receive (13.06% and 11.51%, respectively) the largest spillovers "TO" and "FROM" the system. With a net spillover index of 1.69%, South Africa is the only net transmitter of system spillovers whiles Ghana (-0.17%), Ivory Coast (-0.11%), Kenya (-1.24), and palm oil (-0.18) are net spillover receivers.

Table 14: Total Connectedness Index of Stocks and Rice

	Egypt	Nigeria	Tanzania	Rice	FROM others
Egypt	68.26	0.88	9.33	21.53	31.74
Nigeria	1.35	95.06	2.82	0.78	4.94
Tanzania	13.59	4.66	73.32	8.43	26.68
Rice	18.54	0.41	6.87	74.18	25.82
TO others	33.47	5.95	19.02	30.74	89.18
Inc. own	101.73	101.01	92.34	104.92	TCI
NET	1.73	1.01	-7.66	4.92	**22.29**
NPDC	1	2	3	0	

Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The overall connectedness of rice and stock returns is expressed by the TCI, which is 22.29%, in the right bottom corner of Table 14. This means that the combined dynamics of the system variables may explain a little over 22% of the variations in the system variables. Egypt serves as both the largest provider (33.47%) and the largest recipient (31.74%) of system spillovers. The net transmitters of spillovers are Egypt (1.73%), Nigeria (1.01%), and rice (4.92%). Meanwhile, Tanzania (-7.66%) serves as a net system spillover recipient.

Table 15: Total Connectedness Index of Stocks and Silver

	Namibia	Zambia	Silver	FROM others
Namibia	94.44	0.17	5.39	5.56
Zambia	0.63	98.9	0.47	1.1
Silver	5.27	0.4	94.32	5.68
TO others	5.9	0.58	5.86	12.33
Inc. own	100.34	99.48	100.18	TCI
NET	0.34	-0.52	0.18	**4.11**
NPDC	1	2	0	

Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The TCI of silver and stock returns from African markets is 4.11%, as reported in Table 15. This suggests that roughly 4% of the variations in the system are explained by the combined dynamics of the system variables. Namibia (0.34%) and silver (5.86%) transmit and receive (5.56% and 5.68%, respectively) the largest spillovers "TO" and "FROM" the system. With a net spillover index of -0.52%, Zambia is the only net recipient of system spillovers from the net transmitter positions of Namibia (0.34%) and silver (0.18%) in the system.

Table 16: Total Connectedness Index of Stocks and Soybeans

	Ghana	Malawi	Nigeria	Uganda	Zambia	Soybeans	FROM others
Ghana	94.06	0.7	0.66	1.28	2.18	1.12	5.94
Malawi	0.74	97.24	0.22	0.49	0.76	0.55	2.76
Nigeria	0.95	0.26	96.38	1.16	0.6	0.66	3.62
Uganda	0.86	0.54	5	91.2	1.13	1.27	8.8
Zambia	2.35	0.75	3.2	1.19	91.43	1.08	8.57
Soybeans	0.73	0.43	0.76	2.95	0.98	94.16	5.84
TO others	5.63	2.67	9.84	7.07	5.66	4.67	35.54
Inc. own	99.69	99.92	106.21	98.26	97.09	98.83	TCI
NET	-0.31	-0.08	6.21	-1.74	-2.91	-1.17	**5.92**
NPDC	2	3	2	2	4	2	

Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

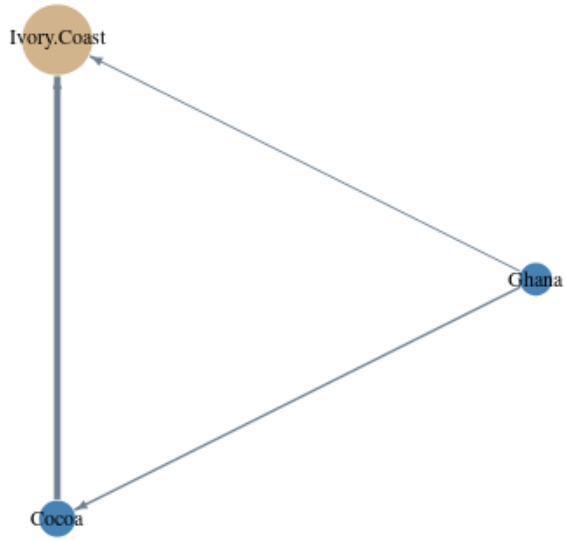
The TCI of soybeans and stock returns from African markets is 5.92%, as reported in Table 16. This suggests that roughly 6% of the changes in the system are explained by the combined dynamics of the system variables. Nigeria (9.84%) and Uganda (7.07%) transmit the largest spillovers "TO" the

system whiles Uganda (8.8%) and Zambia (8.57%) receive the most system spillovers. The net transmitters of system spillovers are the market returns from Nigeria (6.1%) only. Ghana (-0.31%), Malawi (-0.08%), Uganda (-1.74%), Zambia (-2.91%), and Soybeans (-1.17%) are all net recipients of spillovers in the system.

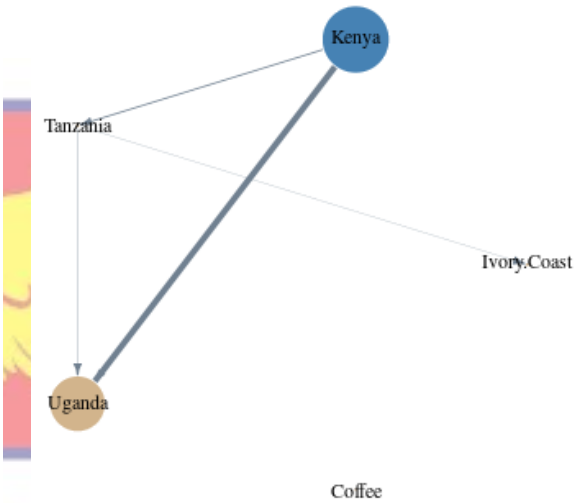
Remarkably, from all the spillover tables, an essential observation that needed to be highlighted was the extent to which individual commodity and equity markets' returns were induced by their 'own' shocks. Indicatively, of the total spillovers they received, the market-own return shocks for the various commodities included cocoa (98.13%), coffee (94.96%), copper (81.25%), corn (89.82%), crude oil (86.48%), gold (92.26%), natural gas (97.37%), palladium (82.18%), palm oil (90.39%), rice (74.18%), sugar (94.32%), and soybeans (94.16%). These findings are similar to individual equity market returns, as they also recorded a high proportion of overall spillovers from self-induced return risks. For instance, from the palladium sample, Zimbabwe records as high as 99.02% spillovers from its own market. Among others, Ivory Coast (98.57%), Nigeria (97.49%), Egypt (97.31%), Malawi (97.42%), Ghana (97.11%), and Zambia (97.07%), all recorded high own market-generated spillovers from their respective corresponding commodity-based samples as indicated above.

The static connectedness analysis of commodity and respective stock markets was cemented with their net pairwise plots, which were reported in Figure 4. This research used network analysis to properly evaluate the pairwise connectedness of net transmitters and receivers of spillovers in the system. The network analysis aided in identifying the net transmitters and net recipients of spillovers on a pairwise basis. Figure 4 shows global commodities and African

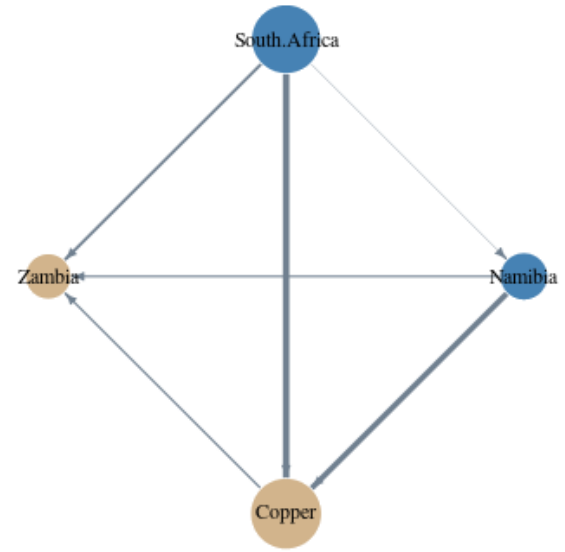
equity market returns' net pairwise connectivity patterns and linkages. These plots complement the NET and NPDC positions of the variables as reported in each of the spillover tables.



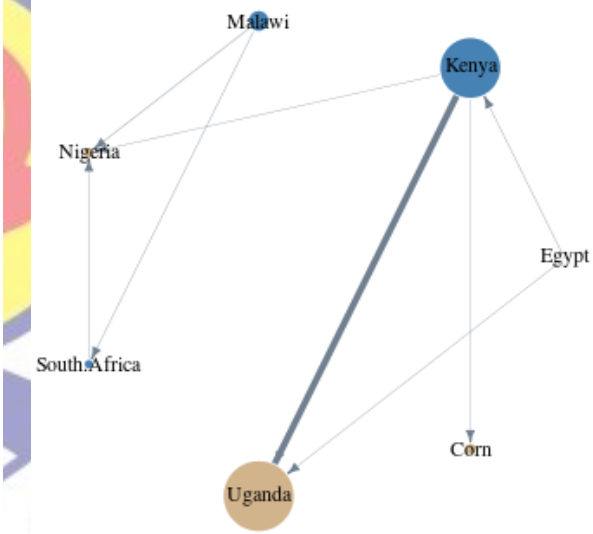
(a) cocoa network



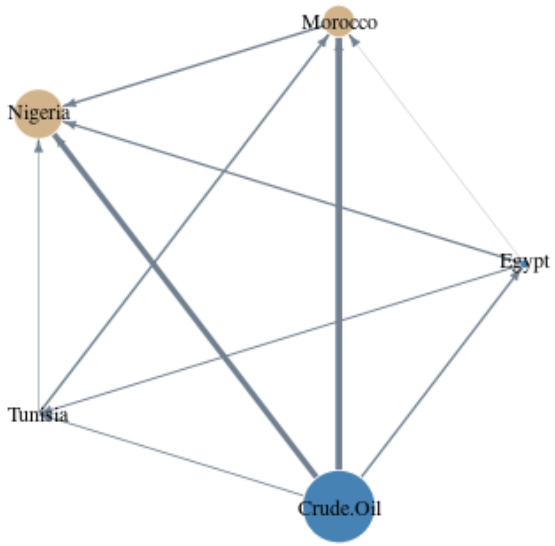
(b) coffee network



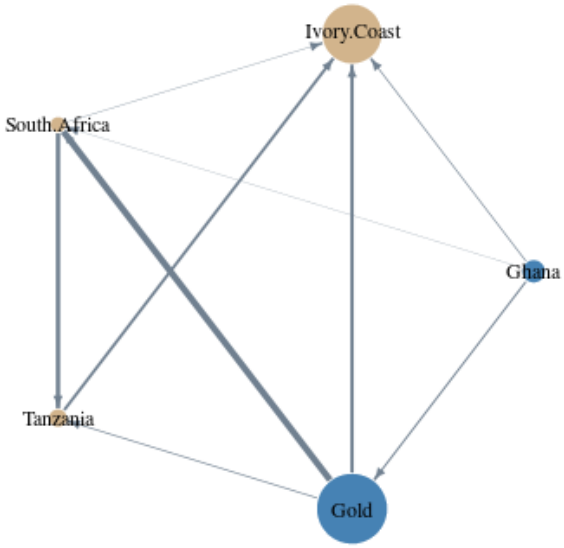
(c) copper network



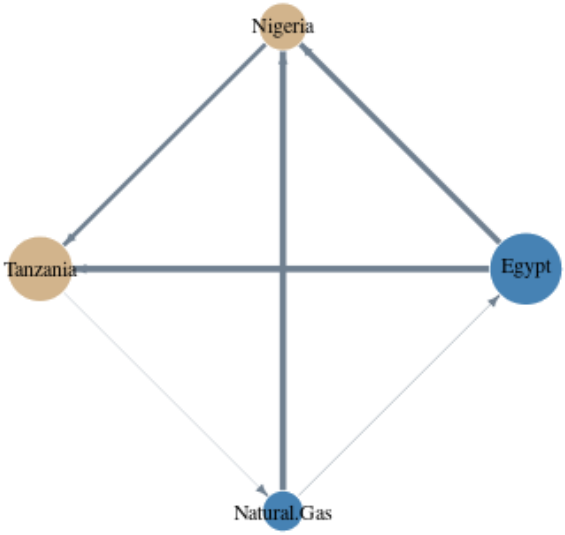
(d) corn network



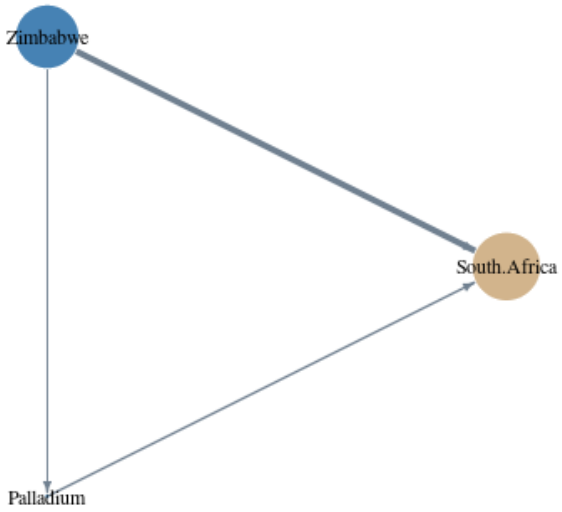
(e) crude oil network



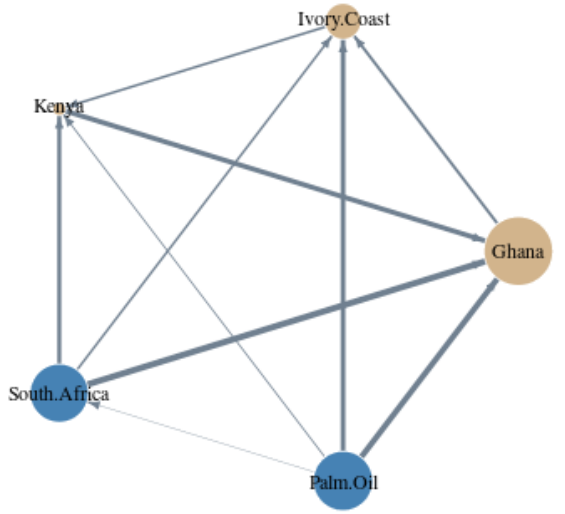
(f) gold network



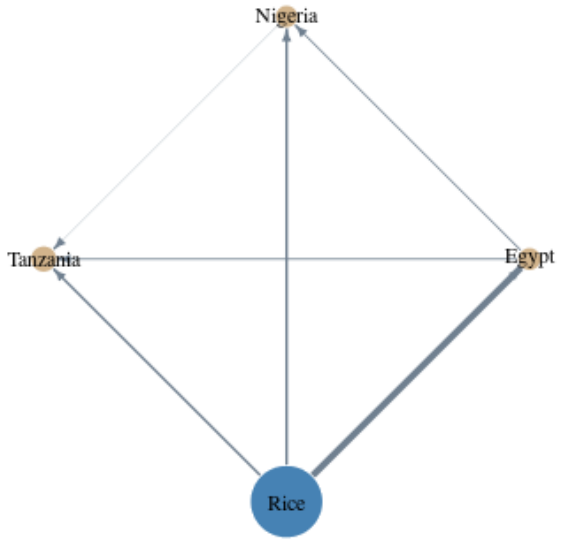
(g) natural gas network



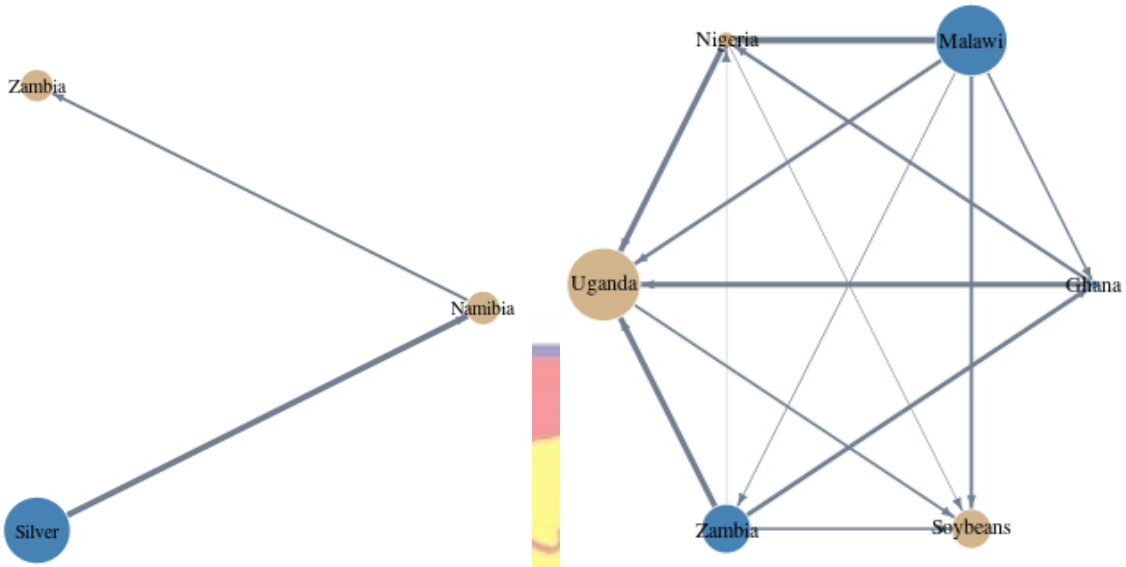
(h) palladium network



(i) palm oil network



(j) rice network



(k) silver network (l) soybeans network

Figure 4: Network Plots of Commodity and Stock Markets' Returns
Source: Estimations based on data from EquityRT (2022) over the period 22/02/2010 to 04/02/ 2022.
Notes: Blue (brown) nodes signify the net transmitter (receiver) of spillovers or shocks. Vertices are weighted by averaged net pairwise directional connectedness measures. The size of nodes represents weighted average net total directional connectedness.

In the respective commodity-based networks, Ivory coast (cocoa), Uganda (coffee), Zambia and copper (copper), Uganda (corn), Nigeria and Morocco (crude oil), Ivory Coast, South Africa, and Tanzania (gold), Tanzania and Nigeria (natural gas), South Africa (palladium), Ghana and Ivory Coast (palm oil), Tanzania, Nigeria, and Egypt (rice), Namibia and Zambia (silver), and Uganda and Soybeans (soybeans), were all net recipients of return spillovers in their (named) networks. The net recipient positions are shown by the brown nodes. All other variables from the network were net transmitters of spillovers, as depicted by the blue nodes. The net recipients are potential hedgers for other variables in the system which were further analysed through the time-varying or dynamic connectedness.

Static spillover analysis by asset/commodity classes

In terms of asset classes, from the static analysis, this research revealed similar spillover patterns for all commodity classes. Among precious metals, except for copper whose overall connectedness with the respective African equities exceeded 20%, all other spillover indices were below 20%. Similarly, in the class of grains, it was the rice and its accompanying African equities whose return spillovers exceeded 20% with corn and soybeans recording less than 20% system spillovers. Among the classes of softs, energies, and the unclassified, all spillovers were below 20%. These results, to some extent, corroborated the interdependence structure revealed for the commodity groups and their respective African equities.

Dynamic connectedness analysis

The study employed the dynamic technique in the second stage of the connectedness analysis for the variables (commodity and stock markets) of interest. This is a rolling window technique that helped overcome notable limitations associated with a static measure. As noted by Diebold and Yilmaz (2009, 2012, 2014), non-stationarity, probable structural breaks, instability, and the influence of fat tails in the data series are among the downsides of the static approach. When the system contains financial asset classes, a dynamic strategy is essential (Bossman, Owusu Junior, et al., 2022; Umar, Jareño, & Escribano, 2021e; Umar, Jareño, & González, 2021; Umar, Riaz, & Zaremba, 2021a, 2021b). Given the intensity of commodity financialisation, utilising dynamic analysis did not only help the researcher to understand the evolution of connectedness but also gave a valuable robustness test and a more informative picture of the linkages between the studied assets (Aharon et al., 2021).

This research employed the spillover connectedness approach of Antonakakis et al. (2020), and resorted to other works that use 200 days as the rolling window size, forecast horizon of 10 days, and lag length of one (Aharon et al., 2021; Antonakakis et al., 2020, 2021; Zaremba et al., 2021a). In the dynamic connectedness, the TCI is presented as a function of time, detailing the degree of market connectedness across the sample period for all samples. The results from the dynamic estimations were displayed in Figure 5 in order of the already defined commodity-based samples. The time periodicities in each sample were plotted against the horizontal axis with the accompanying spillover indices against the vertical axis. Highlights of the dynamic connectivity results were presented as follows.

The dynamic spillover plots showed that the connection between the system variables changes with time, which supported and substantiated the dynamic estimation performed in this research. In particular, one can see that the connectedness witnessed substantial hikes in certain periods. The connectedness index for cocoa and stock markets' returns generally varied from 0.5% to 5.8%. For the remaining commodity-based samples, the connectedness of the respective stock markets against commodities results in connectedness ranging between 5%-35% for the coffee sample, 12% to 45% for the copper sample, 9% to 60% for the corn sample, 5% to 48% for the crude oil sample, 3% to 45% for the gold sample, 3% to 43% for the natural gas sample, 3% to 20% for the palladium sample, 3% to 23% for the palm oil sample, 3% to 48% for the rice sample, 2% to 22% for the silver sample, and 5% to 68% for the soybeans sample.

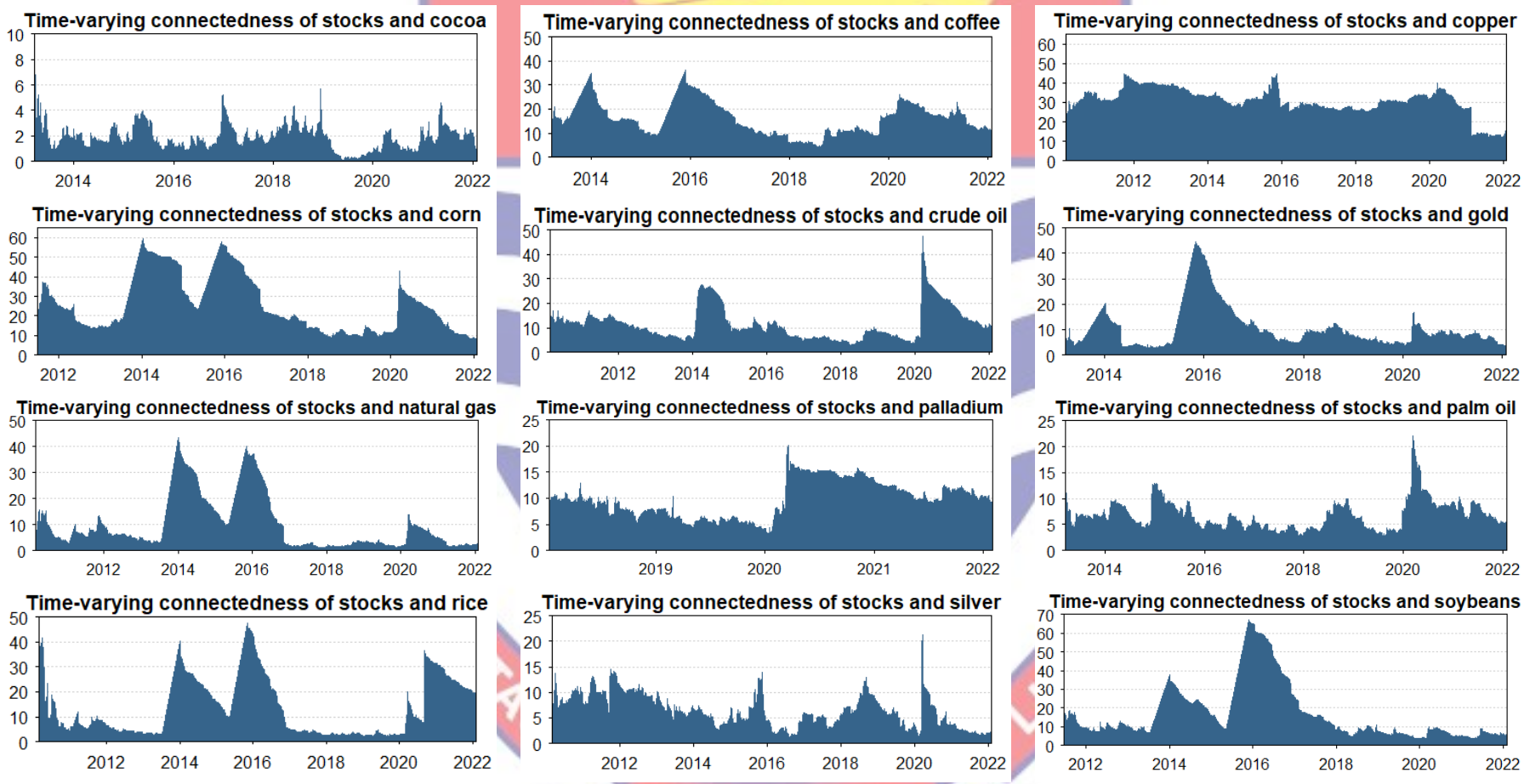


Figure 5: Time-Varying Connectedness of Commodity and Stock Returns
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The spillover plots communicate the essence of the time-varying analysis under a rolling window framework (Antonakakis et al., 2020; Umar, Yousaf, & Aharon, 2021). The intuition is that some essential relationships across time are likely to be hidden if the static connectedness measure is solely relied on (Aharon et al., 2021; Bossman, Owusu Junior, et al., 2022). Hence, in unveiling the intricate connectedness between commodity markets, it was appropriate for this research to conduct a dynamic connectedness analysis to supplement the static models.

Dynamic spillover analysis by asset/commodity classes

In terms of asset classes, from the time-varying spillover analysis, this research revealed similar spillover patterns for all commodity classes as were found for the static spillovers. Among precious metals, except for copper whose dynamic connectedness with the respective African equities exceeded 30%, all other spillover indices were less than or equal to 10% with hikes in 2014, 2016, and 2020. In the class of grains, rice and soybeans with their accompanying African equities had their time-varying return spillovers being less than 10% with some hikes in 2014, 2016, and 2020. Meanwhile, the time-varying spillovers for corn were in higher magnitudes as compared to those of rice and soybeans. Among the classes of softs, energies, and the unclassified, all spillovers were below 10% with similar notable hikes in 2014, 2016, and 2020.

Directional and net spillover connectedness analysis

So far, the general dynamic analysis used in this research has revealed that the interconnectedness of the variables in the system varies across time. Whilst the significance of the dynamic analysis could not be overemphasised, examining the contribution of each variable to the system's overall linkages,

was just as significant. This aids our understanding of each commodity and stock market's potential role(s) in risk reduction. As a result, this research further explored each variable's dynamic connectivity with the whole system. Figure A1 (in the Appendix) contains plots that provide details on how each variable interacts with its respective commodity-based systems.

The magnitude with which spillovers are transmitted or received in each system is commodity-dependent. For the cocoa sample, the "TO" and "FROM" spillovers measure up to 13%; for the coffee sample, up to 80% (transmitted by Kenya) and 60% (received by Uganda) are the highest directional spillovers; for the copper sample, up to 70% (contributed by Namibia and South Africa); for the corn sample, up to 80% (contributed by Kenya and Malawi); for the crude oil sample, up to 80% (transmitted by Morocco) and 60% (received by Egypt and Morocco); for the gold sample, up to 60% (both received and transmitted by Ghana); for the natural gas sample, up to 60% (transmitted by Tanzania) and 50% (received by Tanzania and Egypt); for the palladium sample, up to 30% (transmitted by South Africa and received by Palladium and South Africa); for the palm oil sample, up to 40% (transmitted by South Africa and received by South Africa and Kenya); for the rice sample, up to 90% (received by Nigeria); for the silver sample, up to 32% (contributed by Namibia); for the soybeans sample, up to 80% (contributed by Malawi and Zambia).

In terms of net directional spillovers (as reported in Figure A2 in the Appendix), this research revealed that all variables in the cocoa samples switched between the roles of net transmitters and net recipients of system spillovers. For the coffee sample, Kenya and Uganda were found as net transmitters and recipients, respectively, whiles Ivory Coast, Tanzania, and

coffee had varied transmission positions. From the copper sample, copper and Zambia (Namibia and South Africa) were found to be net spillover receivers (transmitters) across the sample period. Kenya and Uganda, respectively, served as a net transmitter and receiver of spillovers in the corn sample whilst the remaining variables had varied positions across the period. From the crude oil sample, this research reports that Morocco (Tunisia and crude oil) consistently received (transmitted) net spillovers until the COVID-19 period when it (they) transmitted (received) net spillovers. Nigeria was found largely as a net recipient of spillovers whilst Egypt switched positions. All variables in the natural gas, palladium, palm oil, rice, silver, and soybeans samples are inconsistent with their roles as either net transmitters or receivers.

Information flow between returns on African equities and global commodities

The third objective sought to examine the situated information flow between commodities and African equities. The effective transfer entropy – specifically, the Rényi transfer entropy (RTE) approach – was employed to facilitate the achievement of this objective. Other strands of TE such as the Shannon entropy (SE) and the "Largest Lyapunov Exponent" (LLE) based on approximation entropy were considered inappropriate because SE fails to attribute equal weights to all probable expectations in a probability distribution (Adam, 2020) whereas the LLE approximation-based entropy produces results that are biased by small samples (Bossman, 2021; Owusu Junior et al., 2021).

Fat-tails are pervasive in asset pricing, but SE does not overcome this assumption and because this research – as much as possible – aimed to minimise biased results in any form, the LLE was as well ignored. Therefore, with

considerably large samples, this study resorted to the RTE approach, which uses a weighting value q, to overcome the shortfall of SE, as specified in Equation (24). In this research, q was set at 0.30, as employed in the recent literature to account for fat tails (Adam, 2020; Asafo-Adjei, Owusu Junior, et al., 2021; Bossman, 2021; Bossman, Agyei, et al., 2022; Owusu Junior et al., 2021).

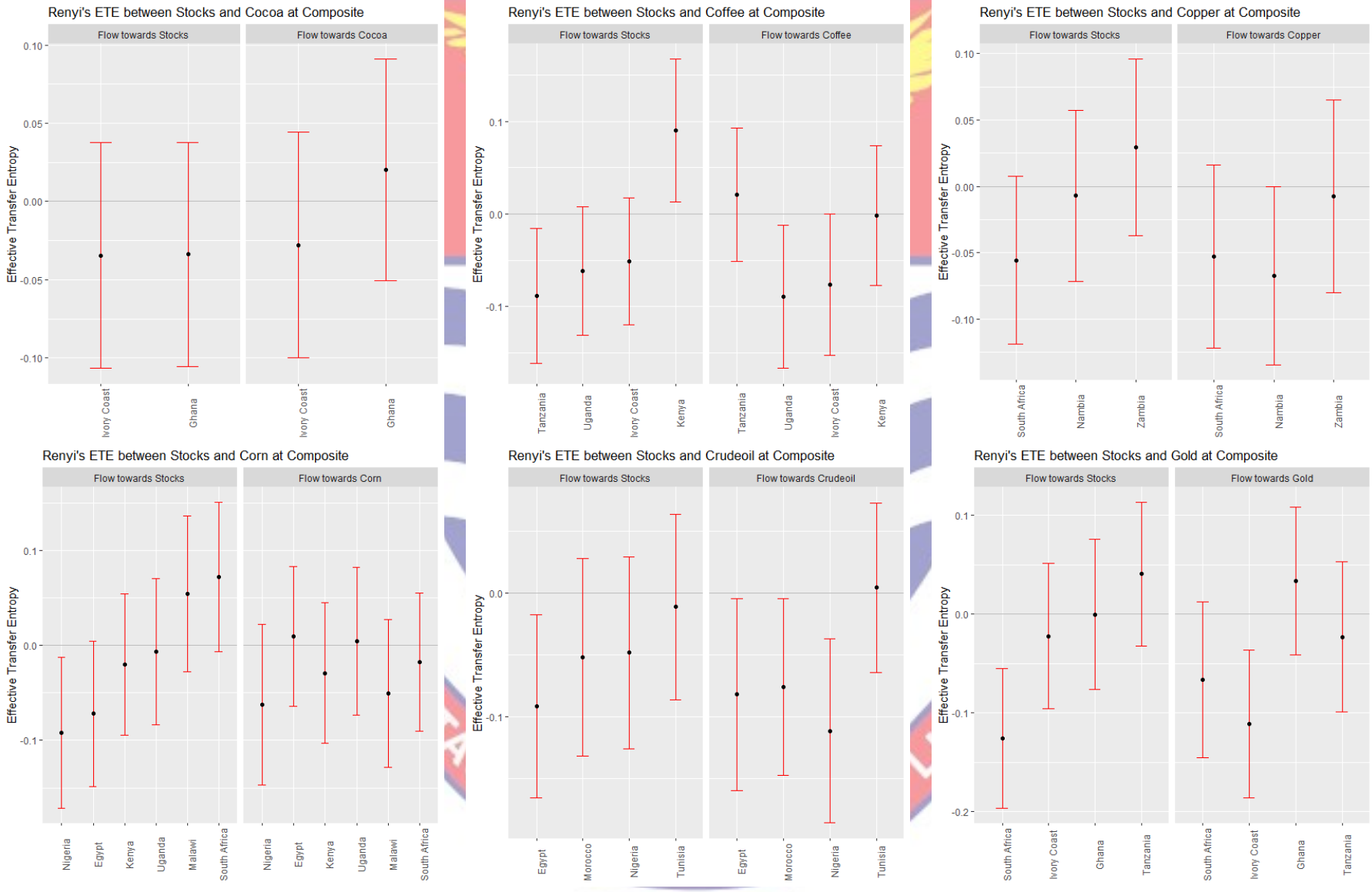
Furthermore, to provide results that are of significant importance for portfolio and policy actions, this research decomposed the signal data series into intramode functions (IMFs) using the ICEEMDAN approach, an Econophysics technique that has seen recent applications in finance literature (Bossman, 2021; Bossman, Agyei, et al., 2022; Colominas et al., 2014; Kou, Yang, Wu, & Li, 2020). With IMFs as inputs for the RTE, the quantification of the extent to which one variable (commodity returns) observe the behaviour of the other (stock returns) is facilitated by the situated information flow theory (SIFT) of Benthall (2019) which is based on the statistics and philosophy of Pearl (2009) and Dretske (1981), respectively.

This research followed the extant literature to represent the short term with IMF1, the medium-term with IMF5, and the long-term with the residual IMF (Ijasan, Owusu Junior, Tweneboah, Oyedokun, & Adam, 2021; Owusu Junior, Tiwari, Padhan, & Alagidede, 2020; Owusu Junior & Tweneboah, 2020). Estimation results were detailed for the signal data (composite) and IMFs, as detailed in Figures 7-10. The numerical ETEs accompanying the ETE plots in Figures 7-10 were reported in Table A1 in the Appendix.

From each Figure, frequency domain (composite) ETEs were demonstrated by black dots located in blue (red) bars. The ends of blue or red bars represent the 95% confidence bounds. Therefore, the hypothesis of *"no*

information flow" is not supported by any confidence bounds that fully fit in either the positive or negative region. ETEs are statistically non-significant if the confidence boundaries cross the origin. High-risk (low-risk) assets are depicted by negative (positive) ETEs.

It is worth noting that in terms of the third objective, which was based on the quantified information flow between the studied commodity and equity markets, the ETEs were largely similar regardless of the commodity or asset class. That is, as depicted by the ETE plots, the direction and significance of the transfer entropies between the returns on global commodities and African equities were largely comparable across commodity groups or asset classes. Therefore, the results were strictly presented based on the data levels, i.e., composite/signal (static domain) and IMFs (frequency domain). Where peculiar ETEs were spotted, they were thoroughly explained and discussed accordingly.



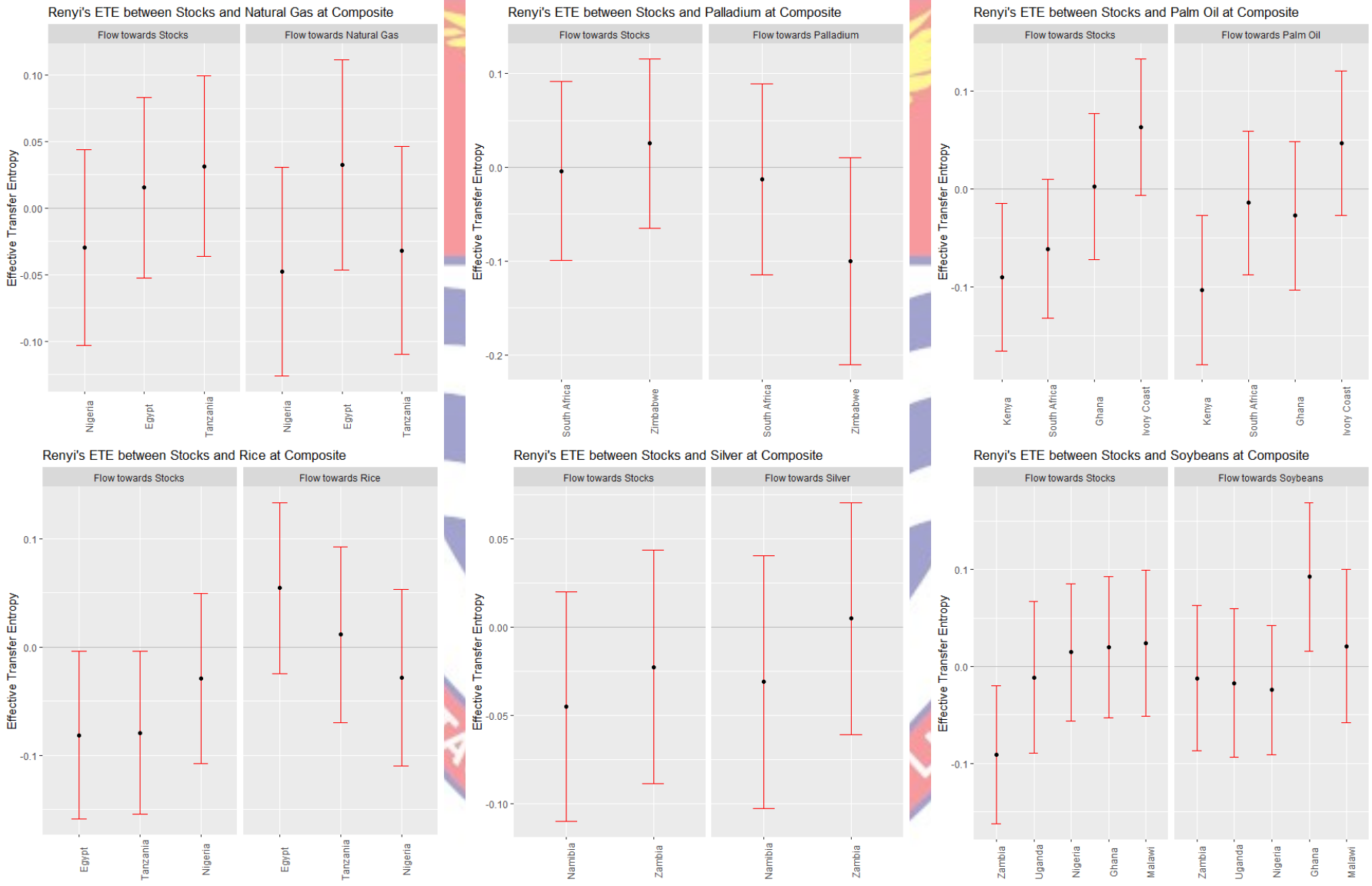
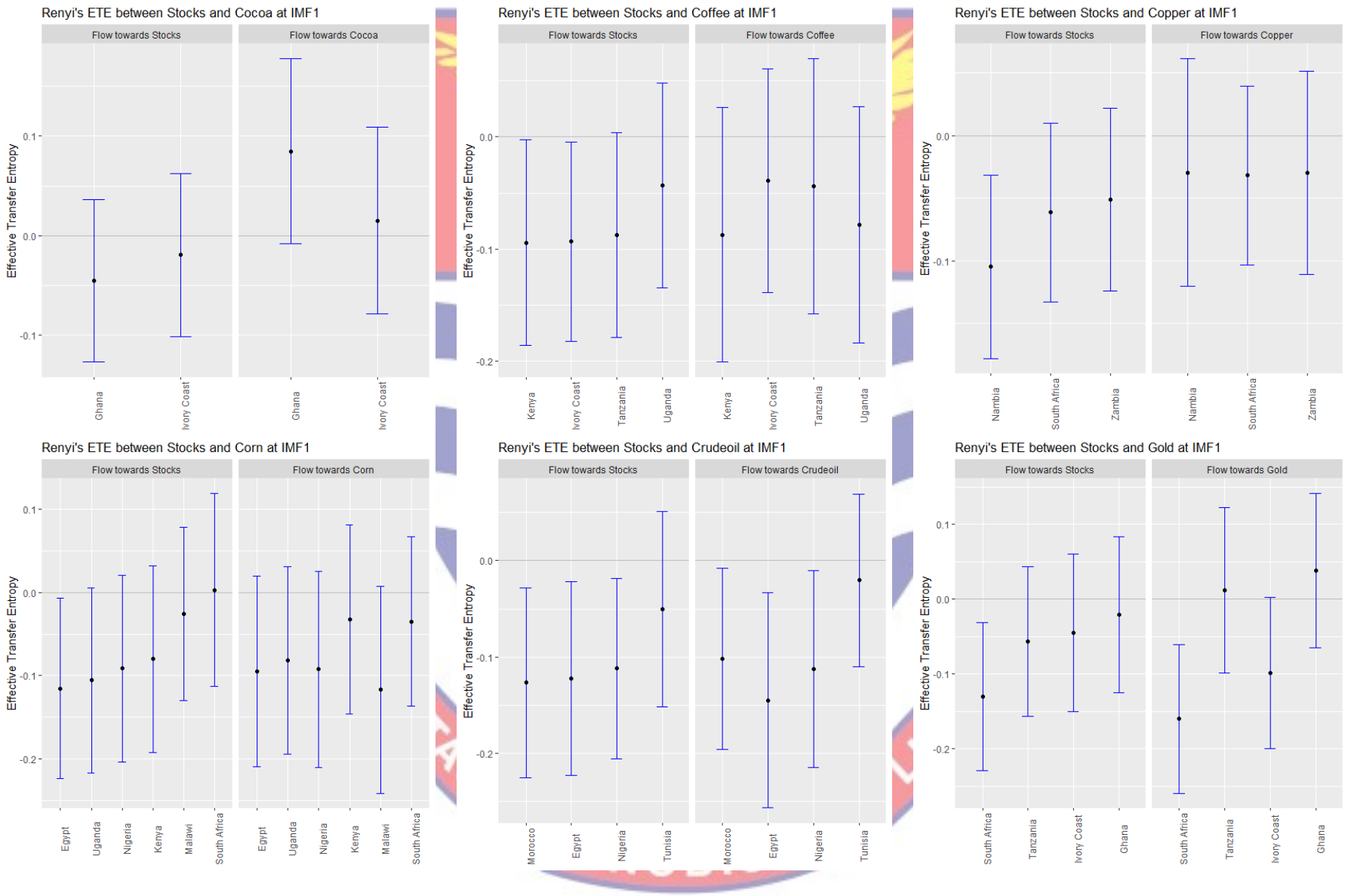


Figure 6: Composite ETEs between Stock and Commodity Markets' Returns
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

From Figure 6, the composite or signal ETEs show differing directions, magnitudes, and significance. Information flow between commodities and equities for the samples cocoa, copper, natural gas, palladium, and silver samples are statistically insignificant. For the coffee sample, Tanzania (Kenya) receives negative information flow from the coffee market. Uganda and Ivory Coast transmit negative flow towards coffee. Thus, the results communicate high uncertainties in African stock returns when the coffee market is hit by a crisis. Nigeria is the only market that receives significant flow from corn at the composite level. The Egyptian market both receives (transmits) negative flow from (to) crude oil, suggesting that the information flow between crude oil and stock markets' returns is bi-directional. The Moroccan and Nigerian markets also transmit significant negative flow to the crude oil market returns.

From the gold sample, the South African (Ivorian) market receives (transmits) negative flows from (toward) gold returns. The bi-directional interplay of information flow found for the crude oil sample also holds for palm oil, where Kenya is both a receiver and transmitter of negative ETE. For the rice sample, when shocks befall the rice market, the Egyptian and Tanzanian stock markets are negatively affected but the same does not hold when shocks befall the stock markets and, hence, makes investments in the Egyptian and Tanzanian markets more uncertain. Zambia receives a negative ETE from soybeans whilst Ghana receives a positive ETE.

Although the signal (composite) ETEs were important to examine how each variable learned the state of the other through observation (Benthall, 2019), they concealed relevant information that are relevant for time-based investors. Therefore, the frequency domain ETEs were further analysed in this research.



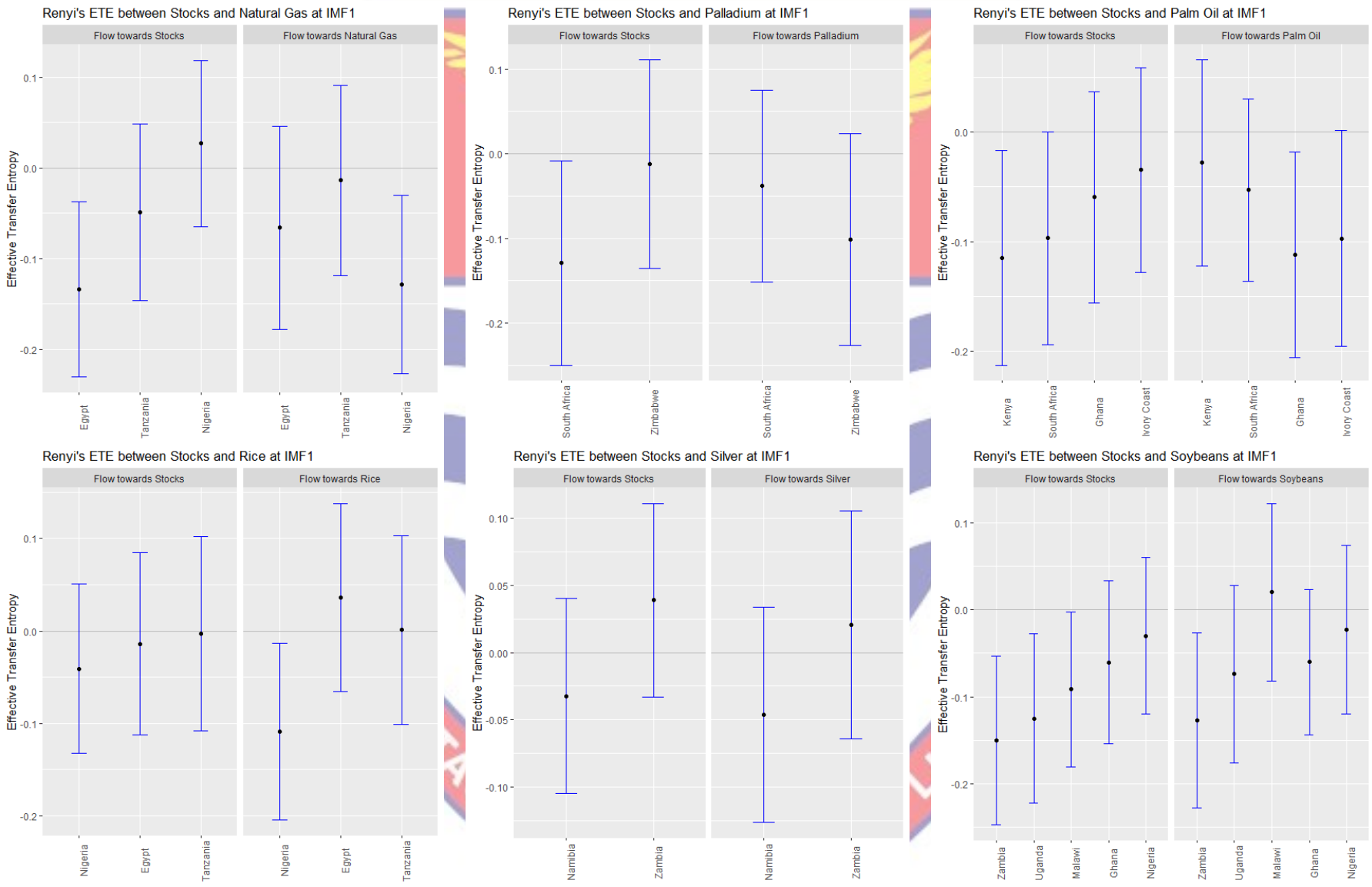
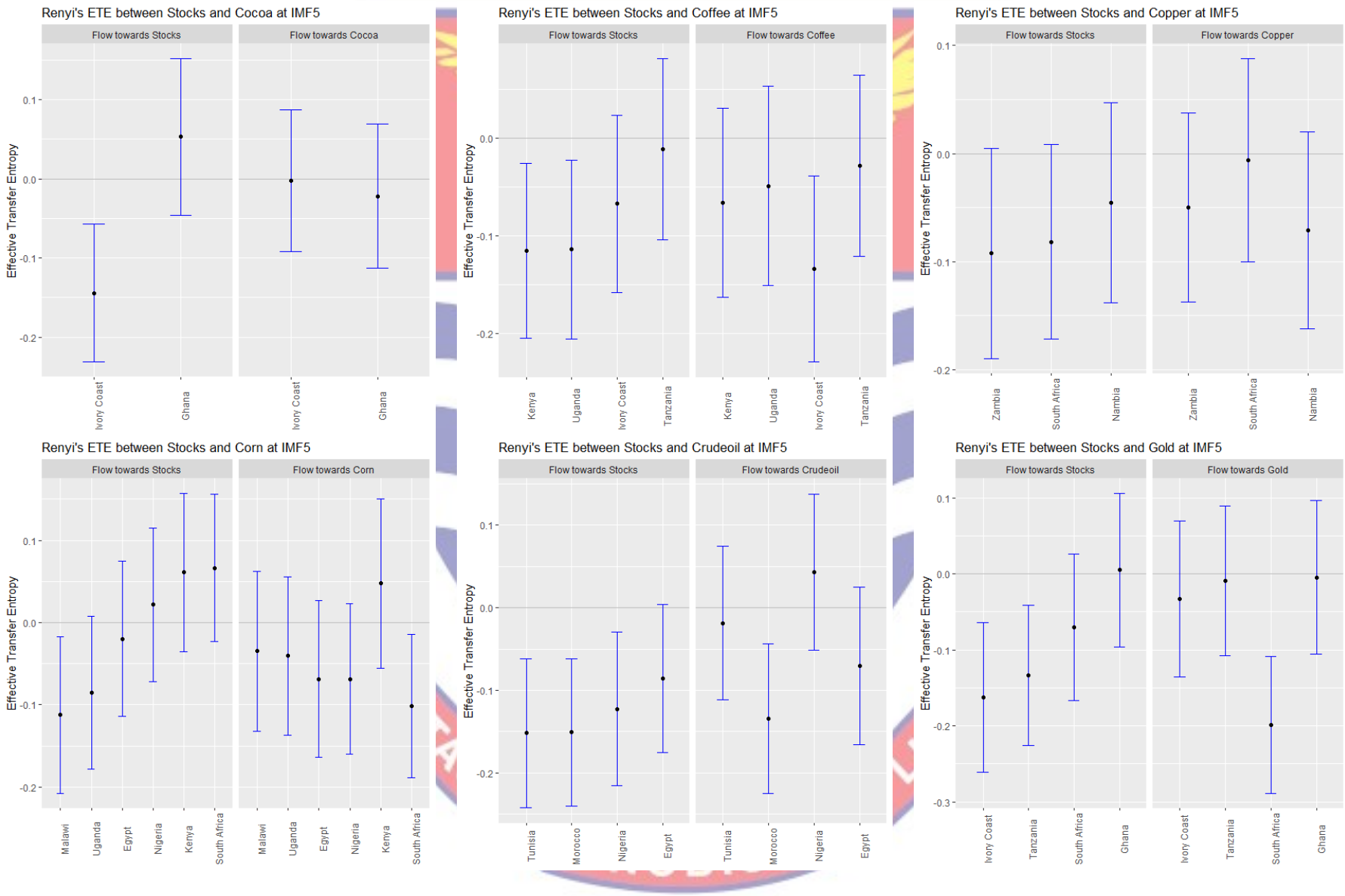


Figure 7: Short-Term ETEs between Stock and Commodity Markets' Returns
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

Figure 7 depicts the short term ETEs from which the study found that Kenya and Ivory Coast receive negative ETEs from coffee. Namibia (Egypt) responds negatively to information flow from copper (corn) in the short term. The bi-directional interplay between crude oil and stocks is strengthened in the short term, as shown by the increased number of negative ETE transmissions between crude oil and the stock markets of Morocco, Egypt, and Nigeria in the short term. The composite ETEs only revealed Egypt as the significant variable but the frequency domain ETEs unravel the potential of additional markets. This further substantiates the need for frequency-domain analysis, as employed in this research.

Bi-causality was also found between the ETEs between South Africa and gold and Zambia and soybeans in the short term. Egypt (Nigeria) receives (transmits) negative flows from (toward) natural gas in the short term. South Africa (Nigeria) receives (transmits) negative flows from (toward) palladium (rice) whilst Uganda and Malawi also receive negative flows from soybeans. The number of negative ETEs increases in the short term, which indicates that returns from equities markets stand high uncertainties given shocks from their respective dominant commodity markets.



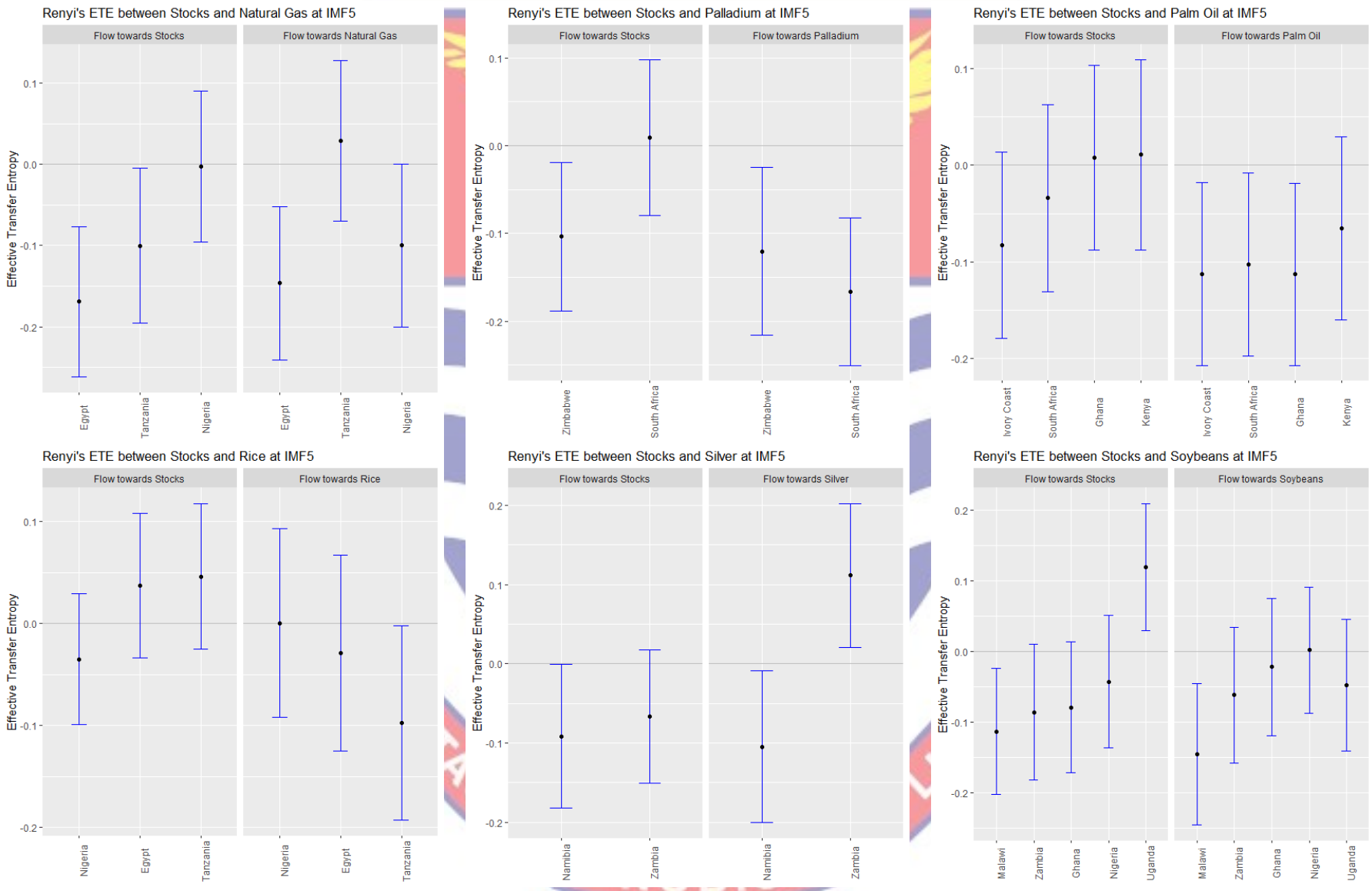
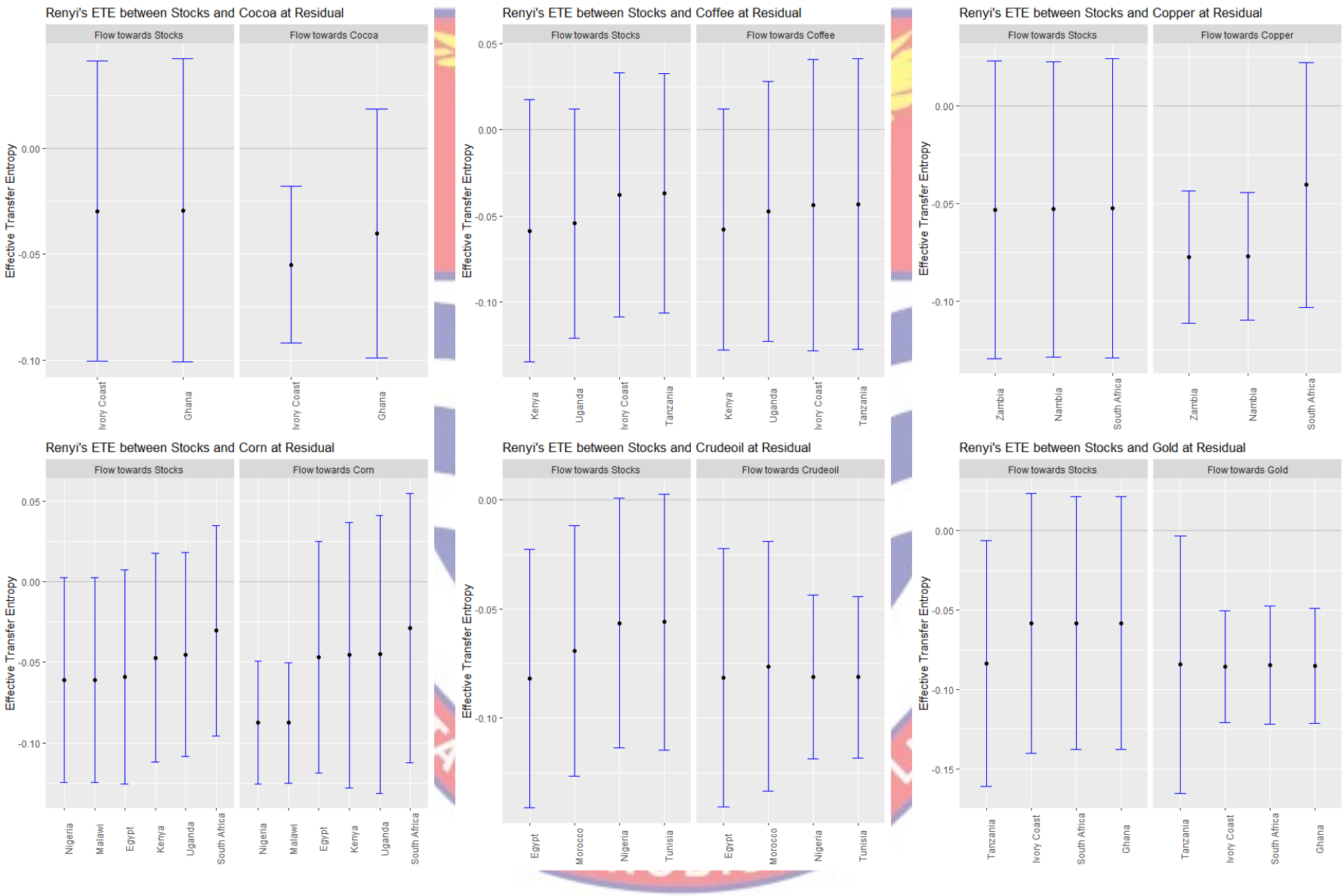


Figure 8: Medium-Term ETEs between Stock and Commodity Markets' Returns
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The transmission of ETEs in the medium-term was depicted in Figure 8. From the cocoa sample, the negative ETE recipient status of the Ivory Coast was found significant in the medium-term; meanwhile, it was insignificant at the signal or composite level. Kenya and Uganda (Ivory Coast) receive (transmits) negative flows from (towards) coffee in the medium-term. Malawi (South Africa) is a negative ETE recipient (transmitter) from (towards) the corn sample. In the medium-term, Nigeria, Tunisia, and Morocco receive negative ETEs from crude oil with Morocco also transmitting negative flows to crude oil. The findings reignited the bi-directional causality in the case of crude oil. Ivory Coast and Tunisia receive negative ETEs from gold whilst South Africa transmits a negative ETE to gold.

Egypt and Tanzania (Egypt and Nigeria) receive (transmit) negative ETEs from (toward) natural gas. The bi-directional (bi-causality) interplay was once again revealed between the Egyptian and natural gas ETEs. This is the same as the case of the ETEs between Zambia and palladium, Namibia and silver, and Malawi and soybeans, all in the medium-term. It is important to note that this research found that South Africa (Tanzania) transmits a negative ETE towards palladium (rice) whilst Ivory Coast, Ghana, and South Africa, all transmit negative flows toward palm oil. From the silver sample, when shocks befall the equities markets of dominant African silver producers or exporters, Namibia transmits a negative ETE to silver whilst Zambia transmits a positive ETE to silver. With the high and low-risk status of Namibia and Zambia, respectively, they could serve as diversifiers for one another during such a market condition. A similar observation holds for the soybeans sample between Malawi (high risk) and Uganda (low risk) in the medium-term.



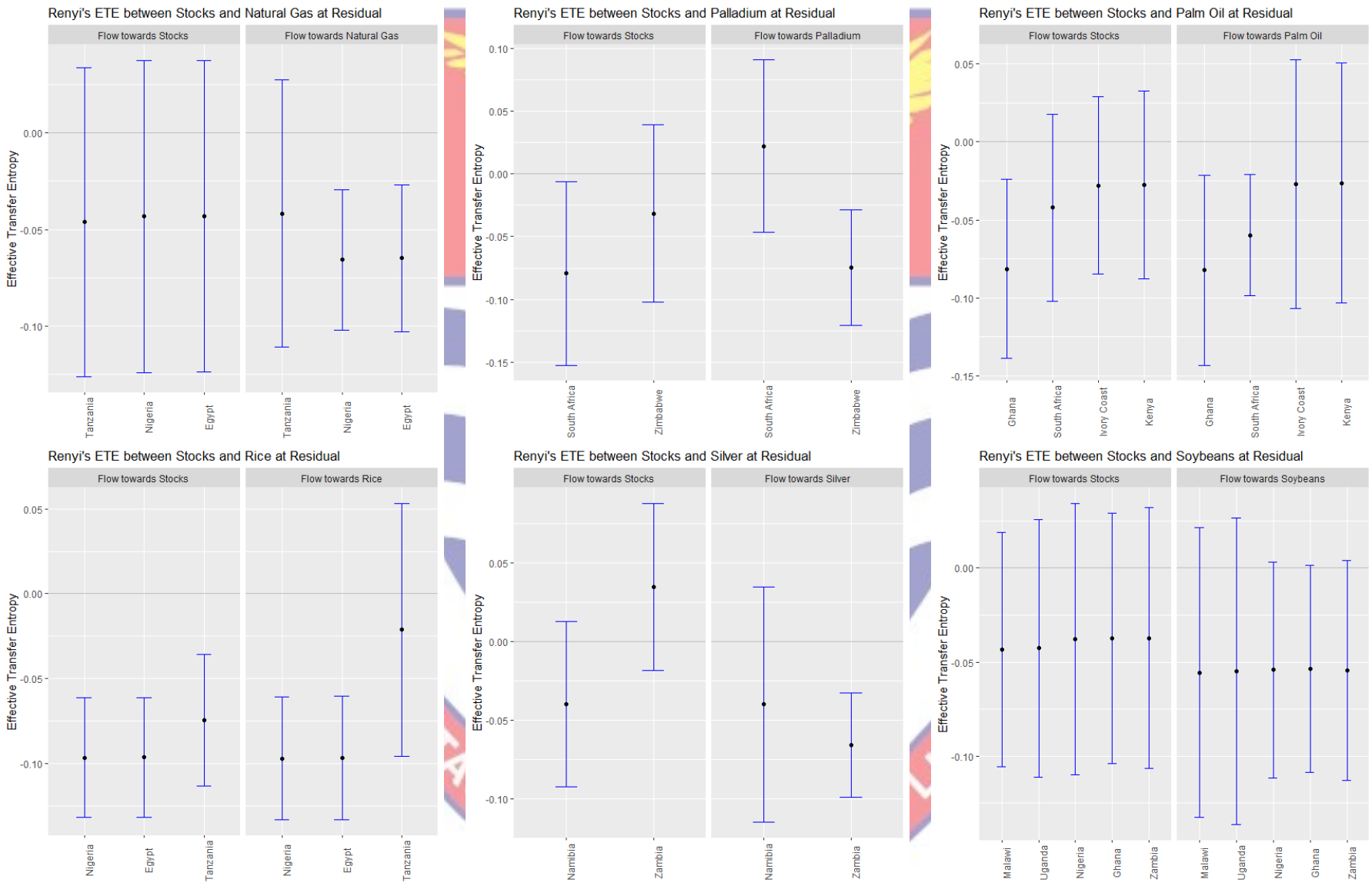


Figure 9: Long-Term ETEs between Stock and Commodity Markets' Returns
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

The ETEs between residual IMFs for equities and commodity markets were detailed in Figure 9. Notably, virtually all ETEs were negative in the long term. South Africa and Zambia revealed exceptional positive ETEs in the palladium and silver samples, respectively, all of which were insignificant. Aside from these exceptional non-significant ETEs, all other ETEs from all commodity-based samples in the long-term were found to be negative with differing magnitudes and significance. As indicated earlier, this research found that the number of negative ETEs increased with increasing timescales or investment horizons. In a similar vein, the number of significant ETEs increased along with the time horizons. This explains why from the long-term ETEs in Figure 9, the number of significant ETEs is higher than those in Figures 8 and 9 (medium- and long-term horizons, respectively).

Discussion

Overall, this research divulged interesting findings in respect of the structure of interdependence, the spillover dynamics, and the information flow between various global commodities and stock markets' returns in Africa. This subsection presents the theoretical, empirical, and intuitive grounds for the various findings that emerged from this research.

Dynamic interdependencies between returns on African equities and global commodities

Upon examining the interdependence structure of African equities and global commodities, this research revealed strong interdependence in the short term but mild-to-moderate interdependence in the intermediate-to-long-term trading scales or time horizons. These findings were largely unsurprising due to the theoretical support offered by the commodity financialisation theory (Tang

& Xiong, 2012) and the interdependence theory (Rosecrance et al., 2015). From the principles of the horizontal interdependence theory, similarities across markets facilitate the flow of funds across borders. It is natural to expect that in their aim to establish a portfolio with fewer risks, international investors would most likely add on assets from related markets and/or economies and this, in turn, could contribute to aggravated interdependencies between assets.

The link between equities and commodities is established from the premise that although commodity markets bear similar characteristics to their equity counterparts, they tend to have minor correlations with equity markets and this influences equity-commodity investments (Boako & Alagidede, 2021; Boako et al., 2020). Therefore, supported by the competitive market hypothesis (CMH) and the modern portfolio theory (MPT), investors search for commodity and equity classes that contribute high returns whilst the associated risks are comparatively insignificant to the portfolios in which these assets are included (Markowitz, 1952). The search for these assets, which is deemed to intensify in transitory periods (Owusu Junior et al., 2021), lands investors on two main assets viz. commodities – which have a low correlation with traditional assets – and African equities – which are deemed to decorrelate with the global financial market (Boako & Alagidede, 2021).

Therefore, in the short term, investors may rush into combining equities and commodities to meet portfolio targets. However, despite the low linkages between commodity and equity markets, given the rising intensity with which commodities are financialised, it is not surprising that the factors that drive the price-generating mechanism of traditional assets would apply to commodities in the short term (Mongars & Marchal-Dombrat, 2006; Tang & Xiong, 2012).

Intuitively, if the pricing and returns realised from either market are affected by economically-ingrained factors, the other market easily responds in a similar fashion. It is in this direction that the high interdependence between commodity and equity markets could be justified in this research.

It is natural that as investors realise high similarities between equities and commodities contained in the same portfolio, they tend to rebalance their holdings in the intermediate-to-long-term periods to minimise risks whilst they optimise returns (Bossman, Agyei, et al., 2022; Owusu Junior et al., 2021) and this explains why low interdependence was revealed in the intermediate- and long-term investment or economic trading horizons. In the mid-to-long-term trading horizons, markets and investors witness the extinction of transitory factors such as the January effect, overreaction of market participants, and other anomalies in asset pricing and returns (Robins & Smith, 2017; Thaler & Kuhn, 1987).

Furthermore, the findings supported the existing conclusion that market participants offer non-homogeneous responses to trends in commodity and equity markets (Boako & Alagidede, 2021; Boako et al., 2020; Boako & Alagidede, 2017; Mongars & Marchal-Dombrat, 2006). From a broader empirical context, the findings from this research lend support to empirical studies that reveal heterogeneous cross-asset linkages (Adam, Gyamfi, et al., 2021; Adam, Kyei, Moyo, Gill, & Gyamfi, 2021; Bossman, Agyei, et al., 2022; Owusu Junior, Tweneboah, & Adam, 2019; Tweneboah, Owusu Junior, & Kumah, 2020).

This research further revealed high interdependencies between African equities and commodities like corn and soybeans. These commodities fall

within the agricultural category, and empirical research reveals that there is a generally high interdependence between agricultural commodities (Fasanya & Odudu, 2020; Frimpong et al., 2021; Hernandez et al., 2021; Živkov, Njegić, & Pećanac, 2019). As already indicated, resulting from financialisation and interdependence, the factors that affect the pricing and returns on assets in commodity markets are not far from stock markets (Hu et al., 2020; Idilbi-Bayaa & Qadan, 2021; Zaremba et al., 2021a). Therefore, it stands to reason that when commodity markets are themselves highly interdependent, other traditional assets tend to mimic their interdependence structure when they are held together in the same portfolio, causing high integration between asset returns.

Spillover connectedness between returns on African equities and global commodities in a unified system

From the static framework, the analysis of the market returns' spillovers between African equities and global commodities suggested a low spillover transmission between all commodity samples and their corresponding African equities. On average, less than a quarter of return spillovers exist between African equities and commodities and this may be preferable in the context of risk management. Meanwhile, static spillovers are unable to communicate the full picture of cross-market or cross-asset shock transmissions (Aharon et al., 2021; Hazgui, Sebai, & Mensi, 2021; Mensi, Al-Yahyaee, Vo, & Kang, 2021). This partly explains why dynamic or time-varying spillovers are essential for asset allocation.

The results from the dynamic connectedness analysis suggested that equity-commodity return spillover transmission varies across time. When particularly paid attention to, the time-varying spillovers suggested that there

are high overall and directional spillovers from either individual equities or commodities. It is worth noting that the spillover index for all samples was time-varying with some extraordinary peaks around 2014, 2016, and 2020-2021. Most of the peaked spillover indices across the samples were recorded around the aforementioned periods, which correspond to stressed market conditions in the history of financial markets. The 2014 hikes could be attributed to the fall of the Russian currency which was followed by the imposition of economic sanctions and the meltdown of Russian equity markets (Islam & Volkov, 2021).

Similarly, the peaked connectedness index recorded in 2016 for all commodity samples was commensurate with the period in which the Brexit dialogues were more intense and brought about the referendum that led to the exit of Britain from the European Union (David, 2016). This event was reported to have caused significant record-breaking losses accumulating to $2 trillion in just a day. It was within the same period in which fears about a Chinese crisis led to a significant decrease in Chinese stock markets' performance, resulting in markets cancelling contracts (Islam & Volkov, 2021). These are linked to commodity-equity investments because, in such tumultuous trading times, equity investors may intensify their search for alternate contracts or investments – like commodities – that would provide yields to cover the losses suffered by existing assets, as the MPT outlines (Markowitz, 1952).

In respect of 2020-2021, peaked return connectedness resulted from the financial market meltdown occasioned by the COVID-19 pandemic. Not only did the pandemic cause plummeting share values globally, but it also affected supply chains which led to a general decline in international economic activities (Agyei et al., 2021; Bossman, 2021; Bossman, Agyei, et al., 2022; Owusu Junior

et al., 2021). The ripple effect of the COVID-19 pandemic has affected business operations and capital flows within and across economies and these have affected corporate earnings that translate into owners' wealth. As a result, through the hypothesis of adaptive markets, it is natural to see the emergence of new markets through structural changes (Ijasan et al., 2021; Lo, 2004) and market participants are likely to adapt to these changes after considering their risk appetite, as expounded by the heterogeneous markets hypothesis (Adam, Gyamfi, et al., 2021; Asafo-Adjei, Owusu Junior, et al., 2021; Bossman, Agyei, et al., 2022; Müller et al., 1993).

The peaked connectedness indices recorded during the 2014 Russian market meltdown, the 2016 Chinese market crash and Brexit, and the 2020/2021 financial market meltdown in the COVID-19 era are further backed by the hypothesis of competitive markets such that, the search for alternate assets by market participants intensify during crises periods, leading to increased spillover transmission among markets (Owusu Junior et al., 2021). Furthermore, the principles of contagion suggest that interdependence fails to exist when the linkages between markets undergo significant changes after one market experiences shock or is hit by a crisis (Bossman, Owusu Junior, et al., 2022; Forbes & Rigobon, 2001, 2002; Owusu Junior, 2020; Owusu Junior, Alagidede, et al., 2020).

Whilst the first objective clarified the interdependence structure between African equities and commodities, this research needed to establish the extent to which the linkages between markets were purely attributable to interdependence and at which moments their interdependence resulted from contagion. The results suggest that commodities and African stock markets are

not entirely immune to international market shocks. Thus, the essence of the second objective could be substantiated in this regard. Aside from the theoretical underpinnings, the results lend support to the findings of Adam (2020) and Anyikwa and Le Roux (2020) in terms of how susceptible African markets could be to global and/or regional market shocks.

This research also assessed the directional spillovers between commodities and African equities, which revealed each variable's contribution to spillovers in addition to how it responded to system spillovers. In the view of portfolio and policy management, it is essential to know the net status (i.e., whether a net transmitter or a net receiver) of each asset in their respective commodity-based systems (Diebold et al., 2017; Diebold & Yilmaz, 2012; Umar, Gubareva, & Teplova, 2021c; Umar, Jareño, & Escribano, 2021e; Umar, Riaz, & Zaremba, 2021a; Zaremba et al., 2021a). For safe-haven and hedging advantages, assets are required to have uncorrelated or low correlation patterns across turbulent and tranquil trading periods, respectively whereas, in tranquil trading periods, diversifiers are expected to have a moderate positive but imperfect correlation with their counterpart assets in a portfolio (Baur & Lucey, 2010). Intuitively, net receivers could be hedgers (safe-havens) for net transmitters (net receivers) of spillover during average (stressed) market conditions.

Impliedly, the findings from the directional spillover analysis suggested that equity returns from Uganda could act as both a hedge and safe-haven for Kenyan equity returns in the coffee sample. From the copper sample, returns from copper and Zambian equities are safe-havens and hedgers for returns from Namibian and South African equities. From the corn sample, Ugandan equity

returns could hedge and also act as a safe-haven for the return spillovers from Kenya. It is important to note that from the crude oil sample, Morocco could act as a hedge for returns from Tunisian equities and crude oil during normal trading periods and other crisis periods. Although their roles as transmitters and receivers changed during the studied COVID-19 period, pairs between them would still yield hedging benefits during the crisis period, making Tunisia and crude oil safe-havens for Moroccan equities. These findings have essential implications for asset and policy management.

An essential observation that needed to be emphasised – from the spillover dynamics between equity and commodity markets' returns – is the extent to which self-induced shocks affect African equity markets as well as global commodities. For instance, among commodities, as much as 98.13% of the return spillovers from global commodity markets could be attributed to their 'own' shocks, as in the case of cocoa. Similarly, of the overall return spillovers presented to various African equities markets, as high as 99.02% is traceable to the self-induced shocks from within the market in question, as in the case of Zimbabwe in the palladium sample. Market integration could be attributed to these increased idiosyncratic spillovers between global commodity and African equity markets. The findings lend support to the empirical literature such as Khalfaoui, Boutahar and Boubaker (2015) and Mensi et al. (2021) who reported high idiosyncratic shocks between equity and commodity market-based spillover systems.

Information flow between returns on African equities and global commodities

Findings of the extent to which one variable learns the state of the other through observation were essential to provide additional insights into the intrinsic information transfer dynamics between the studied variables in a single system (Benthall, 2019). Results from such an analysis helped to examine market efficiency in terms of asset pricing (Fama, 1970, 1998; Fama et al., 1969). The findings from the Rényi effective transfer entropies (ETEs) suggested bi-causal information flows between global commodity and African equity markets' returns. Across both the composite (signal) and frequency domain ETEs, the findings suggested that commodity markets transmitted negative ETEs to equities just as most equities transferred negative ETEs to the respective commodities.

The revelation of negative ETEs implied that knowing the history of the corresponding variable brings more uncertainty than when the history of the recipient variable only is known (Adam, Gyamfi, et al., 2021). Impliedly, the receival of negative ETEs by equities markets suggests that returns on investment in African equities markets bear high risk. Therefore, knowing the history of various commodity market returns results in more uncertainty than when an investor sticks to the history of stock market returns in Africa. This means that once the returns from a particular market are highly risky, adding on assets whose returns bear high-risk results in more uncertainty and portfolio risks. Similarly, when there are negative flows from equities' returns to a particular commodity, knowledge about the commodity's returns bears less

uncertainty than when the returns from equities are incorporated in terms of asset allocation and policy management.

By taking a distinct focus from the previous studies that only focus on connectedness between either African stocks (Anyikwa & Le Roux, 2020; Asafo-Adjei et al., 2020) or commodities (Bahloul & Khemakhem, 2021; Ferreira, Almeida, Dionísio, Bouri, & Quintino, 2022; Frimpong et al., 2021; Hu et al., 2020; Umar, Riaz, & Zaremba, 2021a; Zaremba et al., 2021a; Živkov et al., 2019), or between commodities and African stock markets (Boako & Alagidede, 2021, 2016; Boako et al., 2020; Kablan et al., 2017), this research, through the third objective, provided fresh evidence about the multiscale information flow between global commodities and African equities markets.

Through the transfer entropy analysis, this research revealed that trade between African equities and global commodities results in more uncertainties across investment timescales. Although the implications of this finding do not differ across timescales, the significance is strengthened in the long term, as provided by the residual ETEs, which depict the underlying behaviour of global commodity and African equity markets' returns. Thus, the number of negative and significant ETEs was found to be more at lower frequencies, which represent the long-term. Additional implications were drawn from the perspective of market efficiency as follows.

Fama et al. (1969) contended that distressed economic conditions impact asset prices via the flow of information to investors, which then influences investor behaviour. Thus, for markets to be efficient, it is expected that the extent to which a variable learns the behaviour of the other through observation is similar among all variables in a given system (Benthall, 2019). Impliedly, a

group of stock markets should have a similar response to the flow of information from a given commodity. The results from this research suggested that the quantification of information flow between commodities and equities' returns yields differing magnitudes, directions, and significance. The implication is that the efficiency levels of various commodity and equities markets are quantitatively dissimilar. Hence, these markets are non-efficient based on the mutual information they share.

Whilst these results are contrary to the EMH (Fama, 1970, 1998; Fama et al., 1969), they corroborate the alternative hypothesis to market efficiency (AHME) (Cornell, 2018). The AHME is a more simplistic hypothesis that suggests that rational and irrational investor attitudes are dependent on states of nature and individual investors. It worth's noting that the negative ETEs found in the long-term rather lend support to the long-run market efficiency of Fama (1998). Virtually all the ETEs in the long-term were negative with most ETEs proving significant. This communicated the principle that, in the long-term, when all markets are saturated with available information, the situated information flow between commodities and equities results in comparable magnitudes, direction, and to a large extent, significance (Bossman, 2021; Bossman, Agyei, et al., 2022; Owusu Junior et al., 2021), hence, no undue advantage could be envisaged from the trade between global commodities and African equities.

Economic intuitions of findings based on asset classes

For each objective, and where results are dissimilar among commodity classes, the following economic intuitions and outstanding practical

implications from the discussions were deduced based on the delineated asset classes:

Precious metals

In terms of their interdependence structure, precious metals generally exhibit low coherence with African equities across the mid- to long-term trading periods. The interdependence structure between the returns on precious metals and African equities gives room for diversification benefits in the long term. This research stressed the comparative advantage of African markets in this regard. Since equity returns from other markets are comparatively highly integrated with commodity returns, it stands to reason that regulators of African stock markets and the African economy as a whole could effectively regulate their markets to attract more international investors whose asset allocation includes commodities from the class of precious metals (gold, silver, palladium, and copper). From the return spillovers, notable hedging and safe-haven benefits are envisaged between the studied precious commodity and African stock markets. These markets are largely efficient in the long term, as explicated by the mutual information they share. Hence, the long-term efficiency suggests that institutional investors could gain considerably from the trade of African equity and global commodities, specifically, precious metals.

Grains

In terms of their interdependence structure, grains generally exhibit high coherence with African equities across all trading periods. The interdependence structure between the returns on grains and African equities drives away diversification benefits regardless of the trading horizon. The economic implications are that grains and African equities can hardly be combined for

diversification benefits. This is unsurprising due to the intense connectedness documented between agricultural commodities and grins largely emanating from agricultural production.

Combining multiple equities from grains-producing countries is not recommended. Investors may have to rely on other equities instead of those from top producers or exporters of grains from Africa. This explains why the spillover dynamics between grains and the respective African equities suggested a possible diversification not between grains and equities but between equities only (i.e., for Ugandan and Kenyan equities). Premised on this finding, Kenya and Uganda could be a source for investors with holdings in grains. For competitive advantage to hold for grains, untapped avenues for grains production may be explored by policymakers in African economies to test their resilience with commodity markets.

Softs

In terms of their interdependence structure, softs generally exhibit low (high) coherence with African equities across the short- to mid-term (long-term) trading periods. The interdependence structure between the returns on precious metals and African equities gives room for diversification benefits in the short- and medium-terms. The comparative advantage of African markets was further highlighted in this regard. Regulators from African economies could effectively adjust their markets to attract more international investors whose asset allocation includes commodities from the class of softs (i.e., cocoa and/or coffee). From the return spillovers, notable hedging and safe-haven benefits are envisaged between the studied softs commodities and African stock markets.

The respective softs commodities and their corresponding African equity markets are largely efficient in the long term, as explicated by the mutual information they share. Therefore, institutional investors and other long-term-based investors could gain considerably from the trade of African equity and global commodities, specifically, softs. Likewise, the African continent could realise substantial capital flows through their stock markets when these markets are attractively regulated towards the attraction of international investors. Impliedly, this needs to be accompanied by the mass production and exportation of more softs like cocoa to ensure the availability of their trade across the globe.

Energies

In terms of their interdependence structure, energies generally exhibit low coherence with African equities across the long-term trading periods. The interdependence structure between the returns on energies and African equities gives room for diversification benefits in the long term. Again, this research stressed the potential comparative advantage for African markets in terms of asset allocation and portfolio choice. Equity returns from other markets are comparatively highly integrated with commodity returns and, hence, regulators of African stock markets and the African economy as a whole could effectively regulate their markets to attract more international investors whose asset allocation includes commodities from the class of energies (crude oil and natural gas). From the return spillovers, notable hedging and safe-haven benefits are envisaged between the studied energy commodities and African stock markets.

With bi-directional information flows, energies and the respective African equity markets are largely efficient in the long term, as explicated by the mutual information they share. Hence, the long-term efficiency suggests that

institutional investors could gain considerably from the trade of African equity and global commodities, specifically, energies.

Unclassified

For the unclassified commodity group which was examined, palm oil exhibited high interdependence with the equities from top-exporting or producing African countries. The diversification benefits associated with palm oil and the respective equity markets were identifiable in the long term. This could also provide similar comparative advantages to African economies when the stock and commodity markets are effectively regulated to attract more equities whilst exporting more of the produced commodity. Investors who invest in palm oil may then return to African equities for diversification benefits. In terms of spillovers, diversification may be inconsistent with palm oil and equities. Meanwhile, all markets are efficient regarding information flows in the long term.

This research summarised the empirical findings or results based on the possible implications they have on asset allocation, portfolio selection, and market and policy regulation. Emphasising the global commodity classes and their constituents employed in this research, the implications for portfolio and policy management based on the empirical findings were specifically detailed for each research objective in Table 17.

Table 17: Summarised Findings with Portfolio and Policy Implications

Objective 1: Interdependence structure between returns on global asset classes and African equities markets				
Precious metals (gold, silver, palladium, and copper)	Grains (corn, rice, and soybeans)	Softs (cocoa and coffee)	Energies (crude oil and natural gas)	Unclassified (palm oil)
Gold • Possible diversification in the long term.	*Corn* • Strong interdependence across all trading and investment horizons.	*Cocoa* • Strong interdependence in the long-term • Possible diversification in short-to-mid terms.	*Crude oil* • Possible diversification in the long term.	*Palm oil* • Possible diversification in the long term.
Silver • Possible diversification in the mid-to-long term.	*Rice* • Possible diversification in the long term.	*Coffee* Mixed	*Natural gas* • Possible diversification in the long term.	–
Palladium • Strong interdependence in the long-term • Possible diversification in short-to-mid terms	*Soybeans* • Strong interdependence across all trading and investment horizons.	–	–	–
Copper • Mixed	–	–	–	–
Objective 2: Spillover connectedness of returns on global asset classes and African equities markets				
Precious metals (gold, silver, palladium, and copper)	Grains (corn and soybeans)	Softs (cocoa and coffee)	Energies (crude oil and natural gas)	Unclassified (palm oil)
Copper • Returns from copper and Zambian equities are safe-havens and hedgers for Namibian and South African equity returns.	*Corn* • Ugandan equity returns are a hedge and safe-haven for equity returns from Kenya.	*Coffee* • Ugandan equity returns are both a hedge and safe-haven for their Kenyan counterparts.	Crude oil • Moroccan equity returns are a hedge for returns from Tunisian equities and crude oil in normal trading periods and other crisis periods other than the COVID-19 era. • Tunisian equity and crude oil returns are safe-havens for Moroccan equity returns.	*Palm oil* • Nil
Objective 3: Information flow between returns on global asset classes and African equities markets				
• High uncertainties across the short-, medium-, and long-term frequencies or trading horizons for all global commodity and African equity markets' returns. • Markets are largely efficient in the long term.				

Source: Author's Deductions (2022) based on Empirical Estimations and Findings

Chapter Summary

Motivated by the recent alliances formed among African economies and between the region and top-emerging markets, and the plausible intensity of market integration which may wipe off diversification benefits, this thesis analysed the interdependence structure, spillover connectedness, and information flow between market returns on equities from Africa and global commodities. The empirical results suggested that the interdependence structure of African equities and global commodities is non-homogeneous. This research revealed significant total, directional, and net time-varying return spillovers between African equities and global commodities. The quantification of information flows between the researched commodities and equities suggested that investing in African equities increases the risk associated with market returns for their respective dominant commodity market and vice versa.

The findings presented in this research have a significant impact on asset allocation as well as portfolio and policy management. A summary of the research, the principal findings, and the conclusions and their accompanying recommendations are well documented in the final Chapter.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Introduction

This thesis examined the interdependence structure, spillover dynamics, and mutual information flow between global commodity and equity markets' returns in Africa. From the thorough discussion of the empirical results from the novel and rigorous estimation techniques, this Chapter summarises the principal findings from which practical and theoretical conclusions are deduced. In addition, the Chapter dwells on the main results and conclusions to recommend for asset allocation, portfolio, and policy management. The Chapter climaxed with essential suggestions that could guide future research and knowledge accumulation.

Summary

In recent decades, attracting major private capital flows to the real sector of economies has been integrated into African nations' growth strategy, resulting in the establishment of many alliances among African countries or sub-regions. Whilst these agreements are largely aimed at stimulating economic growth and development as well as investor confidence, the tendency to deepen integration across African markets – through which investors may be hesitant to invest in Africa – cannot go unnoticed. As a result, African markets may be less resilient to global shocks. Notwithstanding, in the wake of the COVID-19 outbreak, commodity market participants in Africa have been warned about their vulnerability to volatility following recent hikes in commodity prices (Karingi, 2021). The implications of these developments suggest that aside from the benefits in terms of improved economic production and fiscal income, price

volatility might contribute to macroeconomic instability, which could impair stock market performance and drive off international investors (Rehman, 2021).

Backed by the modern portfolio, interdependency, and the situated information flow theories, this research examined the dynamic interdependence structure, return spillovers, and the quantified mutual information flow between global commodity classes and African equities. The principally produced and/or exported commodities by African countries influenced the selection of the commodities and the sample period for both stock and commodity market indices was determined by available data for all stock markets, which led to varied sub-sample sizes and periods. All datasets were retrieved from the licenced database of EquityRT (via the link https://www.equityrt.com/). The main research objectives were threefold viz., to examine the dynamic interdependencies between returns on African equities and global commodities; to investigate the spillover connectedness between returns on African equities and global commodities in a unified system, and to analyse the flow of information between returns on African equities and global commodities.

Findings

Following the threefold objectives and accompanying hypotheses tested in this research, the following findings are worth noting:

Concerning the first research objective, this research revealed that the interdependence between the returns on global commodities and equity markets in Africa is high in the short term, specifically within wavelet scales 2~4, which matches the daily to weekly periodicities. The extent of the significance of the interdependence between the studied commodity and equity markets diminishes across the intermediate-to-long-term investment horizons, which suggested that

the interdependence structure between the studied commodity and equity markets is dynamic. With these empirical findings, this research found enough evidence to reject the null hypothesis of "no significant dynamic interdependence between returns on African equities and global commodities."

In respect of the second research objective, the findings from this research suggest that, when examined from the static domain, the return spillovers between global commodity and African equity markets are moderate across commodity-based systems. Meanwhile, the idiosyncratic return spillovers revealed in this research were significantly high, which gave priority to the dynamic spillover analysis. The dynamic spillover analysis explicated that the magnitude, direction, and net return spillovers, recorded by commodity and African equity markets were time-varying over the sample period. More importantly, this research unveiled contagious spillovers in notable crises in the history of financial markets, specifically the 2014 Russian equity market crash, the China equity market crisis in 2016, Brexit, and the financial market meltdown in the COVID-19 era. Premised on these findings, this research had sufficient evidence to reject the hypothesis that "there is no significant spillover effect between returns on African equities and global commodities."

From the third research objective, the study revealed significant effective transfer entropies (ETEs) across the short-, medium-, and long-term horizons. Indicatively, the significance of ETEs was mostly found in the frequency domain, which substantiated the need to examine the efficiency of commodity and equity markets across economic trading horizons rather than in a static paradigm (i.e., the signal or at the composite level only). The findings suggested that investing in a single commodity market results in more

uncertainty when an investor accounts for the return pattern of African equities. Similarly, investing in any single African equity results in high return uncertainties. This research found negative ETEs which suggest that given the mutual information shared, the returns on global commodities and African equities are highly uncertain or risky across investment horizons. The efficiency of global commodity and African equity markets was found significant in the long-term trading period. Therefore, this research found enough evidence to reject the null hypothesis that "there is no significant information flow between returns on African equities and global commodities."

Conclusions

Based on the empirical findings, constructive arguments, and intuitions from theories and financial market hypotheses, this research offered conclusions as follows:

First, in the context of the first research objective, this study concluded that there exist significant interdependencies between commodity and equity markets' returns in Africa. More specifically, this research explicated that the interdependence structure between the studied markets is best assessed in a multiscale framework. Following the VWC analysis, higher scales (lower frequencies), which correspond to the short-term depict intense similarity and integration between the studied global commodity and African equity markets. This is hardly surprising given the rapid increment in trade liberalisation through new alliances and co-operations. In line with the interdependency theory, this research further concluded that among the studied global commodity and African equity markets, a significant shift in market dynamics for one market is directly translated to the other in the short term and this

explains the high degree and significance of the interdependence between global commodity and equity returns in Africa.

The operability of market anomalies such as the January effect and market participants' overreaction in the short term suggests that in the intermediate-to-long-term periods, when investors rebalance their portfolio allocations, these anomalies fade off, giving room for the operability of the fundamental market dynamics between unified markets in the long-run. The forerunning arguments explain why the significance or the strength of interdependence between the studied markets tend to diminish across the medium-to-long-term scales, paving way for potential diversification advantages from the trade of global commodities and African equities (as detailed in Table 17).

Second, this research provided sufficient significant evidence of time-varying return spillovers between global commodities and African equities, the magnitude of which depended on the prevailing market condition. These spillovers were found to be significantly made up of idiosyncratic spillovers propagated within individual markets. Whilst this may be normal among developed market equities, it poses a surprise in the context of African markets, which were known to be dissimilar from the international financial market. From another breadth, this finding may be unsurprising as it lends support to empirical findings.

The recent alliances between African economies coupled with commodity financialisation may be attributable to the changing market dynamics between the studied markets. With these findings, this research concluded that the spillovers between global commodities and African markets

are largely idiosyncratic, as in the case of noticeable developed and developing economies and the same conclusions could be made of global commodities. Moreover, the time-varying spillovers that revealed peaked linkages in stressed market periods divulged that the connectedness between commodity and African equity markets responded to external shocks during significant global events or market crises. Accordingly, this research further concluded that the connectivity dynamics of the studied commodity and equity markets do not only emerge from interdependence but also result from contagion, as empirically defined in the financial contagion literature.

In the context of asset allocation and portfolio management, the net recipient status of various markets is definitive of their roles as hedging instruments during normal average periods whilst they act as safe-havens in turbulent trading phases. This research concluded that the spillover dynamics between markets reveal hedging and safe-haven roles for notable African equities within the coffee, copper, corn, and crude oil samples (as summarised in Table 17). Similarly, pairs of markets with mild time-varying spillovers could facilitate diversification advantages in normal trading periods. Again, this research concluded that the net spillover position of assets may change owing to the time-based behaviour of market participants and this results in some assets switching between roles as diversifiers, hedgers, and/or safe-havens across time and trading conditions.

Third, the studied commodity and equity markets negatively observed each other through the mutual intrinsic information they share. With more significant negative transfer entropies, for any given commodity sample, investment in one equity market results in additional uncertainties – in terms of

asset returns – when investments are held in their accompanying equities or commodities since they all receive negative ETEs. This research concluded that, in the long-term, based on the mutual information shared by commodity and equity markets, for any investment in either equity or commodity, adding on similar equities or commodities from the same unified system increases the risk associated with market returns. This research divulged that information transfer between commodity and equity markets' returns is bi-directional across diverse frequencies.

In the context of market efficiency, the nature of information transfer between the studied global commodity and African equity markets implies that there are little or negligible chances for any equity-commodity combination to reduce risk or uncertainty associated with market returns. However, with notable variations in the significance of ETEs across the short- and medium-term frequencies, this study concluded that the studied commodity and African equity markets are significantly efficient regarding the situated information flow between them. Specifically, the study underscored the operability of the adaptive and heterogeneous markets hypotheses, the alternative hypothesis to market efficiency, and the competitive markets hypothesis in the short- and medium-term horizons whereas the efficient market hypothesis and the long-term market efficiency operate in the long-term economic trading horizon only.

Recommendations

The analysis of the dynamic interlinkages between global commodity and African equity markets in this research yielded intriguing findings backed by theories and significant financial market hypotheses. Following the empirical

findings, the following recommendations in the light of asset, portfolio, and policy management are worth noting.

Market regulation and policy management

First, the high interdependence between global commodity and African equity markets in the short-term results from the liberalised markets and financialisation of commodity markets. As a result, there is the need to proactively regulate production schedules in terms of commodities to mitigate losses that may be borne by commodity producers or exporters in the wake of plummeting commodity prices. This may lessen the degree to which losses suffered in the commodity markets are translated to poor production and earnings in local or multinational corporations. Given that market shocks may be translated to other markets with which they integrate, limiting the losses in one market would most likely mitigate the ripple effect on other counterpart markets.

There is a need for market regulators to deploy vibrant measures that could limit the creation of market shocks or the transmission of shocks across markets. This is to ensure that the potentially high interdependence structure revealed by the VWC analysis does not actualise in the long term owing to new alliances, financialisation, and trade liberalisation. Investors with portfolios containing combinations of global commodities and African equities need to be warry of high interdependencies in the short term as well as the potential market integration between African markets in the long term. For commodity-equity-based portfolios, timely assessments of each asset's performance are a key to determining the right balance for each class of asset.

Second, owing to financial market contagion, financial market regulators and investors need to care for idiosyncratic risks that are largely propagated internally within markets. In the case of African markets, proper management of the internal market shocks would significantly lessen their interrelations with global markets. Despite the benefits of market integration, the associated decrement of capital flows and direct foreign investments cannot be overlooked when equity investments are considered. This may warrant thorough assessments of terms of trade and agreement, particularly in newly proposed alliances. Managing the interrelations and interdependence between economies could result in controlled impacts of financial market contagion. With such characteristics, decoupled markets attract investors who seek to diversify their portfolio holdings.

Overall, in terms of policy, this research divulged that, when effectively managed, African markets could continue being viable surrogates for international investors and through sustained capital flows, the growth of the continent could gradually contribute to poverty reduction. Indicatively, more production and exportation of commodity classes – such as precious metals, softs, and energy – would attract investors – who hold such assets in their portfolios – to African markets for diversification advantages. Increased capital flow, economic growth, and bridging the gap between developed and developing markets would be an added advantage when the findings and conclusions of this research are considered by economic practitioners, policymakers, or regulators.

African economies have, for the past decade, focused on the attraction of increased capital flows, but the role of portfolio creation might have been

ignored or given less attention by regulators and economic practitioners. This research recommends that economic practitioners and policymakers should carefully consider the empirical findings and conclusions from this research to supplement their basic strategy for capital accumulation with international portfolio management. By so doing, they are required to strengthen the various equities markets across the continent to attract more international investors. This strategy would not only result in capital flows, but it would also fasten the pace of economic growth among the countries in the continent and also help to bridge the wide gap between advanced continents and an emerging continent like Africa. In general, the collective role of the fundamental strategy adopted by the African continent and the contribution from international portfolios would contribute to poverty reduction.

Investors

Moreover, investors could take advantage of the net spillover positions of global commodity and African equity markets to diversify and hedge against losses from integrated markets across divergent market conditions. The dynamic nature of the spillovers between global commodity and African stock markets suggests that portfolio managers should deploy effective risk management strategies that capitalise on the non-homogeneous roles of some assets as diversifiers, hedgers, and safe-havens across time horizons.

Furthermore, the intrinsic information content possessed by markets serves as a guide to predicting the efficiency levels of markets. Through information transfer, short-term traders could monitor the loopholes in the market efficiency levels between global commodities and African equities to take advantage of arbitrage when needed. Long-term investors like institutional

investors are assured of efficient market dynamics between global commodity markets and African equities. Therefore, investments in global commodities and African stocks could be monitored on their information content to predict market performance across time horizons. Given the uncertainty in returns based on information content, investors are urged to explore other assets that bear low uncertainties with global commodity and African stock markets' returns.

Suggestions for Further Research

Future studies on the research area could go in a fascinating direction. Having established the dynamic interrelations between global commodity and African equity markets, future works could ascertain the conditional relationship between commodity and equity markets' returns. In this regard, several strands of quantile dependency approaches could be investigated. Similarly, with the high uncertainties revealed for the studied markets based on the situated information they share, future studies could consider forecasting techniques to predict returns and volatilities which could be used as inputs for proactive asset allocation and portfolio management.

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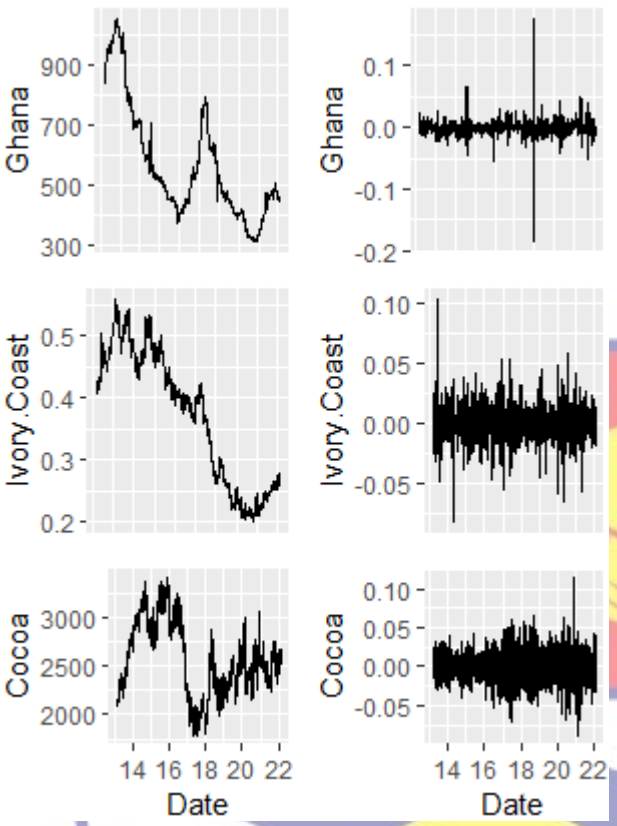
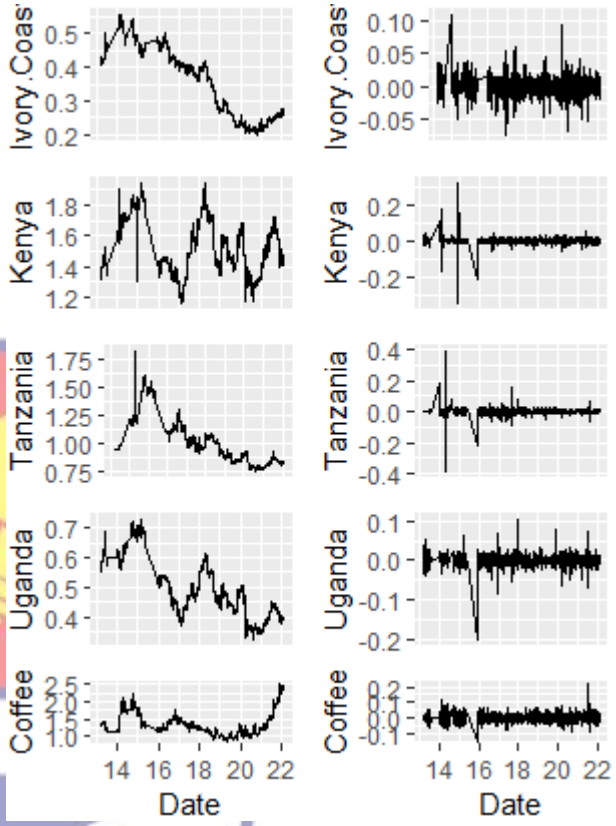
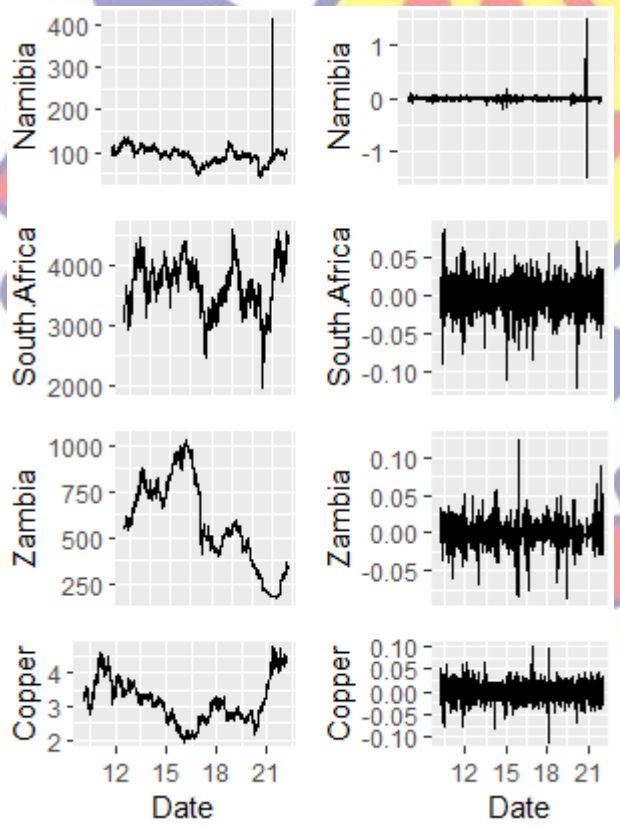
APPENDIX



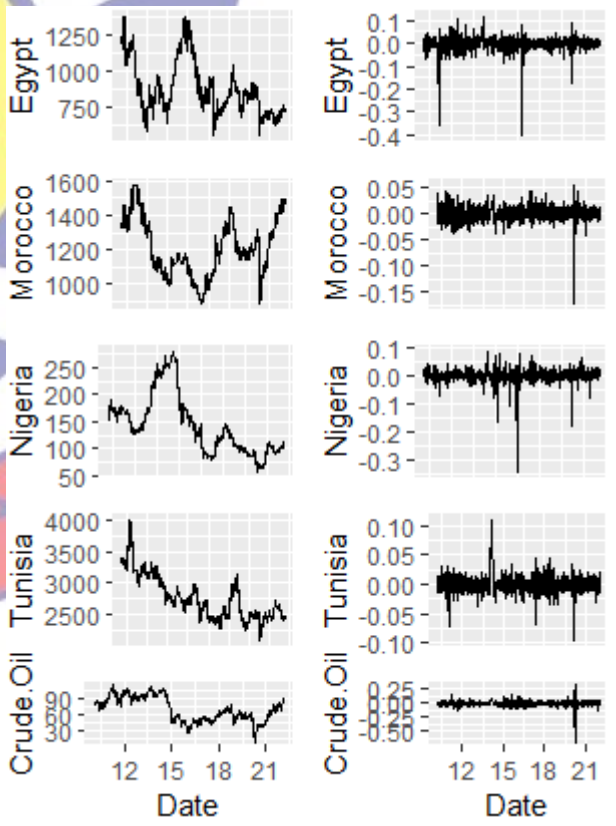
(a) cocoa sample



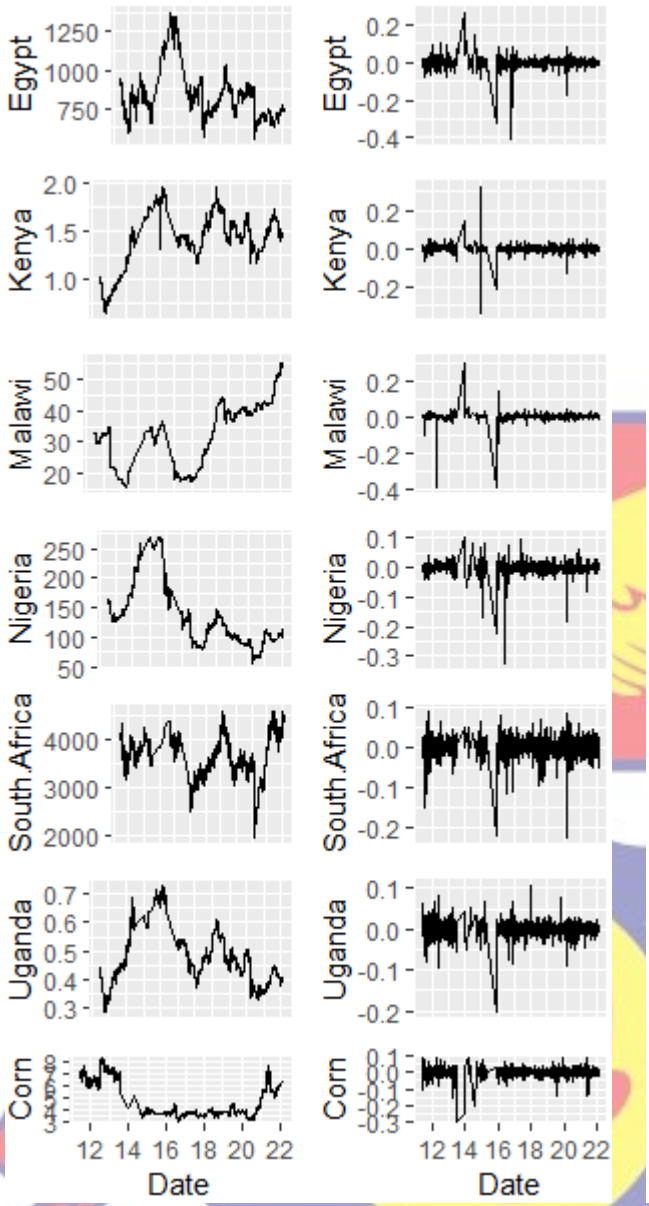
(b) coffee sample



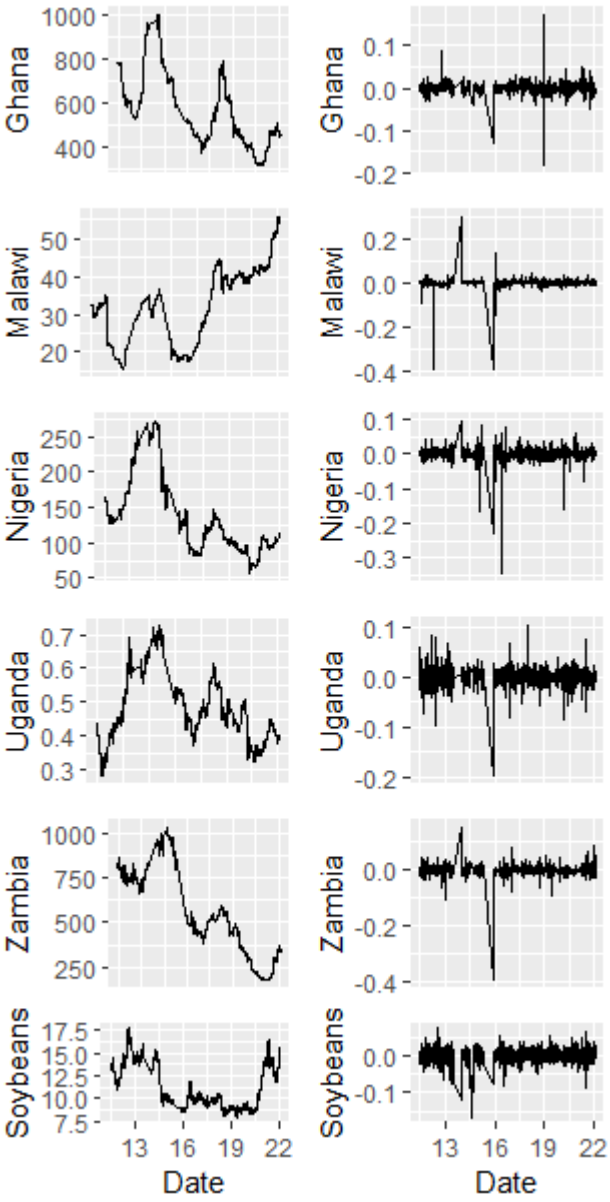
(c) copper sample



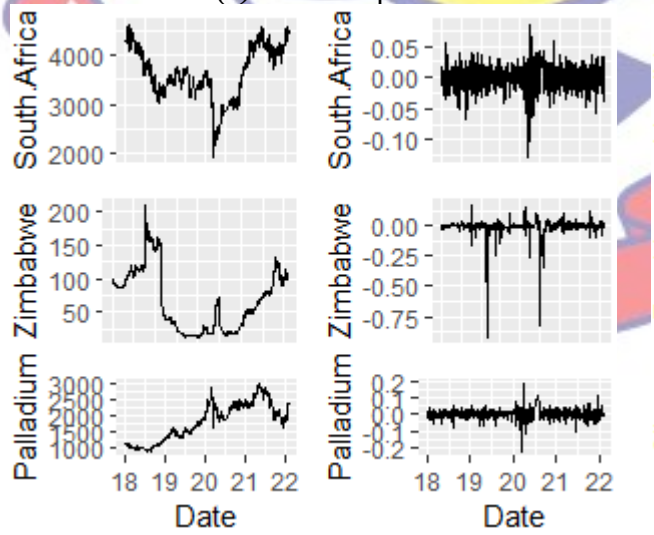
(d) crude oil sample



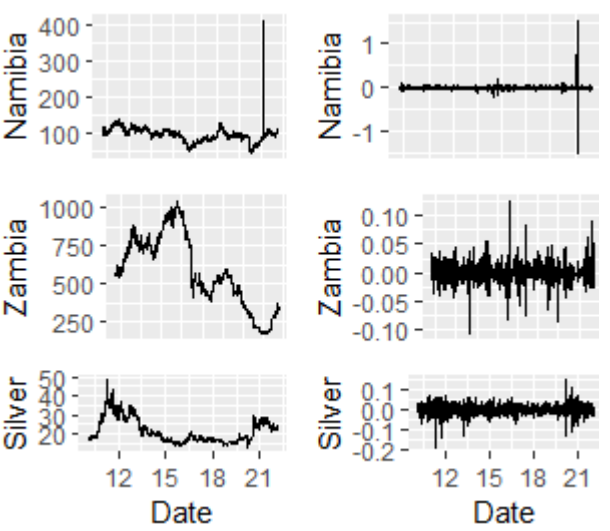
(e) corn sample



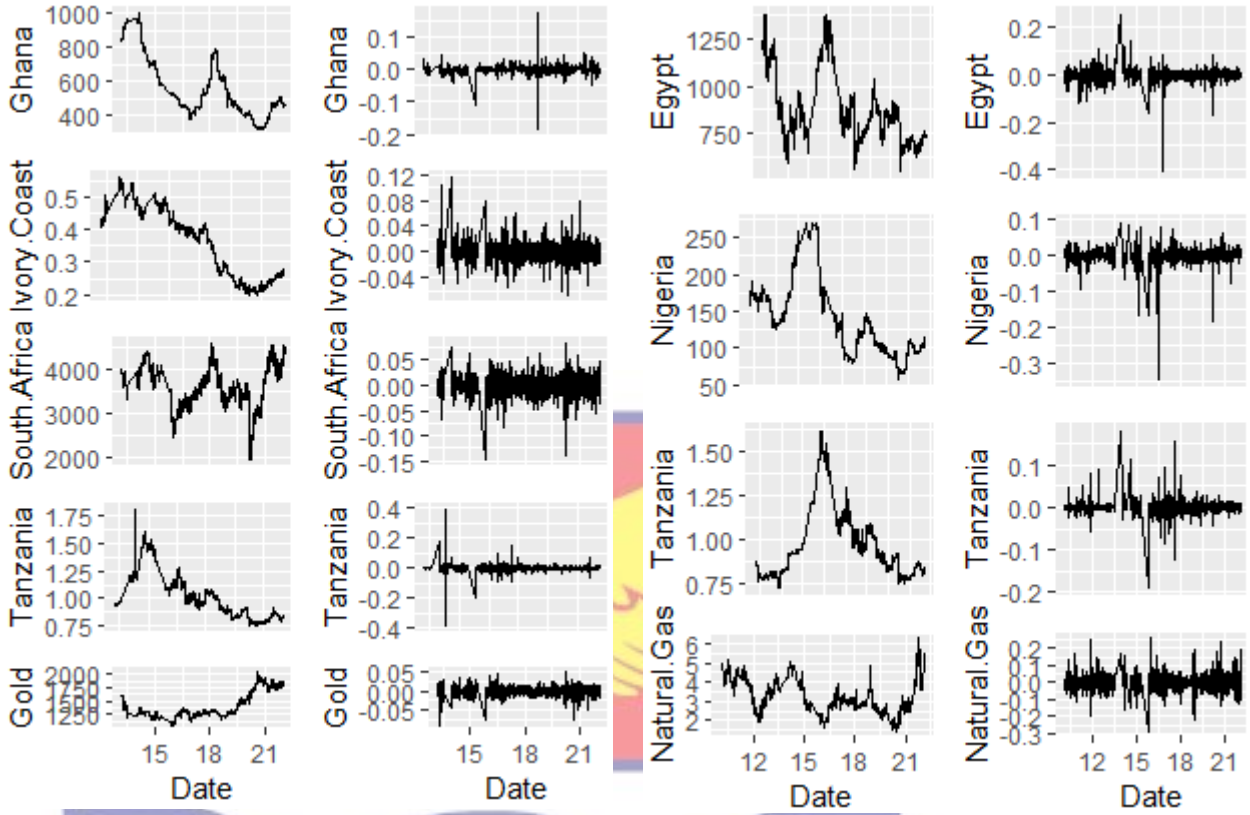
(f) soybeans sample



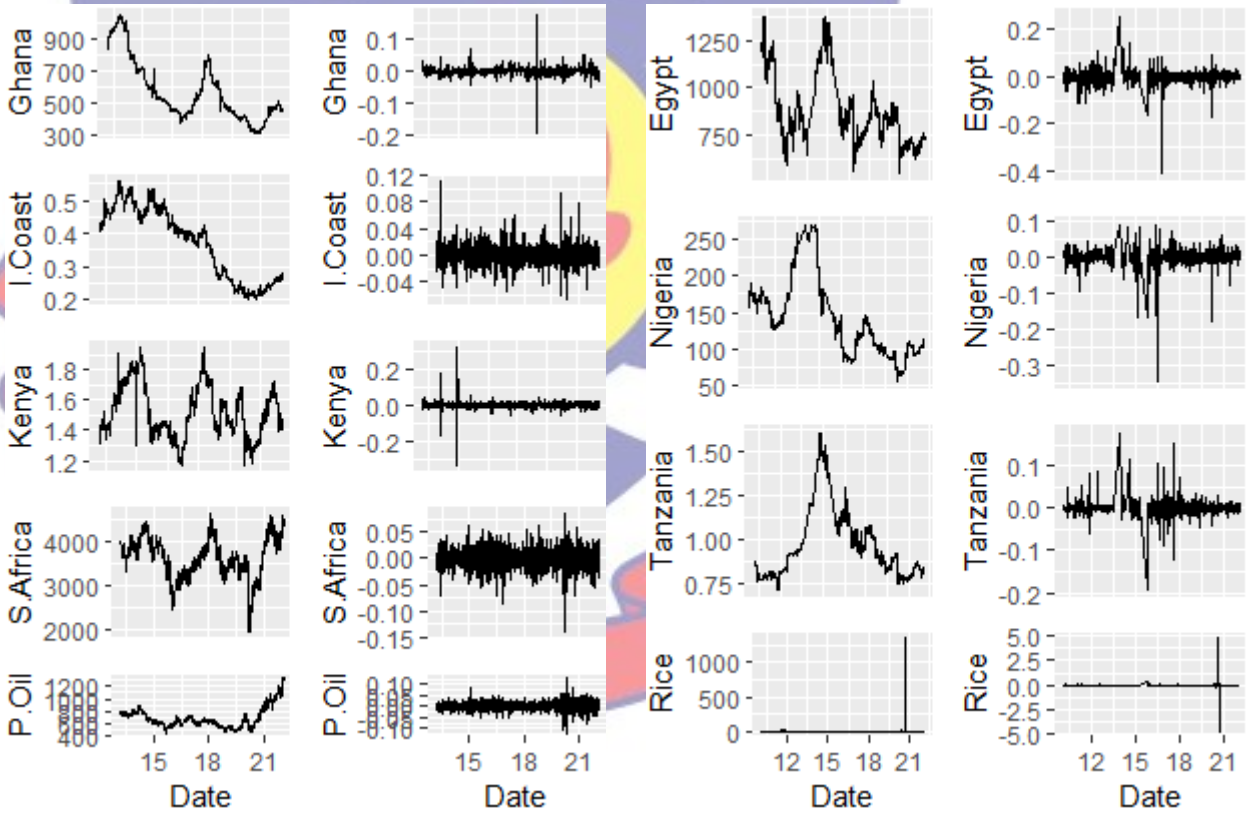
(g) palladium sample



(h) silver sample



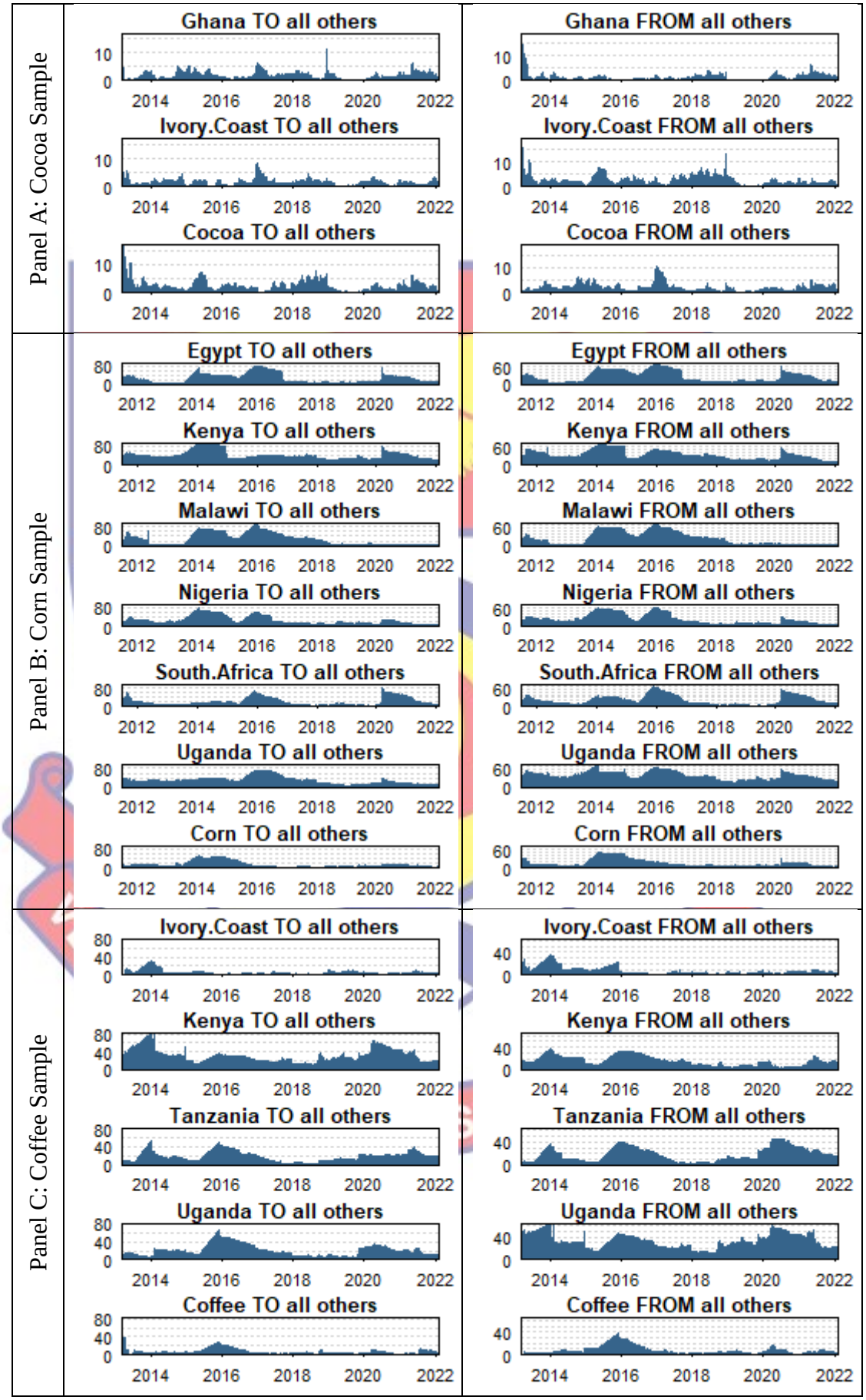
(i) gold sample *(j)* natural gas sample

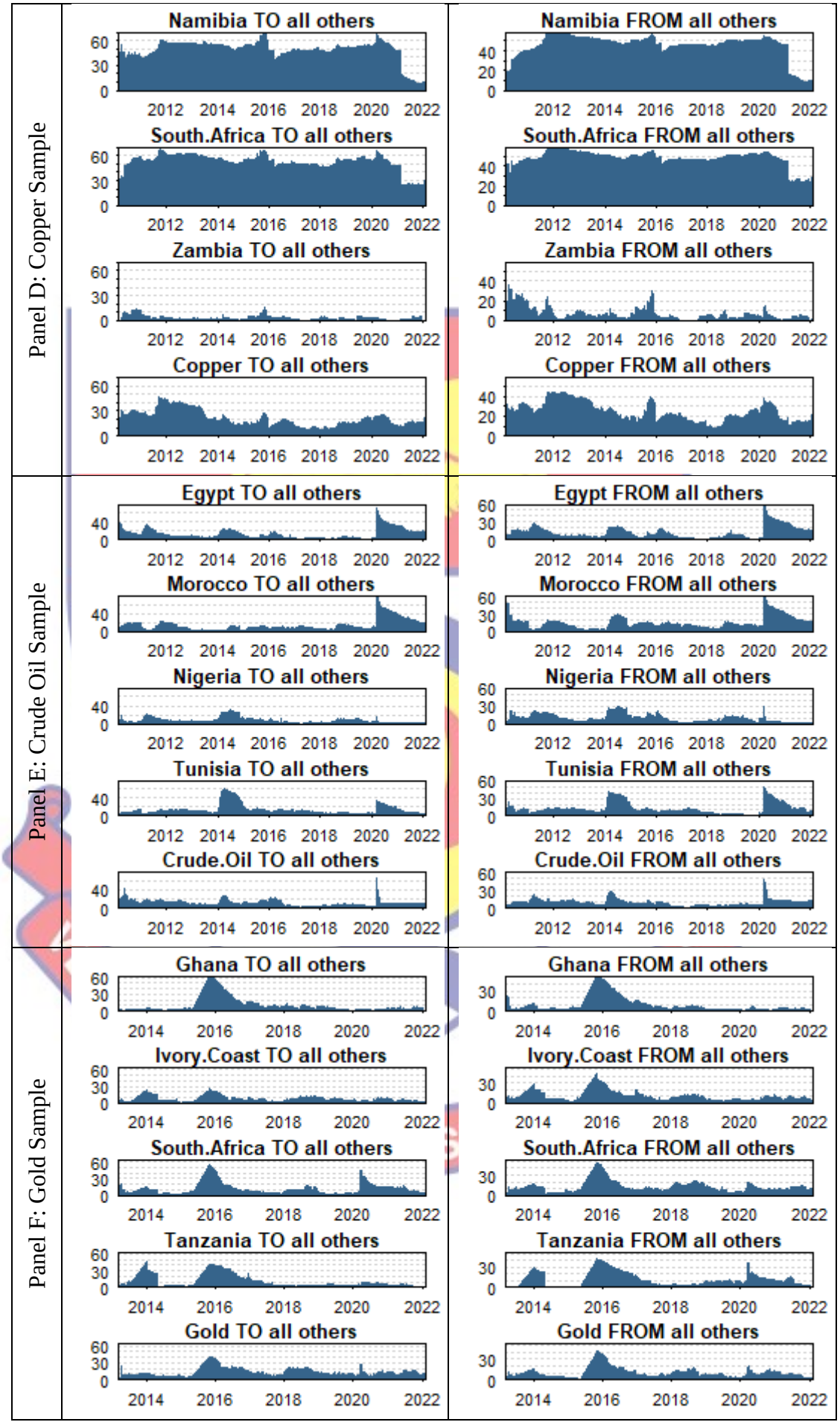


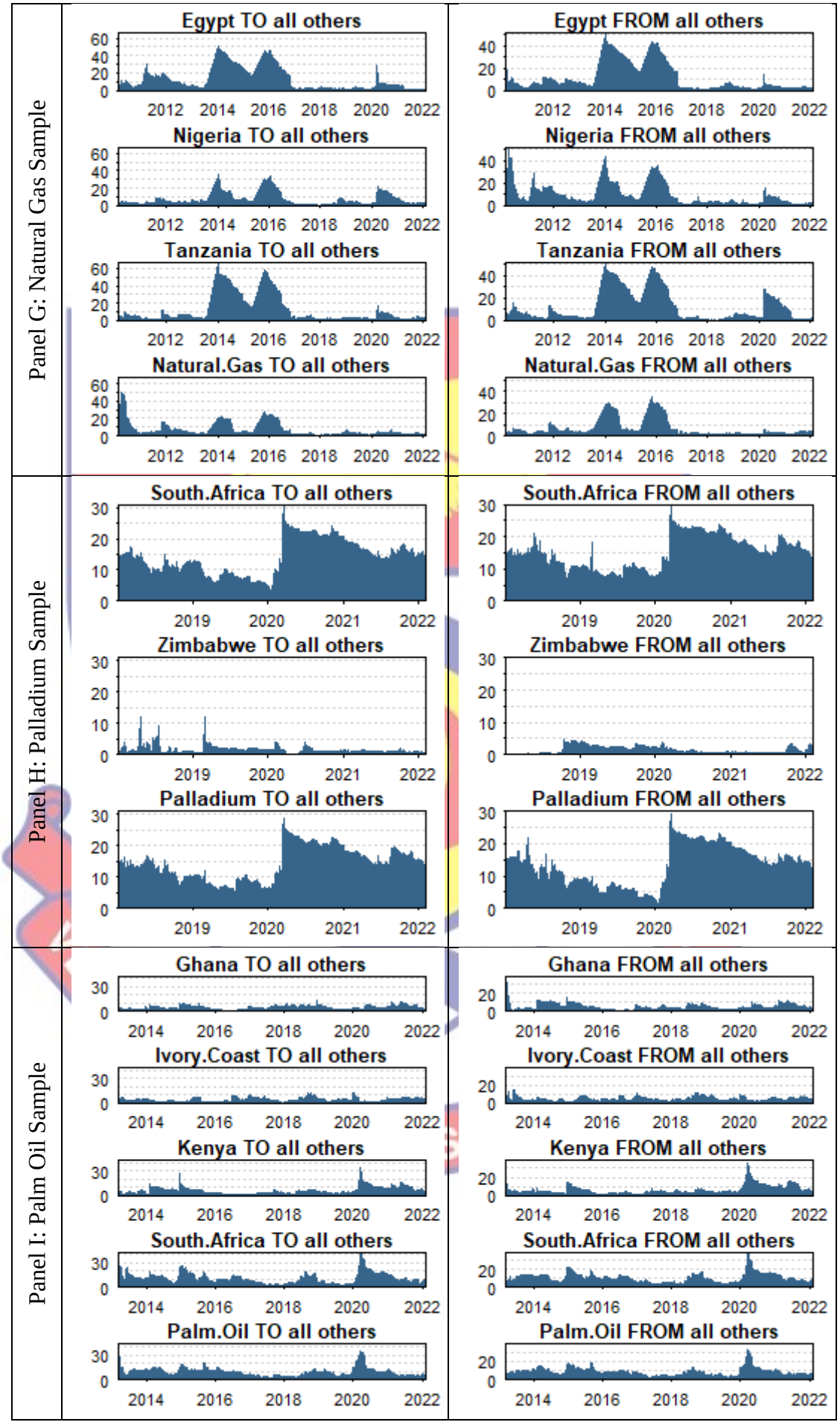
(k) palm oil sample *(l)* rice sample

Figure A1: Time Series Plots of Stock and Commodity Indices and Returns
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.

Directional Spillover Plots







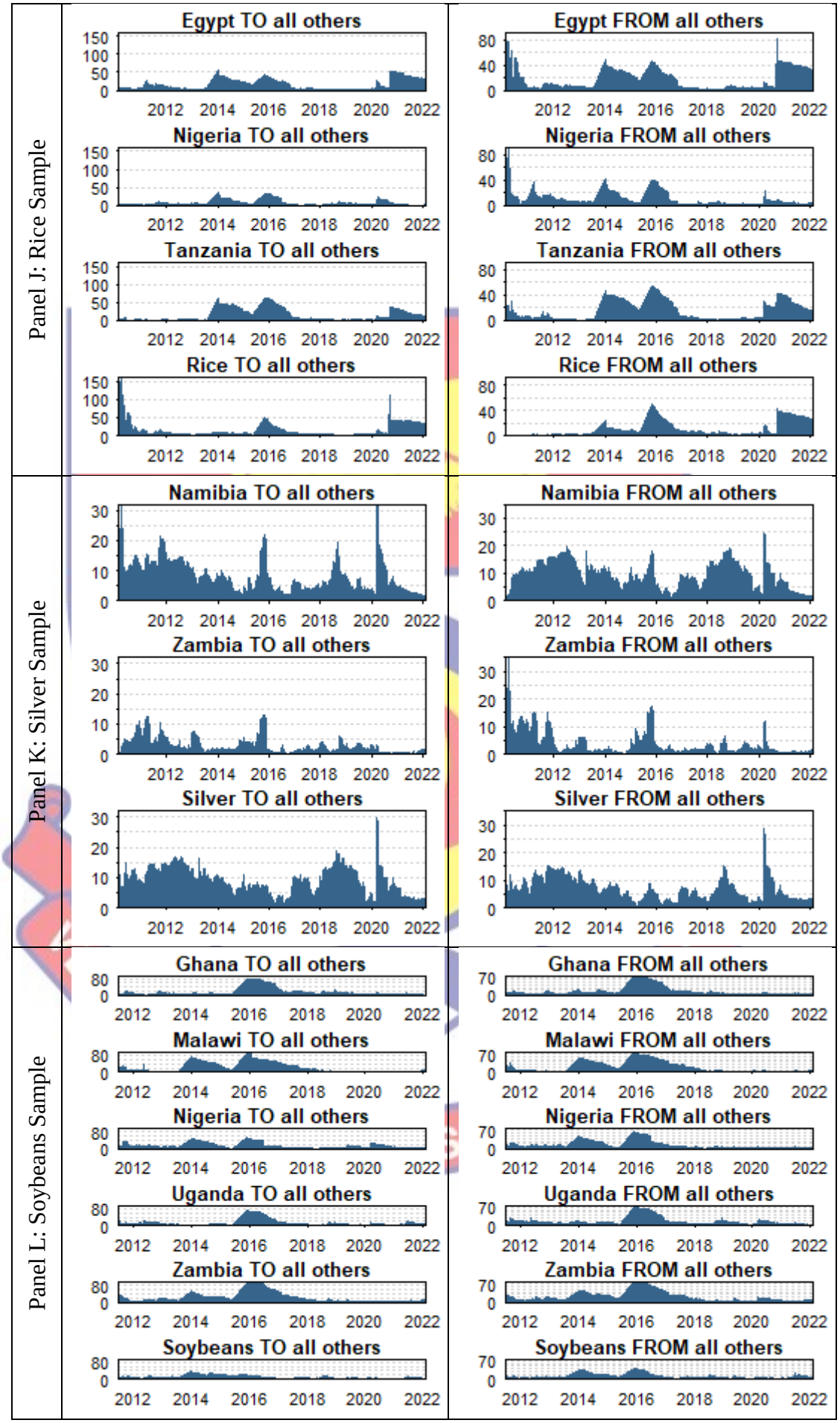
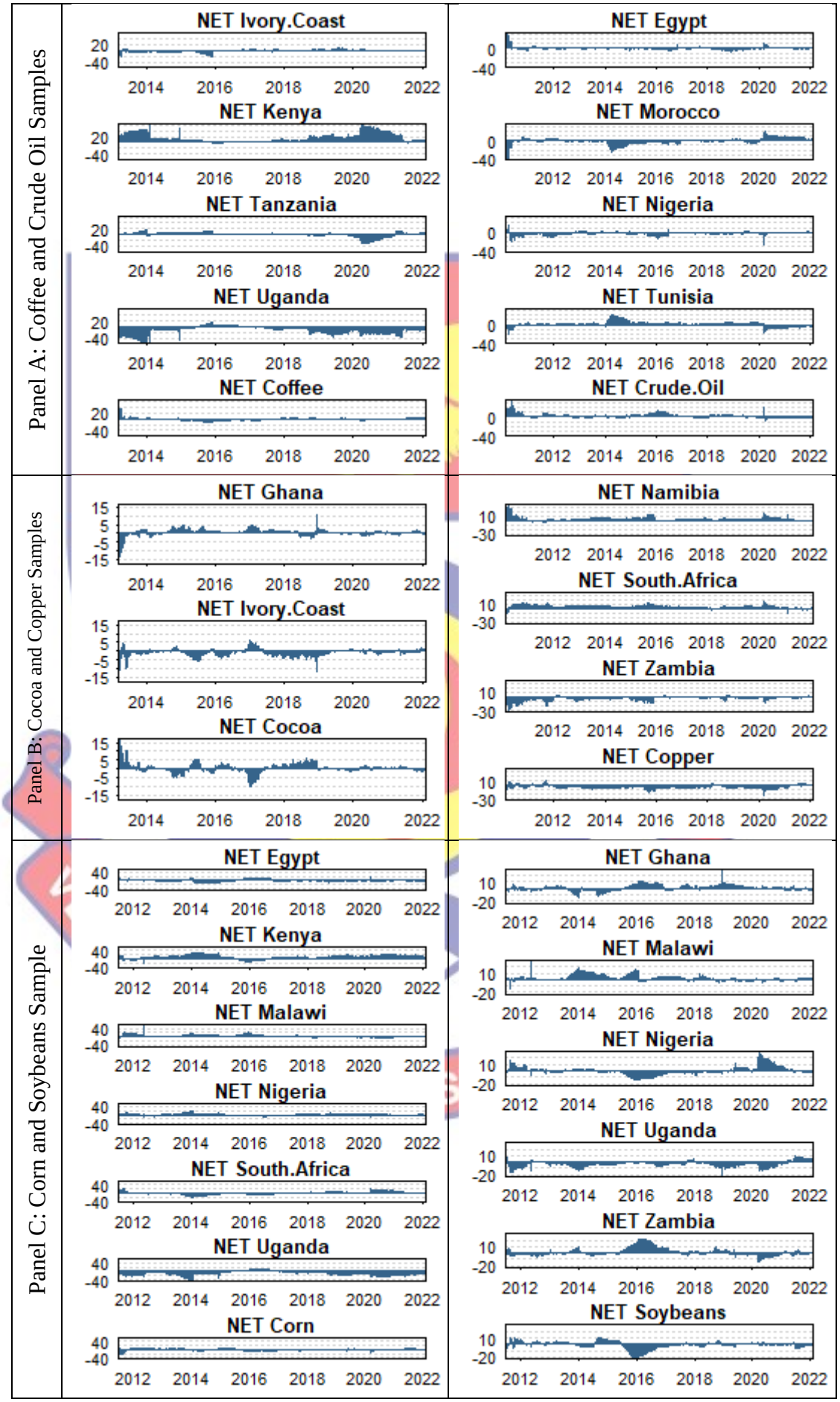


Figure A2: Directional Spillovers between GACs and AEMs
Source: Estimations based on data from EquityRT (2022) over the period 22/02/2010 to 04/02/2022.

Net Directional Spillover Plots



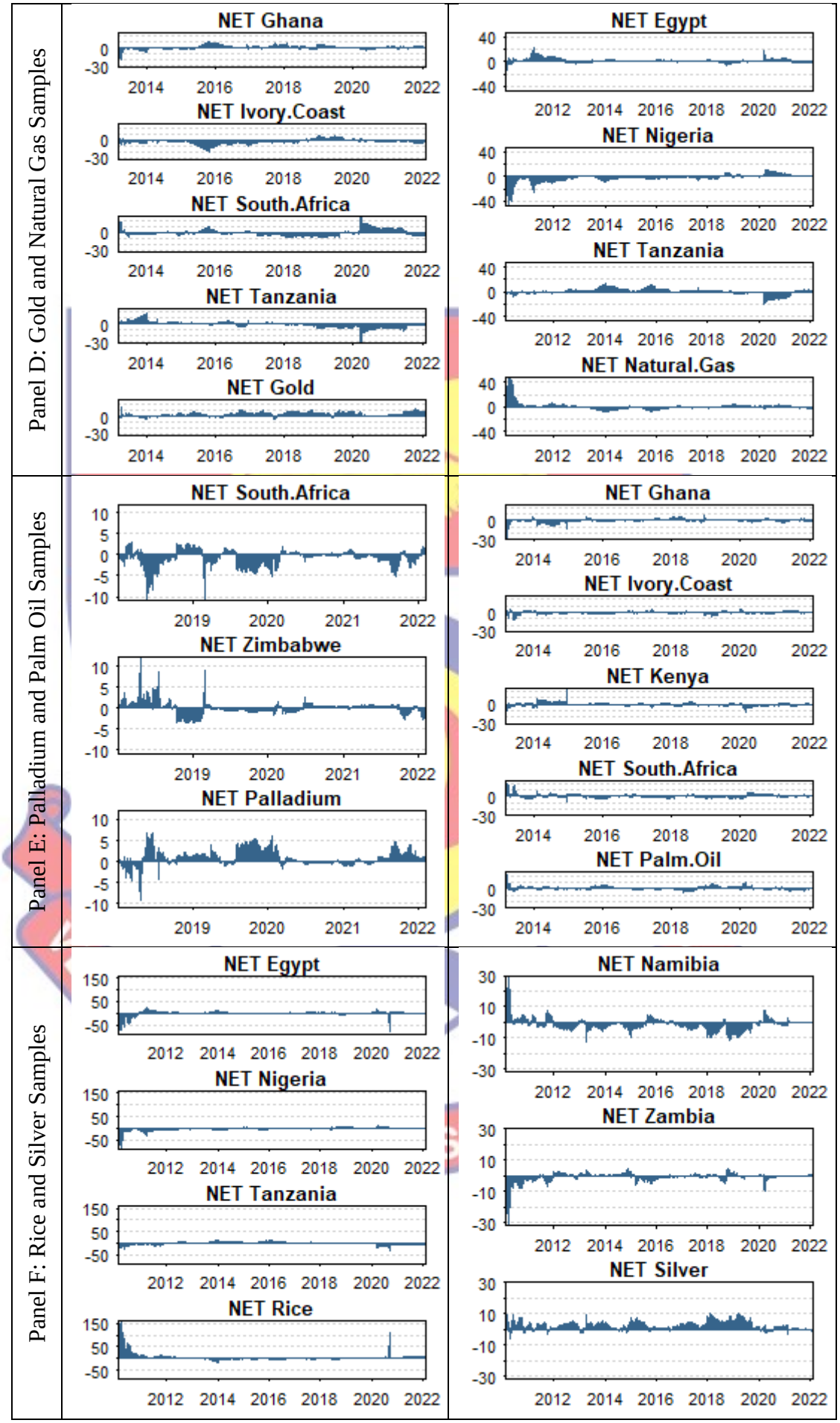


Figure A3: Net Directional Spillovers between GACs and AEMs
Source: Estimations based on data from EquityRT (2022) over the period 22/02/2010 to 04/02/2022.

Estimates of Effective Transfer Entropy

Table A1: Numerical ETEs

Panel A: Cocoa Sample												
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)	
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Ghana	Cocoa->Stocks	-0.0339	0.0435	-0.7801	-0.0458	0.0496	-0.9236	0.0529	0.0600	0.8810	-0.0293	0.0436	-0.6713
Ghana	Stocks->Cocoa	0.0203	0.0430	0.4732	0.0848	0.0567	1.4961	-0.0218	0.0554	-0.3935	-0.0401	0.0358	-1.1206
Ivory Coast	Cocoa->Stocks	-0.0344	0.0439	-0.7838	-0.0196	0.0498	-0.3928	-0.1445	0.0529	-2.7317	-0.0296	0.0431	-0.6861
Ivory Coast	Stocks->Cocoa	-0.0278	0.0439	-0.6336	0.0151	0.0571	0.2643	-0.0027	0.0545	-0.0490	-0.0550	0.0225	-2.4454
Panel B: Coffee Sample												
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)	
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Ivory Coast	Coffee->Stocks	-0.0512	0.0417	-1.2291	-0.0932	0.0540	-1.7256	-0.0671	0.0552	-1.2155	-0.0379	0.0431	-0.8787
Ivory Coast	Stocks->Coffee	-0.0768	0.0464	-1.6546	-0.0390	0.0607	-0.6427	-0.1341	0.0579	-2.3164	-0.0436	0.0514	-0.8476
Kenya	Coffee->Stocks	0.0902	0.0469	1.9216	-0.0942	0.0558	-1.6873	-0.1151	0.0543	-2.1175	-0.0588	0.0462	-1.2712
Kenya	Stocks->Coffee	-0.0017	0.0458	-0.0368	-0.0872	0.0690	-1.2625	-0.0658	0.0589	-1.1168	-0.0578	0.0424	-1.3626
Tanzania	Coffee->Stocks	-0.0886	0.0442	-2.0028	-0.0872	0.0555	-1.5718	-0.0109	0.0563	-0.1933	-0.0369	0.0423	-0.8730
Tanzania	Stocks->Coffee	0.0211	0.0438	0.4828	-0.0439	0.0690	-0.6356	-0.0283	0.0565	-0.5015	-0.0432	0.0513	-0.8416
Uganda	Coffee->Stocks	-0.0618	0.0421	-1.4679	-0.0436	0.0554	-0.7859	-0.1137	0.0557	-2.0411	-0.0544	0.0404	-1.3460
Uganda	Stocks->Coffee	-0.0896	0.0470	-1.9074	-0.0784	0.0640	-1.2242	-0.0488	0.0620	-0.7873	-0.0472	0.0458	-1.0315
Panel C: Copper Sample												
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)	
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Namibia	Copper->Stocks	-0.0071	0.0393	-0.1811	-0.1047	0.0445	-2.3531	-0.0456	0.0562	-0.8113	-0.0529	0.0460	-1.1500
Namibia	Stocks->Copper	-0.0672	0.0408	-1.6456	-0.0296	0.0553	-0.5343	-0.0712	0.0554	-1.2848	-0.0771	0.0199	-3.8685
South Africa	Copper->Stocks	-0.0557	0.0385	-1.4456	-0.0615	0.0433	-1.4200	-0.0819	0.0549	-1.4929	-0.0522	0.0466	-1.1215
South Africa	Stocks->Copper	-0.0528	0.0420	-1.2595	-0.0318	0.0434	-0.7338	-0.0063	0.0573	-0.1094	-0.0404	0.0381	-1.0596
Zambia	Copper->Stocks	0.0295	0.0405	0.7278	-0.0513	0.0444	-1.1568	-0.0925	0.0591	-1.5656	-0.0532	0.0463	-1.1488
Zambia	Stocks->Copper	-0.0076	0.0442	-0.1712	-0.0299	0.0493	-0.6074	-0.0501	0.0532	-0.9405	-0.0773	0.0207	-3.7395

Panel D: Corn Sample													
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)		
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Egypt	Corn->Stocks	-0.0721	0.0465	-1.5504	-0.1153	0.0658	-1.7536	-0.0200	0.0574	-0.3488	-0.0592	0.0405	-1.4632
Egypt	Stocks->Corn	0.0093	0.0446	0.2085	-0.0952	0.0696	-1.3674	-0.0687	0.0580	-1.1851	-0.0467	0.0438	-1.0660
Kenya	Corn->Stocks	-0.0203	0.0451	-0.4511	-0.0799	0.0682	-1.1714	0.0611	0.0585	1.0432	-0.0471	0.0393	-1.1974
Kenya	Stocks->Corn	-0.0291	0.0451	-0.6458	-0.0322	0.0693	-0.4651	0.0475	0.0624	0.7618	-0.0456	0.0501	-0.9097
Malawi	Corn->Stocks	0.0542	0.0496	1.0925	-0.0259	0.0634	-0.4091	-0.1122	0.0579	-1.9370	-0.0610	0.0386	-1.5790
Malawi	Stocks->Corn	-0.0510	0.0473	-1.0772	-0.1169	0.0757	-1.5446	-0.0348	0.0590	-0.5894	-0.0877	0.0228	-3.8530
Nigeria	Corn->Stocks	-0.0920	0.0481	-1.9124	-0.0915	0.0681	-1.3439	0.0216	0.0565	0.3823	-0.0611	0.0387	-1.5807
Nigeria	Stocks->Corn	-0.0623	0.0514	-1.2122	-0.0924	0.0719	-1.2856	-0.0685	0.0554	-1.2367	-0.0874	0.0232	-3.7640
South Africa	Corn->Stocks	0.0723	0.0477	1.5145	0.0032	0.0707	0.0447	0.0666	0.0545	1.2216	-0.0303	0.0398	-0.7614
South Africa	Stocks->Corn	-0.0178	0.0443	-0.4025	-0.0349	0.0621	-0.5628	-0.1014	0.0529	-1.9172	-0.0288	0.0510	-0.5646
Uganda	Corn->Stocks	-0.0064	0.0468	-0.1358	-0.1056	0.0678	-1.5566	-0.0853	0.0565	-1.5117	-0.0452	0.0387	-1.1695
Uganda	Stocks->Corn	0.0044	0.0471	0.0926	-0.0815	0.0685	-1.1903	-0.0403	0.0585	-0.6878	-0.0449	0.0526	-0.8550
Panel E: Crude Oil Sample													
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)		
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Egypt	Crude Oil->Stocks	-0.0914	0.0450	-2.0328	-0.1222	0.0611	-1.9996	-0.0860	0.0545	-1.5767	-0.0818	0.0359	-2.2765
Egypt	Stocks->Crude Oil	-0.0819	0.0472	-1.7356	-0.1447	0.0676	-2.1402	-0.0705	0.0581	-1.2126	-0.0815	0.0360	-2.2626
Morocco	Crude Oil->Stocks	-0.0520	0.0485	-1.0727	-0.1266	0.0598	-2.1177	-0.1510	0.0542	-2.7858	-0.0692	0.0349	-1.9827
Morocco	Stocks->Crude Oil	-0.0760	0.0433	-1.7538	-0.1019	0.0570	-1.7868	-0.1346	0.0552	-2.4383	-0.0763	0.0348	-2.1903
Nigeria	Crude Oil->Stocks	-0.0482	0.0472	-1.0212	-0.1117	0.0569	-1.9614	-0.1228	0.0567	-2.1657	-0.0564	0.0348	-1.6208
Nigeria	Stocks->Crude Oil	-0.1112	0.0450	-2.4713	-0.1125	0.0622	-1.8092	0.0434	0.0575	0.7555	-0.0812	0.0228	-3.5580
Tunisia	Crude Oil->Stocks	-0.0114	0.0456	-0.2493	-0.0502	0.0617	-0.8141	-0.1519	0.0548	-2.7706	-0.0560	0.0357	-1.5669
Tunisia	Stocks->Crude Oil	0.0043	0.0416	0.1028	-0.0202	0.0544	-0.3715	-0.0188	0.0566	-0.3323	-0.0811	0.0225	-3.6040

Panel F: Gold Sample												
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)	
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Ghana	Gold->Stocks	-0.0004	0.0463	-0.0083	-0.0203	0.0634	-0.3196	0.0050	0.0614	0.0809	-0.0581	0.0484	-1.2005
Ghana	Stocks->Gold	0.0334	0.0453	0.7378	0.0385	0.0627	0.6138	-0.0049	0.0615	-0.0800	-0.0850	0.0220	-3.8660
Ivory Coast	Gold->Stocks	-0.0224	0.0445	-0.5023	-0.0444	0.0640	-0.6935	-0.1627	0.0600	-2.7135	-0.0582	0.0497	-1.1706
Ivory Coast	Stocks->Gold	-0.1110	0.0454	-2.4426	-0.0984	0.0615	-1.5997	-0.0330	0.0624	-0.5299	-0.0856	0.0214	-3.9954
South Africa	Gold->Stocks	-0.1258	0.0428	-2.9361	-0.1304	0.0601	-2.1698	-0.0707	0.0585	-1.2070	-0.0581	0.0484	-1.2019
South Africa	Stocks->Gold	-0.0669	0.0479	-1.3958	-0.1601	0.0602	-2.6583	-0.1988	0.0545	-3.6462	-0.0846	0.0226	-3.7395
Tanzania	Gold->Stocks	0.0404	0.0442	0.9133	-0.0561	0.0607	-0.9236	-0.1334	0.0561	-2.3795	-0.0838	0.0470	-1.7826
Tanzania	Stocks->Gold	-0.0232	0.0462	-0.5026	0.0118	0.0671	0.1751	-0.0088	0.0599	-0.1476	-0.0842	0.0492	-1.7101
Panel G: Natural Gas Sample												
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)	
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Egypt	Natural Gas->Stocks	0.0154	0.0412	0.3730	-0.1336	0.0586	-2.2821	-0.1690	0.0562	-3.0083	-0.0431	0.0490	-0.8797
Egypt	Stocks->Natural Gas	0.0326	0.0482	0.6754	-0.0657	0.0681	-0.9646	-0.1464	0.0572	-2.5601	-0.0648	0.0231	-2.8029
Nigeria	Natural Gas->Stocks	-0.0296	0.0448	-0.6616	0.0271	0.0558	0.4850	-0.0026	0.0565	-0.0451	-0.0432	0.0491	-0.8795
Nigeria	Stocks->Natural Gas	-0.0478	0.0476	-1.0036	-0.1284	0.0598	-2.1474	-0.1000	0.0609	-1.6429	-0.0657	0.0221	-2.9717
Tanzania	Natural Gas->Stocks	0.0315	0.0412	0.7636	-0.0488	0.0592	-0.8241	-0.1003	0.0579	-1.7308	-0.0463	0.0486	-0.9527
Tanzania	Stocks->Natural Gas	-0.0319	0.0475	-0.6730	-0.0137	0.0636	-0.2150	0.0292	0.0602	0.4846	-0.0417	0.0421	-0.9906
Panel H: Palladium Sample												
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)	
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
South Africa	Palladium->Stocks	-0.0041	0.0580	-0.0709	-0.1290	0.0735	-1.7560	0.0094	0.0539	0.1745	-0.0793	0.0445	-1.7838
South Africa	Stocks->Palladium	-0.0127	0.0620	-0.2047	-0.0379	0.0689	-0.5496	-0.1664	0.0510	-3.2633	0.0222	0.0419	0.5294
Zimbabwe	Palladium->Stocks	0.0254	0.0550	0.4612	-0.0119	0.0749	-0.1587	-0.1037	0.0516	-2.0101	-0.0317	0.0430	-0.7375
Zimbabwe	Stocks->Palladium	-0.1002	0.0670	-1.4956	-0.1011	0.0762	-1.3262	-0.1204	0.0582	-2.0702	-0.0746	0.0281	-2.6515

Panel I: Palm Oil Sample												
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)	
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Ghana	Palm Oil->Stocks	0.0024	0.0455	0.0536	-0.0596	0.0588	-1.0143	0.0078	0.0581	0.1350	-0.0814	0.0349	-2.3307
Ghana	Stocks->Palm Oil	-0.0274	0.0462	-0.5917	-0.1121	0.0569	-1.9685	-0.1130	0.0572	-1.9763	-0.0821	0.0371	-2.2141
Ivory Coast	Palm Oil->Stocks	0.0633	0.0424	1.4937	-0.0346	0.0568	-0.6089	-0.0827	0.0584	-1.4166	-0.0279	0.0346	-0.8053
Ivory Coast	Stocks->Palm Oil	0.0464	0.0449	1.0321	-0.0973	0.0599	-1.6226	-0.1126	0.0574	-1.9610	-0.0269	0.0485	-0.5551
Kenya	Palm Oil->Stocks	-0.0901	0.0458	-1.9689	-0.1149	0.0597	-1.9240	0.0108	0.0600	0.1805	-0.0276	0.0365	-0.7563
Kenya	Stocks->Palm Oil	-0.1034	0.0463	-2.2339	-0.0278	0.0573	-0.4856	-0.0651	0.0576	-1.1308	-0.0263	0.0469	-0.5605
South Africa	Palm Oil->Stocks	-0.0613	0.0433	-1.4161	-0.0968	0.0591	-1.6368	-0.0341	0.0587	-0.5804	-0.0421	0.0364	-1.1560
South Africa	Stocks->Palm Oil	-0.0144	0.0446	-0.3220	-0.0529	0.0505	-1.0462	-0.1029	0.0575	-1.7884	-0.0598	0.0237	-2.5258
Panel J: Rice Sample												
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)	
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Egypt	Rice->Stocks	-0.0815	0.0469	-1.7353	-0.0142	0.0599	-0.2370	0.0370	0.0431	0.8593	-0.0964	0.0213	-4.5308
Egypt	Stocks->Rice	0.0545	0.0480	1.1354	0.0363	0.0618	0.5870	-0.0291	0.0584	-0.4983	-0.0967	0.0220	-4.3866
Nigeria	Rice->Stocks	-0.0289	0.0478	-0.6043	-0.0408	0.0554	-0.7353	-0.0350	0.0391	-0.8936	-0.0964	0.0214	-4.5140
Nigeria	Stocks->Rice	-0.0284	0.0493	-0.5750	-0.1090	0.0579	-1.8833	0.0004	0.0563	0.0074	-0.0969	0.0219	-4.4203
Tanzania	Rice->Stocks	-0.0793	0.0458	-1.7335	-0.0031	0.0639	-0.0493	0.0461	0.0435	1.0593	-0.0745	0.0236	-3.1611
Tanzania	Stocks->Rice	0.0115	0.0493	0.2327	0.0011	0.0620	0.0170	-0.0976	0.0577	-1.6900	-0.0211	0.0453	-0.4668
Panel K: Silver Sample												
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)	
Market	Direction	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Namibia	Silver->Stocks	-0.0451	0.0395	-1.1417	-0.0323	0.0441	-0.7314	-0.0913	0.0550	-1.6600	-0.0396	0.0318	-1.2436
Namibia	Stocks->Silver	-0.0312	0.0434	-0.7190	-0.0464	0.0486	-0.9541	-0.1046	0.0580	-1.8035	-0.0399	0.0454	-0.8787
Zambia	Silver->Stocks	-0.0228	0.0402	-0.5674	0.0391	0.0439	0.8900	-0.0666	0.0509	-1.3071	0.0347	0.0324	1.0732
Zambia	Stocks->Silver	0.0047	0.0400	0.1165	0.0208	0.0516	0.4032	0.1114	0.0553	2.0144	-0.0657	0.0201	-3.2717

Panel L: Soybeans Sample													
		Signal/Composite			IMF1 (Short-Term)			IMF5 (Medium-Term)			Residual IMF (Long-Term)		
Market	Direction	*B*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats	*β*	*SE*	*t*-stats
Ghana	Soybeans->Stocks	0.0199	0.0444	0.4476	-0.0607	0.0569	-1.0674	-0.0787	0.0564	-1.3943	-0.0375	0.0405	-0.9261
Ghana	Stocks->Soybeans	0.0926	0.0467	1.9830	-0.0602	0.0508	-1.1849	-0.0219	0.0587	-0.3725	-0.0538	0.0334	-1.6069
Malawi	Soybeans->Stocks	0.0242	0.0461	0.5242	-0.0914	0.0542	-1.6865	-0.1130	0.0544	-2.0789	-0.0433	0.0379	-1.1421
Malawi	Stocks->Soybeans	0.0211	0.0480	0.4387	0.0201	0.0620	0.3244	-0.1447	0.0607	-2.3829	-0.0555	0.0467	-1.1867
Nigeria	Soybeans->Stocks	0.0147	0.0432	0.3397	-0.0300	0.0545	-0.5504	-0.0424	0.0572	-0.7410	-0.0378	0.0439	-0.8608
Nigeria	Stocks->Soybeans	-0.0244	0.0408	-0.5970	-0.0228	0.0588	-0.3878	0.0021	0.0541	0.0395	-0.0541	0.0349	-1.5494
Uganda	Soybeans->Stocks	-0.0113	0.0477	-0.2374	-0.1250	0.0590	-2.1193	0.1195	0.0546	2.1884	-0.0427	0.0417	-1.0241
Uganda	Stocks->Soybeans	-0.0171	0.0465	-0.3670	-0.0741	0.0620	-1.1952	-0.0477	0.0565	-0.8438	-0.0547	0.0495	-1.1062
Zambia	Soybeans->Stocks	-0.0909	0.0433	-2.0988	-0.1502	0.0587	-2.5605	-0.0856	0.0585	-1.4647	-0.0372	0.0421	-0.8835
Zambia	Stocks->Soybeans	-0.0121	0.0455	-0.2654	-0.1275	0.0611	-2.0881	-0.0615	0.0585	-1.0511	-0.0544	0.0355	-1.5321

Notes: *β* signifies effective transfer entropy estimates; *SE* is the estimate's standard error, and *t*-stats are the test statistics.
Source: Estimations based on data from EquityRT (2022) over the period 22nd February 2010 to 4th February 2022.